Beach Erosion Hazard Vulnerability Assessment of Bamburi Beach in Mombasa, Kenya

M. A. Mwakumanya

***Abstract*—Beach accretion and/or erosion are evident on the Kenyan shoreline leading to loss of the aesthetic value of the beaches and destruction of shoreline properties. It is more prevalent on the Bamburi shoreline, which is about 4*km* long, and has been attributed to anthropogenic and natural processes that interfere with longshore drift depriving the beaches of sediments. Inadequate hazard assessments of the morphological processes on the beaches have made shoreline management interventions impracticable. Hazard vulnerability assessment obtained from the mean beach sediment volume was used to understand the differential and site specific spatial vulnerability of beaches to erosion on the shoreline. Accretion was revealed along Baharini challets - Private home, Whitesands-Sai rock, Papweza-Bamburi villas and Giriama beach-Jambo Ree shorelines, while erosion was experienced at Private home – Severine beach, Severine beach – Whitesands beach, Sai rock - Papweza, Bamburi villas – Kenyatta beach and Kenyatta beach - Giriama beach shorelines. Site specific vulnerability differences and morphological dynamics are evident along the shoreline. Spatial adaptive management strategies, including set back regulations and impact assessments, revegetation of the shoreline and simple engineered protection structures should be adopted and enforced to ensure stability of the shoreline and the beach system.**

***Index Terms*—Beach erosion, beach vulnerability index, erosion vulnerability, beach profile.**

I. Introduction

Beach erosion hazard has a devastating effects on the economic and social welfare of the coastal communities. Beach erosion threatens the existing and potential tourism and other coastal development facilities on the shoreline. Shoreline developments have collapsed and the aesthetic value of the sandy beaches destroyed due to the shoreline instability, causing social and economic consequences to the coastal communities [1]. Shoreline users have put up rudimentary measures to protect the shoreline, which consequently aggravated shoreline instability and the beach dynamics due to wave erosion. Wave erosion mitigation interventions such as the sea walls, boulder rocks, revetments and sand sacks prevalent on the shoreline have not been successful because their implementation have not been informed by the morphodynamic processes on the shoreline (Fig. 1). Inadequate understanding of the morphodynamic processes on the shoreline and the resultant site-specific erosion vulnerability of the beach system have exacerbated the erosion vulnerability [1]-[3]. The increasing interest in coastal areas and the resultant unregulated developments on the fragile shoreline have altered the natural processes, threatening the equilibrium of the beach system [4]. Shoreline instabilities add terrigenous materials into the beach system [2] affecting the morphological dynamics and the aesthetic value of the beaches. The Kenyan coastal zone is exposed to numerous climate–based hazards and increased population influx, which have heavily impacted on the shoreline environment causing shoreline degradation [5]-[7]

This study uses the mean beach sediment volume analysis to decipher the spatial erosion vulnerability along Bamburi beach and to provide viable data to coastal zone managers, environmental engineers, policy makers and coastal zone users to develop and adopt appropriate and sustainable shoreline management interventions.

Shoreline instability and beach erosion have increasingly become a major social, economic and environmental concern where it poses serious challenges to the environment and human settlements [4], [8], [9], due to the emerging threats of global climate change and sea level rise [10], [11]. Short term initiatives aimed at shoreline erosion mitigation and protections have been implemented by different organizations [12] with minimal success in Kenya, which consequently exacerbated the shoreline erosion. Lack of long-term monitoring data and technical support on morphodynamic processes have made shoreline management strategies difficult to implement. However, a manual by [13] provides a framework for analyzing and improving awareness of the risks from shoreline change and provides information to identify and select options to mitigate the risks from shoreline change to coastal communities and the supporting environment.

Fig. 1. Some photos showing shoreline protection measures at Bamburi beach.

The success of a shoreline management strategy requires

Manuscript received November 12, 2020; revised January 22, 2021. This work was supported in part by Pwani University and the Higher Education Loans Board (HELB) for funding this study.

M. A. Mwakumanya is with Pwani University, P.O. Box 195-80108, Kilifi, Kenya (e-mail: m.mwakumanya@pu.ac.ke).

identification of vulnerable areas based on the erosion and development trends, which contribute to planning to counteract erosion [4], [14]. This attempt supports incorporation of shoreline change into comprehensive shoreline management plans [13].

