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Assessment of Shoreline Changes in the Period 1969-2010 in Watamuarea, Kenya

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Abstract- Watamu coastlineis a major attraction site for tourist and also a source of income for the local people. However, the shoreline has been changing due to erosion. This study sought to find the trend of shoreline changes, and the factors attributed to the changes. Aerial photographs of 1969 and 1989 and a recent satellite image of 2010 were used to digitize the shoreline.The Digital Shoreline Analysis System (DSAS) in ArcGIS environment was used to create transects and statistical analyses for the shoreline.Several GPS points were taken in October 2013 and 2014 during ground truthing following the High Water Mark (HWM). The 9.8 km long Watamu shoreline was divided in-to 245 transects with 40 meter spacing in order to calculate the change rates. The rates of shoreline change were calculated using the End Point Rate (EPR), Net Shoreline Movement (NSM), and Weighted Linear Regression (WLR) statistic in DSAS. In addition, Focused Group Discussion (FGD)and key informants interview were conducted with curio sellers, boat operators, fishermen, safari sellers, and longtime residents and hoteliers in order to get information about the drivers of shoreline change.The analysis from WLR indicated a mean of -0.89 m/year where 69.7% of transects fall under erosion and 30.2% accretion. The result from EPR and NSM revealed mean shoreline change of -0.7m/year and -30.3m/period respectively from1969 to 2010 with negative signs indicating erosion. Both EPR and NSM results showed out of 245 transects 158 or 64.4% experienced erosion and 87 transects or 35.5% accretion in the 41 year study period.Shoreline erosion was mainly attributed to anthropogenic factors. These include construction near the High Water Mark, defensive structures and sea walls, and destruction of vegetation along the beach. Therefore, it will be advantageous if all institutions and stakeholders with responsibilities for such coastal areas to work in collaboration so as to keep the coastline and its marine life and resources from further damage and erosion.

Keywords: aerial photographs, arcgis, coastline, digital shoreline analysis system, satellite image, shoreline erosion, watamu, kenya.

I. Introduction

A shoreline is defined as the interface between the land and the sea (WIOMSA, 2010) and the immediate position of the land–water line at one instant in time (Boak and Turner, 2005). Because of the active nature of water bodies and the coastal land, the shoreline is constantly changing (Paterson et al, 2010). Shoreline change depicts the way in which the position of the shoreline moves with time (WIOMSA, 2010). Several studies point out that two main factors can be responsible to change the shoreline, these are; human activities along the shore or natural processes (Richmond, 1997, Keqizhang et al., 2004, Boak and Turner, 2005, Hanslaow, D.J., 2007, Paterson et al, 2010,). An example of natural process can be sea level rise (SLR), change from storms and climate (Keqizhang et al., 2004) extreme weather events, including an increase in the intensity and frequency of waves on the shoreline face and beaches (Pearson et al., 2005). Williams and Gutierrez (2009) pointed out that sea-level rise is one of the most important impacts for shoreline change which causes variations in waves, currents and sediment availability in most US coastal areas. Shoreline can also move landwards through the process of erosion; or seawards by sediment accretion (WIOMSA, 2010). Shoreline change can also be used as a good indicator of possible coastal erosion and the best indicator for describing coastal erosion is the shoreline retreat rate (Boak and Turner, 2005).

Many beaches around the world are subject to problems associated with beach erosion and recession (Hanslaow, D.J., 2007). Paterson et al, (2010) defineshoreline erosion as the group of natural processes including; weathering, dissolution, abrasion, erosion, and transportation, by which material is worn away from the earth's surface.In Kenya Hoorweg and Muthiga (2009) reported that costal environment influenced by naturally occurring process such as erosion and sedimentation carried by Sabaki River.In addition to these natural processes, human action to control and mitigate erosion and maintain navigation channels can change the shoreline (Williams and Gutierrez, 2009). According to Richmond (1997), human actions such as the destruction of mangrove forests, seagrass beds, and coral reefs caused by tourism development can increase the exposure of the coast to wave actions which leads to erosion. In Kenya for example, a study by Kairu and Nyandwi, (2000) showed, that in the last three decades rapid development in the tourism industry has taken place on the beaches which have experienced increasing coastal erosion problems. Another study along the Kenyan coast by Government of Kenya, (2010a)indicated that in the built up areas, erosion in some cases has been exacerbated by human