Beach systems are highly dynamic and vulnerable zones [15] that have attracted increasing attention from coastal stakeholders and attempts are made to understand and mitigate beach erosion risks [16]. The spatial analyses of the littoral marine ecosystems require the understanding of the littoral sediment processes and anthropogenic activities, their distribution and characteristics on the near shore [4], [17]. Sediment processes and properties have management implications, which are likely to impact on the coastal environments, and/or threaten the welfare of the coastal communities [2], [18]. Various coastal vulnerability assessments have been used to assess coastal and beach erosion vulnerability [19], with Beach Vulnerability Index (BVI) emanating from the Coastal Vulnerability Index (CVI) based on the beach physical processes [14], [20], [21]. Such assessments include the use remote sensing technologies and Geographic Information System (GIS) technologies, such as the Digital Shoreline Analysis System (DSAS) where Net Shoreline Movement (NSM) and Linear Regression Rate (LRR) strategies were employed to examine shoreline variability which reveal erosion and/or accretion trends [22], [23], [24]. Geological analyses as well as empirical mathematical models [4], [24], [21] have gained relevance in coastal erosion and shoreline instability studies to provide better understanding of the shoreline processes, which subsequently provide for appropriate design and anthropogenic shoreline management strategies. In Kenya, sea level rise and sediment grain sizes analyses have been used by [2], [3], [17] to evaluate the hydrodynamics and morphological parameters and their impact on shoreline instability, which consequently affect beach system processes. This study used sediment volume change rates over a period of one year by computing cross-sectional areas between profiles along the entire beach shoreline and quantitatively calculating the sediment volume change rates of the beach morphology. This method adds on the existing approaches on shoreline instability and erosion studies on the Kenyan shoreline.

II. Study Area

The study was conducted within a period of one year from March 2013 to February 2014 along the Mombasa shoreline at Bamburi beach stretching for about 4 km long, on the Kenya coast. The study area is situated between latitudes 04^0 00′ 30.5’’ South and 03^0 58′ 55.9’’ South and longitudes 039^0 43′ 35.0’’ East and 039^0 44′ 37.7’’ East from Ras Iwetine in the southeast to Shanzu headland in the northeast of the beach (Fig. 2). The general trend of the Bamburi shoreline is about 030^0 to 210^0 from the magnetic north. Banburi beach was selected because of the distinct spatial variations in beach erosion along the Bamburi shoreline. The beach morphological changes depicted exchange and transfer rates of sediment that affected the beach dynamics with apparent temporal and spatial alternate erosion and/or accretion on the beach (Fig. 3). The beach is characterized by coarse sand of different grain sizes, which are susceptible to short term morphological changes and vulnerability to wave attack [1]. The variations in the grain sizes cause spatial differences in the vulnerability of the beach to wave erosion [3], [14]. Intensive shoreline developments have encroached and gone beyond the 60 *m* setback line as determined by the Environmental Management and Coordination Act Cap 387 of the laws of Kenya [25], creating potential erosion hazard that consequently influence the socio-economic and ecological value of the beach.

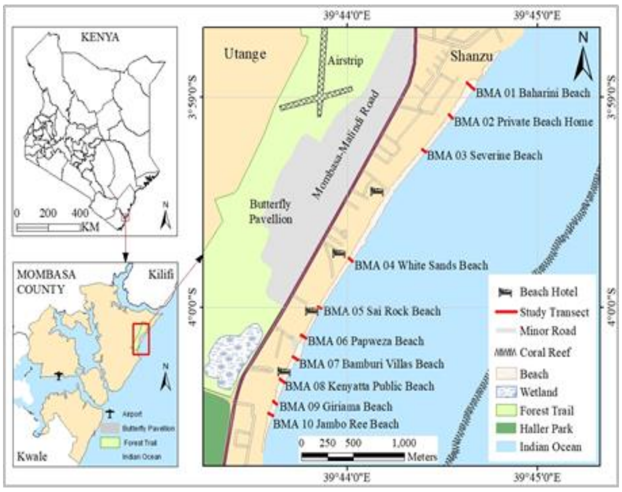

Fig. 2. Location of study area and study transects.


Fig. 3. Some of photos showing erosion activities at Bamburi beach.