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interference, with the construction of seawalls. Sea walls increase reflected wave energy, leading to erosion and flattening of the adjoining beach, an example of the effect of sea walls can be seen at Mtwapa in Kenya, where walls have been built to protect shoreline properties (Kairu and Nyandwi, 2000). According to the study by Government of Kenya, (2010a)the Kenya coastal areas are showing clear signs of damage and degradation due to over-exploitation, land use changes which has led to erosion, siltation and hydrologic modifications. The results were; loss of coastal and marine habitats, fish landing sites, beaches, turtle nesting areas, and damage to properties adjacent to the shoreline.Erosion is moderate to severe in parts of Watamu beach area (Government of Kenya, 2010b).

According to Moore et al., (2006), several coastal areas are heavily populated and have been continuously changing hence, shoreline change analysis research has become a common goal of most coastal management plans. Furthermore, shoreline change analysis has become a suitable tool to understand temporal and spatial trends of beach erosion and accretion triggered by natural and human impacts (Limber et al., 2007). Therefore, understanding the process causing shoreline change and quantifying the shoreline change rate is crucial for better coastal area management. This research focused on measurement of the rate of shoreline change and defines the drivers of shoreline erosion and accretion in the period 1969-2010 in Watamu.

II. Material and Methods

a) Study site

The study area is located in Kilifi County on the north coast of Kenya'scoastal region. It also borders the Watamu Marine National Park and Reserve. According to the report by Government of Kenya, (2010b) the morphology of this coastline is a fringing reef coast, comprising sandy beaches and reef limestone terraces. A study by Tychsen (2006) confirmed that the coastal region in Kenya is by and large low lying and categorized by an extensive fossil reef which lies a few meters above present sea level. The total area under study covered 9.8km starting from the mouth ofMida–Creek to the main Watamu beach front (Figure 1)up to the Jacaranda area.