III. Methods

A total of ten (10) transects were identified from semi-permanent benchmarks on sites with different spatial characteristics on the shoreline. The transects were selected on areas of distinct morphological variations indicating exposure to wave attack, dominance to recreation and tourism activities and presence of development infrastructure close to the shoreline. The transects were located from about 10m behind the high tide water mark through the beach face to about 20m from the beach toe orthogonal to the shoreline. A Garmin 12 XL handheld Global Position System (GPS) receiver was used to identify the benchmarks’ coordinates for subsequent identification during the study period and georeferencing of the study area for mapping purposes.

A. Determination of Beach Profiles

Mean monthly beach profiles were obtained profiles from beach elevations measured twice a month on the beach face during low tide levels. Two ranging rods were aligned across the shoreline on the beach face using an Abney level to establish profile line on each sampling station (Fig. 4). Pegs were placed on each profile station along the profile lines at intervals of 5*m* from which beach elevation measurements were taken. The surveyor's Abney level was placed and leveled at one profile station where the backsight and foresight readings were taken from a graduated staff placed at each station along the profile line. The Abney level was leveled whenever it was moved to another profile station to minimize any collimation errors. The procedure of leveling and reading the backsight and foresight was repeated until the last profile station was reached.

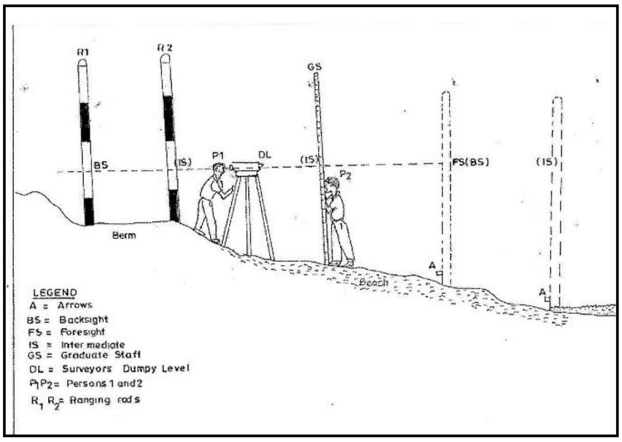

Fig. 4. Schematic drawing showing beach profile measurement.

The mean beach profiles were obtained by calculating the difference between the mean staff readings of the foresight and that of the backsight. The differences in each station were reduced from the mean datum benchmark measurements. The mean reduced profile values were plotted to obtain profile lines for each transect from which the mean cross-sectional area and mean sediment volume changes were calculated.

B. Calculation of Reduced Beach Cross-Sectional Area

Beach profile cross-sectional area was calculated from the reduced vertical elevation of the profile measured at each profile station. The profile cross-sectional area (*A*) is hypnotically the area of a triangle obtained by multiplying the half of the base of the triangle (H_2) with the vertical height (*vh*). The profile cross-sectional area for each transect was calculated as follows;

$$A = \frac{1}{2} Vh.H_2 \quad (1)$$

where: *A* = is the profile cross-sectional area

Vh = is the reduced vertical elevation of the profile measured at the beach toe (Vertical Height)

H_2 = is the horizontal distance of the beach on the profile (The base of the cross-sectional triangle)

H_2 is the base of a right angled triangle formed by the cross section, which is obtained using the trigonometric formula

$$Cos\ \alpha_2 = \frac{Adjacent}{Hypotenues}$$

where:

H_2 is the adjacent and

W_2 is the monthly mean beach width measured on the face of the beach

Thus,

$$Cos\ \alpha_2 = \frac{H_2}{W_2} \quad (2)$$

Therefore, H_2 is obtained as;

$$H_2 = W_2.Cos\ \alpha_2 \quad (3)$$

The angle subtended at the base of the cross section triangle (α_2), which denotes the monthly mean beach slope is calculated using the following trigonometric formula;

$$Sin\ \alpha_2 = \frac{W_2}{Vh} \quad (4)$$

The value of α_2 can be obtained by converting the value of Sin from the trigonometric tables

The total reduced cross-sectional area for the beach section was obtained by multiplying the profile cross-sectional area with the distance of the beach, which gives the beach sediment volume for the section. The total beach sediment volume for the entire Banburi beach shoreline was obtained by summing up the beach sediment volumes of each beach section. The mean cross-sectional area change over the study period was obtained by subtracting the individual subsequent cross-sectional area values from the initial values obtained at the beginning of the study.