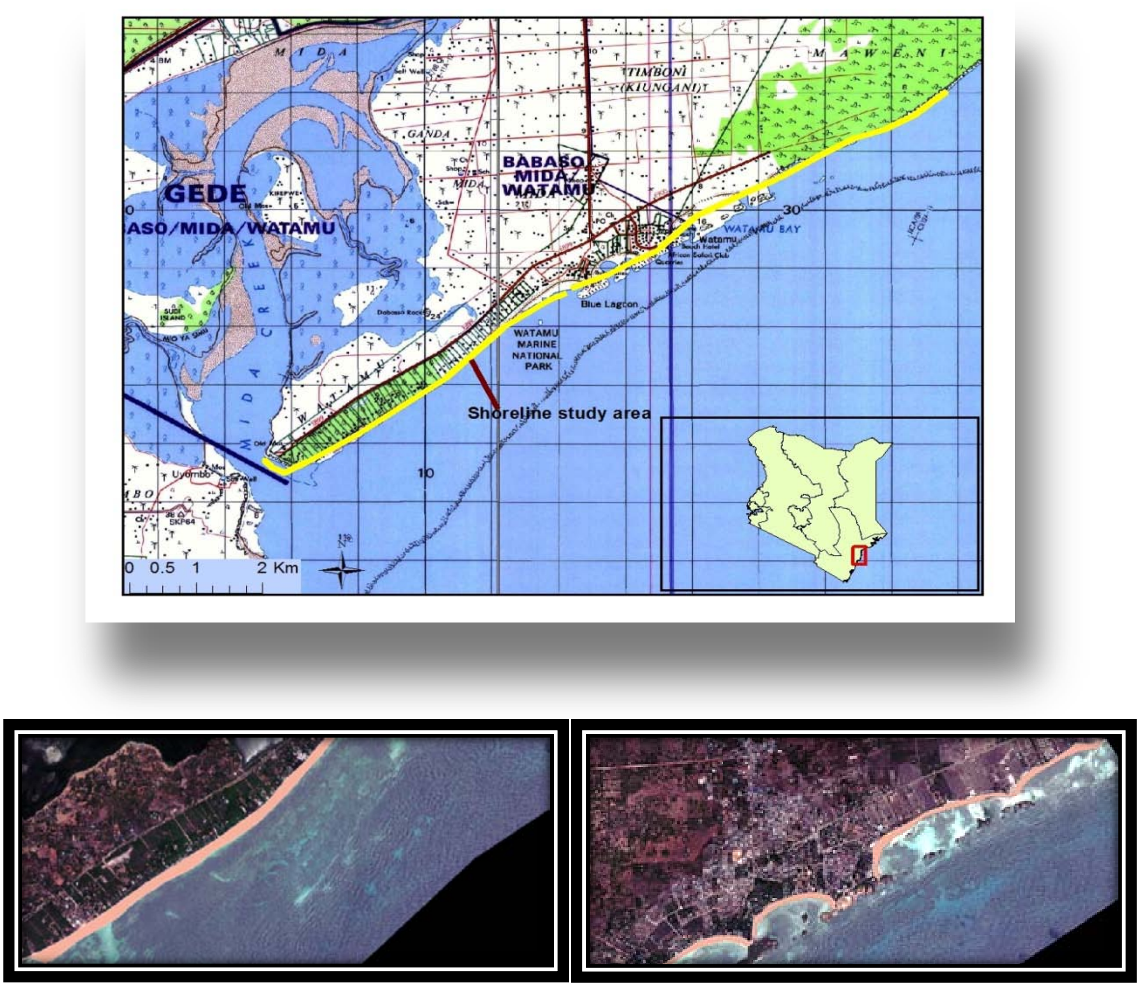

Figure 1 : Study site

b) *Data Sources and Study Approach*

i. *Data sources*

The sources of shoreline data were; aerial photographs, satellite images, topographic maps and GPS points. The aerial photographs had a scale of 1:60,000 and 1: 50,000 for 1969 and 1989 respectively. The satellite image used for 2010 was WorldView with 0.5 m resolution. The aerial photographs were scanned at a minimum resolution of 800 dpi and geo-referenced using ERDAS IMAGINE 2014 software. A SPOT image of 2002 and WorldView 2010 geo-referenced satellite images were used as a source of Ground Control Points (GCP) in ERDAS AutoSync Workstation to geo-reference the aerial photographs with root mean square error of ±2m. The aerial photographs mosaiced using ERDAS IMAGINE 2014software mosaic toolbox.

ii. *Shoreline extraction*

The shoreline change datawas extracted from aerial photographs of 1969, and 1989 and satellite image of 2010 using ArcGIS.9.3.1 software. The shoreline change rate measurement followed the approach used by(Hanslow 2007, Thieler et al., 2009, Borrelli 2009,andFletcher et al., 2012)which includes: digitizing a shoreline on georeferenced images, and quantifying rates of shoreline change. Several literature suggest the use of High Water Line (HWL) shoreline indicators which include a debris line; wet/dry line and; change from low-marsh to high-marsh vegetation along marsh shorelines to delineate shoreline change (Crowell et al., 1991, Borrelli, M., 2009, Boak and Turner). According to Crowell et al., (1991) HWLis the best indicator of the land-water interface for historical shoreline studies. Based on this approach the shoreline was digitized onscreen using HWL indicator from the aerial photographs and the 2010 satellite image using ArcGIS.9.3.1 software. Additionally, GPS points collected in November 2013 and 2014 along the shoreline following HWLwere used to definecurrent shoreline.

iii. *Shoreline data analysis*

A geo-database was created in ArcGIS for the digitized shoreline positions with attribute tables for all shorelines which comprised;year, ID, shape and uncertainty. The historical change in shoreline was analyzed using a Digital Shoreline Analysis System (DSAS 4.3) computer software which is an extension for ArcGIS. The Digital Shoreline Analysis System (DSAS) computes rate-of-change statistics from multiple historic shoreline positions residing in a GIS (Thieler et al., 2009).