C. Estimation of Reduced Beach Sediment Volume Change

The reduced beach sediment volume change which is the rate at which sand is brought into the beach and the rate at which sand leaves the beach over a period of time, was estimated from the reduced heights of the beach profiles and expressed in terms of the volumes of beach materials lost or gained over the study period using the formula;

$$V = D\left(\frac{A_1}{2} + A_2\right)\frac{1}{2} \quad (5)$$

where *V* = Sediment volume

D = Distance between adjacent profiles

A_n and A_{n+1} = Cross sectional areas of the two adjustment profiles, *n* and *n*+1.

The distance between adjacent benchmarks were obtained using a linen tape.

D. Beach Erosion Vulnerability Assessment and Mapping

The erosion and accretion vulnerability was described on the basis of the changes in the mean beach sediment volumes between profiles. The positive or negative changes in the mean beach sediment volumes depict accretion or erosion of beach sediment, showing accretion and erosion of the beach respectively. Rate of change in the beach sediment volume was obtained by getting the range between the highest and the lowest beach sediment volume values. The range was then divided by the predetermined five relative erosion hazard vulnerability categories (Very high, High, Medium, Low and Very low). A positive reduced mean sediment volume change rate means that more sediment is carried away than is deposited and results in erosion of that spatial segment of the beach, while a negative reduced mean sediment volume change means that more sand deposition than erosion leading to accretion. Beach erosion hazard vulnerability map was generated to depict the hazard vulnerability 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 [26] of scale 1:250,000. The method is expressed in form of a flow chart as follows in Fig. 5.

IV. Results

A. Analysis of Reduced Beach Cross-Sectional Area

The mean cross-sectional area along Bamburi beach varied significantly (Table I) from one beach segment to another, depicting the spatial variability in beach erosion vulnerability. The mean cross-sectional area ranged between 109.12 m^2 at Whitesands beach and 42.77 m^2 at Private home beach with mean change rate of 8.65 m^2 and -0.42 m^2 respectively (Table I).

B. Assessment of the Accreted Beach Systems

The distance of the Baharini challettes - Private home shoreline is about 300 m. The beach recorded a mean volume of about 12,762 m^3 (Table III). There were also distinct variations on the beach volume change rate during the study period with a mean volume change rate of -887 m^3 (Table III). The mean change rate depicts very low erosion activities, which implied an accretion of the beach system. Whitesands - Sai Rock Beach Shoreline section is characterized by some vegetation and it is open with coconut trees providing protection measures especially to the aeolian processes. The distance of the section of the shoreline was about 800 m and recorded a mean sediment volume of about 48,726 m^3 and a mean volume change rate of about -2,740 m^3 (Table III), denoting very low erosion processes on the shoreline. Papweza - Bamburi Villas beach shoreline is about 500 m long comprised of the seasonal Bamburi River, which provided a pathway for the terrigeneous materials on to the shoreline. The mean sediment volume is about 26,502 m^3 and a mean volume change rate of about -2184 m^3, implying that there are very low erosion processes on this section of the shoreline. This in essence meant an accretion of the section of the shoreline. Giriama - Jambo Ree Beach Shoreline of about 200 m had a mean sediment volume of about 9,550 m^3. The section of the shoreline experienced a sediment volume mean change rate of about -126 m^3, depicting low erosion rate (Table III). This situation could be attributed to protection of the shoreline by the Ras Iwetine promontory. The strong southeast trade winds were sheltered from attacking the shoreline, leading to deposition during this period. The relatively calm northeast monsoon winds caused further deposition of the sediment from the adjacent pathways at Kenyatta beach and Bamburi River, leading to general accretion of the shoreline throughout the year.

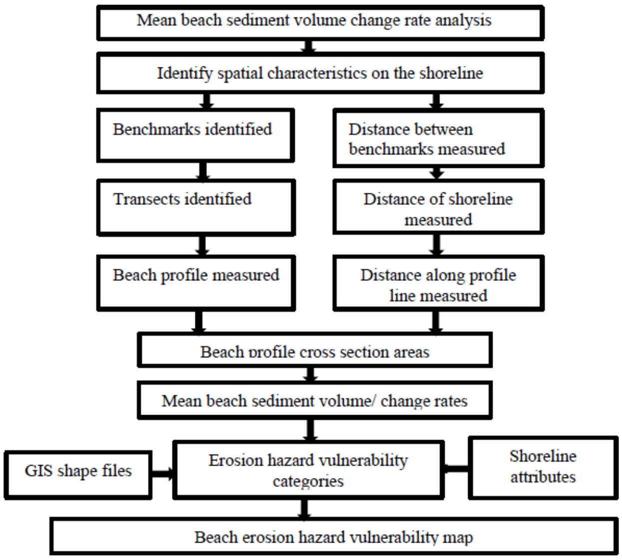

Fig. 5. Flow chart showing steps in beach erosion hazard vulnerability assessment.