Three statistical methods were used to calculate the change in rates of shoreline from 1969-2010. The methods were End Point Rate (EPR), Net Shoreline Movement (NSM), and Linear Weighted Regression (WRL). In DSAS work flow the EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline Thieler et al, 2009). The NSM reports the total distance between the oldest and youngest shoreline(Thieler et al, 2009).In the computation of rate-of-change statistics for shorelines, greater emphasis is placed on data points for which the position uncertainty is smaller. The weight (w) is defined as a function of the variance in the uncertainty of the measurement (e) (Thieler et al, 2009):

$$w = 1/(e^2) \quad (1)$$

Where

e = shoreline uncertainty value

The uncertainty field of the shoreline feature class is used to calculate a weight. In conjunction with weighted linear regression rate, standard error of the estimate (WSE), standard error of slope with user-selected confidence interval (WCI), and R-squared value (WR2) are obtained (Thieler et al, 2009).

The error or uncertainty that comes from different sources of data were calculated based on a number of studies(Crowell et al., 1991, Fletcher et al.,2012, Lauraand Javier, 2013). Using the approach by Laura and Javier, (2013) three main sources of errors identifiedwere; image resolution error (R), geo-referencing error (G), and a physical component of the error or shoreline proxy (D). Fletcher et al (2012), suggested the inclusion of digitization error, hence this variable was included in the following formula (Ed)

$$Ep=\sqrt{G^2 + R^2 + D^2 + \mathrm{Ed}^2} \quad (2)$$

Where

G= Geo-referencing error, R= Image resolution error, D= Shoreline proxy error, Ed= Digitization error

Using the above formula the uncertainty corresponding to each individual image was ±4.6 m and ±2.4 m for the aerial photographs and satellite image respectively.

iv. *Field verification*

Two ground truthing exercises were conducted in the study area during 2013 and 2014. In October 2013a number of GPS points were collected by walking along the beach during low tide following the HWM. At the same time digital photos were taken to improve knowledge of specific points along the Watamu shoreline (Figure 2). After the preliminary analysis of shoreline change results, an additional field verification was conducted in October 2014. During this time Focused Group Discussion and key informant interviews were conducted with;curio sellers, boat operators, fishermen, safari sellers, longtime residents, and hoteliers in order to get information about possible drivers of shoreline change in Watamu. A number of pictures were taken along the shoreline to compare with the 2013 pictures.

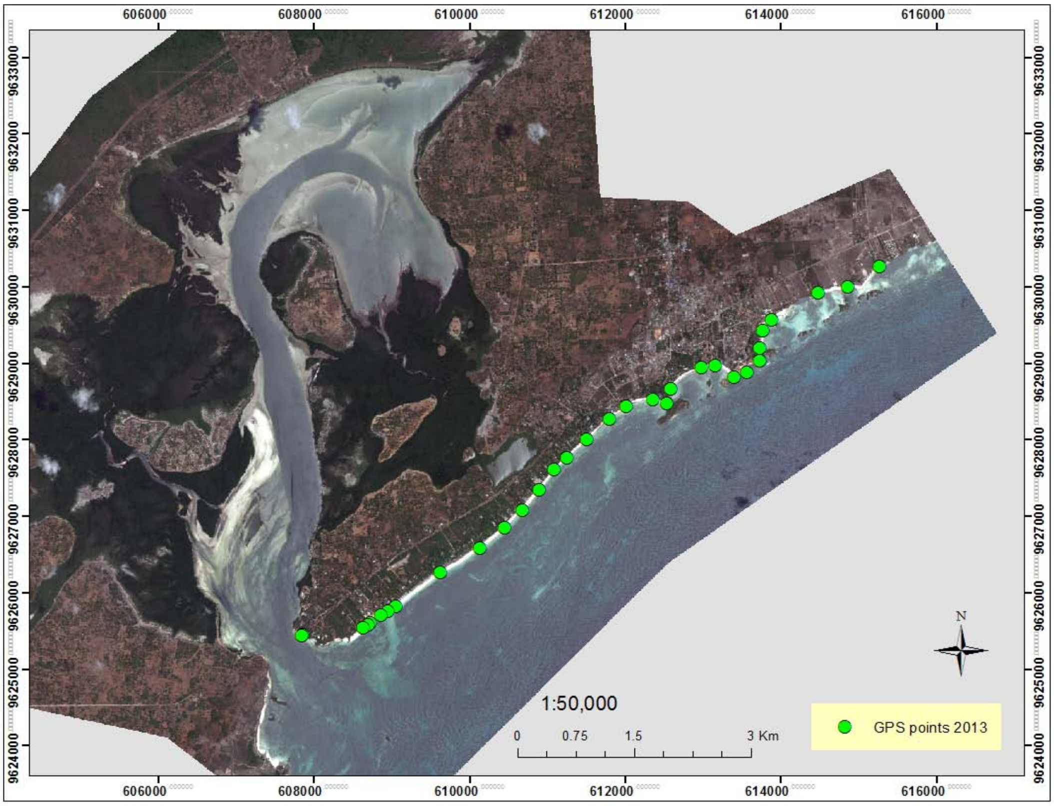

Figure 2 : GPS points taken in 2013 following the HWM overlaid on the satellite image of 2010