TABLE I: Mean Beach Cross-Sectional Area and Mean Change Rates

Beaches/Transect	Mean Cross-sectional area (m^2)	Mean Change Rate (m^2)
BMA 01: Baharinin Chalettes	84.62	-13.01
BMA 02: Private Home	42.77	-0.42
BMA 03: Severine	43.09	6.83
BMA 04: Whitesands	109.12	8.65
BMA 05: Sai Rock	67.25	-11.16
BMA 06: Papweza	65.61	9.05
BMA 07: Bamburi Villas	73.17	-13.23
BMA 08: Kenyatta	71.35	0.02
BMA 09: Giriama	60.63	1.81
BMA 10: Jambo Ree	65.19	-2.17

TABLE II: Erosion Hazard Vulnerability Ranking Categories

Mean volume category	Erosion vulnerability ranks
5866 – 4144	Very High
4144 – 2423	High;
2423 – 702	Moderate
702 - -1019	Low
-1019 - -2740	Very Low

C. Assessment of the Eroded Beach Systems

The Private home-Severine shoreline is about 200 *m* and records a mean volume of about 6,625 m^3. The sediment mean volume change rate during the study period is 484 m^3, denoting moderate erosion activities (Table III). This section of the shoreline is relatively gentle with some shore protection structures in front of the private properties. These structures seem to have affected the moderate erosion activities experienced. Severine - Whitesands beach shoreline stretched for about 1000 m long with the shoreline dominated by beach hotels constructed far beyond the buffer zone seaward and a lot of walking and trampling on the sediment materials by the beach tour operators and curio shop dealers who displayed their wares on the beach. The shoreline records a mean sediment volume of about 65,499 m^3, with the highest variation of volume changes during the study period (Table III). The sediment volume mean change rate during the year is 5,866 m^3, which according to the erosion hazard procedure denoted very high erosion. The erosion rate is attributed to the prevalence of the human activities, the boulder rock shoreline and the head ward erosion intensively experienced at the Whitesands beach shoreline. Sai Rock - Papweza beach shoreline characterized by intensive shoreline retreat with sea walls collapsing. The distance between Sai Rock and Papweza beach is about 600 m, with a mean volume change rate of about 1,121 m^3 depicting moderate erosion processes on the section of the shoreline (Table III). This is because of the accretion that is evident at Sai Rock section. Bamburi Villas - Kenyatta Beach Shoreline stretches for about 200 m with a mean volume recorded as 10,793 m^3 and a mean volume change rate of about 659 m^3 (Table III). This implies that the section experiences relatively low erosion rates and considerable accretion of the shoreline. This is attributed to the Bamburi River that contributes to influx of the terrigenous materials from the main land. There were intermittent tendencies in the monthly volume throughout the study period. Kenyatta - Giriama Beach Shoreline is about 200 m long, dominated by beach recreational activities throughout the year. However, the shoreline recorded a mean sediment volume of about 9,631 m^3 and mean volume change rate of about 182 m^3 denoting a general low erosion process (Table III). This is because of the influx of the sediment materials through dune recession during the rainy season in Kenyatta beach, which acts as sediment source from the land. The influx could have been also through the seasonal Bamburi River.

TABLE III: MEAN VOLUME (M^3) AND MEAN VOLUME CHANGE RATES (M^3)

Shoreline	Distance (*m*)	Mean beach volume (m^3)	Mean beach volume Change Rate	Erosion vulnerability ranking
Baharini Chalettes – Private Home	300	12,762	-887	Low
Private Home - Severine	200	6,625	484	Moderate
Severine - Whitesands	1000	65,499	5,866	Very High
Whitesands – Sai Rock	800	48,726	-2740	Very Low
Sai Rock - Papweza	600	29,771	1,122	Moderate
Papweza – Bamburi Villas	500	26,501	-2,184	Very Low
Bamburi Villas - Kenyatta	200	10,793	659	Low
Kenyatta - Giriama	200	9,630	181	Low
Giriama – Jambo Ree	200	9,550	-126	Low

D. Erosion Hazard Vulnerability Assessment

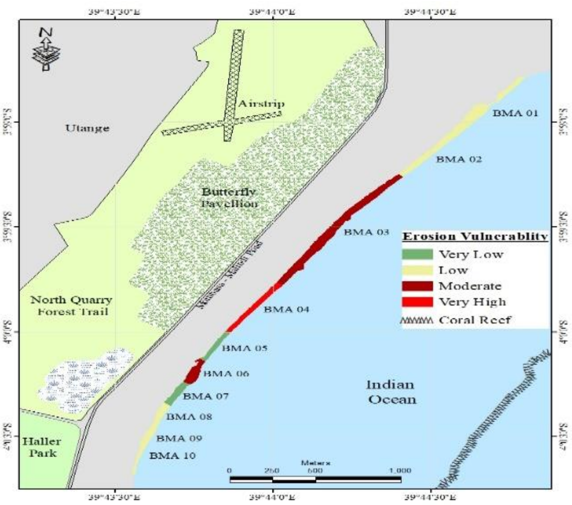

Fig. 6. Beach Erosion vulnerability map based on mean beach sediment volumes.

Beach erosion hazard vulnerability map (Fig. 6) elucidates incidences of erosion and accretion. 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 serious erosion during the study period with very high rate of retreat towards land, which was attributed to the construction of the Papweza beach hotel on the shoreline making the adjacent areas to experience 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 very low vulnerability to erosion in terms of the median grain size changes and slope angle change rate, Low potential to erosion in terms of the volume change rate.

Generally, the beach erosion hazard vulnerability at Bamburi beach shoreline varied from very high to very low potential (Fig. 5. The beach erosion hazard vulnerability assessment along the Bamburi beach shoreline reveals that the beach is under serious anthropogenic threats and that there is need to reverse the scenario to avoid long term impacts, which would be costly.

V. DISCUSSION

The spatial morphological variations have exposed the shoreline to wave attack with the anthropogenic activities aggravating the vulnerability of the beach system to erosion hazard. Shoreline instability and the consequent site specific beach erosion vulnerability has threatened tourism activities, the coastal environment and coastal developments [22]. An understanding of the vulnerability of the beaches to erosion hazard is fundamental to deal with its consequences [8]. Anthropogenic activities such the construction of seawalls and using of unregulated boulder rocks on the shorelines of Severine - Whitesands and Private home - Severine have exacerbated the beach erosion vulnerability Direct exposure to the ocean implies the near shore hydrodynamic characteristics influence the longshore drift affecting the morphology of the beach, the consequences of which are either accretion or erosion. Bamburi beach system is sheltered to the Southeast by Ras Iwetine and to the Northeast by the Shanzu cliff, causing accretion on the beach systems in those areas, while the rest of the system is open to wave attack increasing the vulnerability of the beach system to erosion hazard.

Assessment and mapping of beach erosion hazard vulnerability for the shoreline assists marine and coastal stakeholders in planning to reduce impacts from natural and anthropogenic hazards. Understanding of the vulnerability of the beach to erosion hazard is a precursor of the natural and anthropogenic processes on the shoreline and mitigation measures are to be guided by the spatial shoreline and beach system dynamics. The mean beach sediment volume analysis provides useful data information on the understanding of the shoreline beach system dynamics and the vulnerability to beach erosion hazard. [27] asserts that initial character of the beach system, process changes over a range of timescales and the causal factors to spatial and temporal variability of the beaches are important to identify the change, guide the planning of management operations, and appraise the performance and impacts of management approach. This will be utilized in the formulation of appropriate hazards mitigation strategies as argued by [14]. Beach Vulnerability Index (BVI) can be used for sustainable management of beaches against such hazards like climate change and the fluctuating tidal currents and waves.

Beach erosion mitigation measures have been limited to sea walls and revetments in Kenya, largely due to lack of technical knowledge and experience on construction of structures. Since the coastal system is complex these defenses have not succeeded in many locations and instead aggravated the vulnerability of beach systems to erosion hazards. An integrated management approach coupled with an enabling governance environment is ideal to deal with the multiple challenges facing the Kenyan coastal zone [7], [28].

VI. Conclusion

Beach sediment volume change rates analysis can be used to identify the potential vulnerability of the beach to erosion hazard due to changing site-specific natural and anthropogenic processes. It was evident that the beach system is susceptible to erosion due to anthropogenic structural mitigation failures. The intended protection measures fail to achieve the set objectives of protecting the beaches from being vulnerable to beach erosion hazard. Stakeholders should be sensitized on the threat inherent from beach erosion hazard caused by the unregulated and controlled protection measures and developments on the shoreline. The spatial variations in beach erosion vulnerability indicate the differences in the beach and shoreline processes, thus calling for site-specific mitigation measures. Set back regulations and impact assessments, revegetation of the shoreline and simple engineered protection structures should be adopted and enforced to reduce the vulnerability of the beach to erosion hazard and to ensure stability of the shoreline and the beach system.

Conflict of Interest

I wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. I confirm that the manuscript has been read and approved by the authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

Acknowledgment

I wish to express my heartfelt gratitude to Pwani University and the Higher Education Loans Board for funding this study. I appreciate the effort of Justin Kimani of Pwani University in helping in generating the beach erosion vulnerability maps using the Arc GIS software.

References

[1] A. M. Mwakumanya and M. P. Tole, "Coastal erosion at Mombasa Beaches. Hydrodynamic and morphological interaction," *Recent Studies in Coastal Ecology from Kenya*, African Studies Centre, Leiden Netherlands, Research report 70/2003, 2003, ch 8, pp. 133-144.

[2] P. A. W. Abuodha, "Implication for coastal processes for the management of the Shanzu - Bamburi coastal zone, Mombasa, Kenya," *WIOMSA/MARG 1/2006-02 Technical Reports*, Dar es Salaam, Tanzania, 2006, p. 38.

[3] A. M. Mwakumanya and B. D. O. Odhiambo, "Beach morphological dynamics. A case study of Nyali and Bamburi beaches in Mombasa, Kenya," *Journal of Coastal Research*, vol. 23, no. 2, pp. 374-379, March, 2007.

[4] A. C. Jimenez, J. I. Euan Avila, M. M. V. Lacouture, and R. S. Casarin, "Classification of beach erosion vulnerability on the Yucatan coast," *Coastal Management*, vol. 44, no. 4, pp. 333-349, 2017.

[5] C. B. Awuor, V. Orindi, and A. O. Adwera, "Climate change and coastal cities: The case of Mombasa, Kenya," *Environment and Urbanization*, vol. 20, no. 1, pp. 231–242, April, 2008.

[6] P. Jo-Ellen, D. Echeverria, J. Dekens, and J. Maitima, "Climate risks, vulnerability and governance in Kenya: A review," UNDP Climate Risk Management Report, November, 2012.

[7] L. Ojwang, S. Rosendo, L. Celliers, D. Obura, A. Muiti, J. Kamula, and M. Mwangi, "Assessment of coastal governance for climate change adaptation in Kenya," *Earth Futures*, vol. 5, October 2017.

[8] T. S. Andrade *et al*., "Vulnerability to beach erosion based on a coastal processes approach," *Applied Geography*, vol. 102, pp. 12–19, January 2019.

[9] R. M. Murali, M. Ankita, and P. Vethamony, "A new insight to vulnerability of Central Odisha coast, India using analytical hierarchical process (AHP) based approach," *Journal of Coastal Conservation*, vol. 22, pp. 799–819, April 2018.

[10] N. D. Kumar and D. H. Prasad, "Coastal erosion studies — A review," *International Journal of Geosciences*, vol. 5, no. 3, pp. 341-345, November, 2013.

[11] D. Scavia, J. C. Field, D. F. Boesch, R. W. Buddemeier, V. Burkett, D. R. Cayan, C. Mason, D. J. Reed, T. C. Royer, M. Fogarty, M. A. Harwell, R. W. Howarth, A. H. Sallenger, and J. G. Titus, "Climate change impacts on U.S. Coastal and marine ecosystems," *Estuaries*, vol. 25, no. 2, pp. 149-164, April, 2002.

[12] UNEP and WIOMSA, *The Regional State of the Coast Report*, Western Indian Ocean, Government Printer, Nairobi, Kenya, p. 566, 2015.

[13] Y. Shaghude, W. Mburu, R. Arthurton, A. Dubi, S. Gachuiri, J. Kangwe, C. Magori, F. Msuya, R. Mwaipopo, N. Nyandwi, J. Ochiewo, H. Ong'anda, R. Sallema, I. Sanga, M. Shalli, and J. Uku, *Shoreline Change in Tanzania and Kenya: Manual for Assessment and Design of Mitigation Strategies*, Zanzibar, 2014.

[14] G. Alexandrakis and S. A. Poulos, "An Holistic approach to beach erosion vulnerability assessment," *Scientific Reports 4*, no. 6078, August 2014

[15] Government of Kenya, "State of the coast report Kenya II. Enhancing integrated management of the coastal and marine resources in Kenya," Government Printers, Nairobi, Kenya, p. 144, 2017.

[16] A. N. N. Muzuka and Y. W. Shegude, "Grain size distribution along the Msasani Beach, North of Dar Es Salaam Habour," *Journal of African Earth Sciences*, vol. 30, no. 2, pp. 417-426, 2000.

[17] R. S. Arthurton, "The fringing reef coasts of Eastern Africa — Present processes in their long-term context," *Western Indian Ocean Journal of Marine Science*, vol. 2, no. 1, pp. 1-13, 2003.

[18] A. M. Mwakumanya, "Beach sediment grain size distribution on Nyali - Bamburi shoreline in Mombasa, Kenya," *Journal of Science, Technology, Education and Management (J-STEM)*, vol. 2 no. 2, 2008.

[19] L. Lin and P. Pussella, "Assessment of vulnerability for coastal erosion with GIS and AHP techniques case study: Southern coastline of Sri Lanka," *Natural Resource Modeling*, October 2017.

[20] B. J. Boruff, C. Emrich, and S. L. Cutter, "Erosion hazard vulnerability of US coastal counties," *Journal of Coastal Research*, vol. 21, no. 5, pp. 932-942, September, 2005.

[21] J. A. Beluru and A. V. Hegde, "GIS based approach for vulnerability assessment of the Karnataka coast, India," *Advances in Civil Engineering*, vol. May, 2016.

[22] O. Sytnik, L. D. R ό, N. Greggio, and J. Bonetti, "Historical shoreline trend analysis and drivers of coastal change along the Ravenna coast, NE Adriatic," *Environmental Earth Sciences 77*, no. 779, November 2018.

[23] M. D. Harley, I. L. Turner, M. A. Kinsela, J. H. Middleton, P. J. Mumford, K. D. Splinter, M. S. Philips, J. A. Simmons, D. J. Hanslow, and A. D. Short, "Extreme coastal erosion enhanced by anomalous extra tropical storm wave direction," *Scientific Reports*, vol. 7, no. 1, p. 6033, July 2017.

[24] S. Saravanan, N. Chandrasekar, M. Rajamanickam, C. Hentry, and V. Joevivek, "Management of coastal erosion using remote sensing and GIS techniques (SE India)," *International Journal of Ocean and Climate Systems*, vol. 5, no. 4, pp. 211-221, 2014.

[25] GoK. *Environmental Management and Coordination Act, (Cap 387)*, Government Printers, Nairobi, Kenya, p. 38, 2015.

[26] UNEP, "Eastern African atlas of coastal resources, Kenya," (Resource Map 1:250,000), National Geographical Institute, Brussels Belgium, 1997.

[27] J. G. S. Keijsers, A. Poortinga, M. J. P. M. Riksen, and J. Maroulis, "Spatio-temporal variability in accretion and erosion of coastal fore dunes in the Netherlands: Regional climate and local topography," *PLoS One*, vol. 9, no. 3, 2014.

[28] Integrated Coastal Area Management, "Towards integrated and sustainable development of Kenya coast," *Findings and Recommendations for Action Strategy in the Nyali-Bamburi-Shanzu Area*, Coast Development Authority, Kenya, p. 76, 1996 .

Maarifa Ali Mwakumanya was born in April 1969 in Kwale county, Kenya. He is a coastal geomorphologist who graduated with a PhD in environmental earth sciences from Moi University in Eldoret, Kenya and a master of philosophy in geography (geomorphology) from the same university.

He is currently the dean of the School of Environmental and Earth Sciences and researcher/ lecturer of Geography and Environmental Sciences at Pwani University in Kilifi, Kenya.