III. Result

a) Shoreline changes

The Watamu shoreline covers 9.8km was digitized from 1969 and 1989 aerial photographs and 2010 satellite image (Figure 3). A total of 245 transects were generated with 40 m spacing and an average change rate calculated from 1969 to 2010.

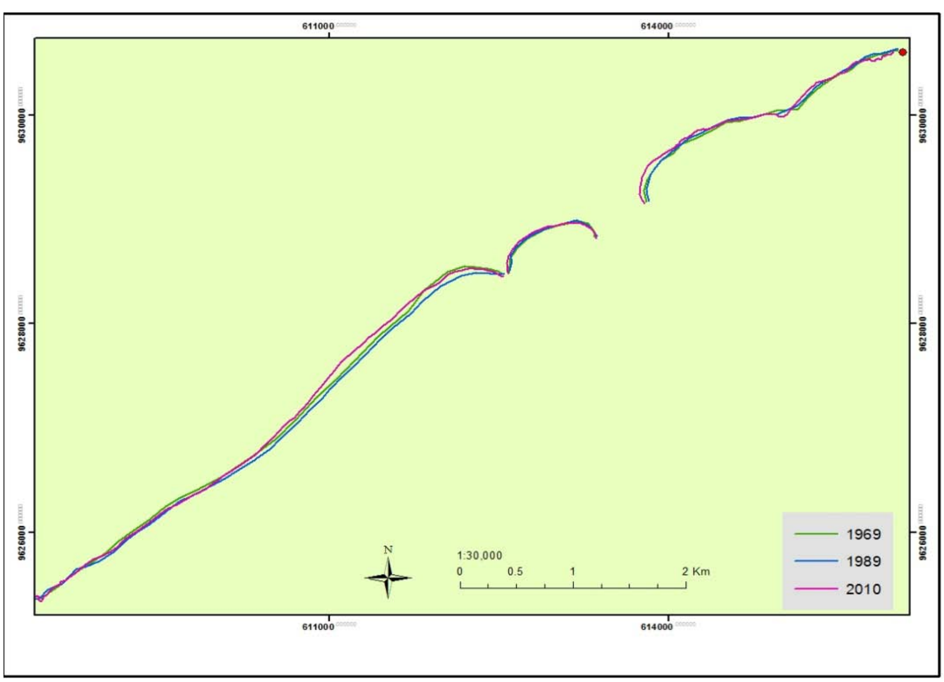

Figure 3 : Extracted shorelines

The shoreline analysis for the period 1969-2010 revealed that most of the beach front underwent erosion with accretion observed in small patches. The WLR shoreline analysis for the beachfront showed a mean of -0.89 m/year where 69.7% of transects fall under erosion and 30.2% accretion (Table 1).This analysis gives emphasis on data points for which the position uncertainty was smaller. The EPR and NSM analysis revealed mean shoreline change of -0.7m/year and -30.3m/period respectively from1969 to 2010 (Table 1). The mean shoreline movement from 1969 to 2010 was -30.3m/year with a standard deviation of 19.4. The EPR calculates the rate of shoreline change whereas the NSM reports the distance between the oldest and youngest shorelines for each transect. Both EPR and NSM results showed 158 transects or 64.4% experienced erosion, and 87 transects or 35.5% with accretion (Figure 4 and 5).

Table 1: Overall shoreline change rates from 1969 to 2010

Shoreline Statistics	Shoreline change (m/year and m/period)	
	Erosion	Accretion
End point rate (EPR) (m/year)	-0.74	0.47
Weighted linear regression (WLR) (m/year)	-0.89	0.41
Net shoreline movement (NSM) (m/period)	-30.3	19.5

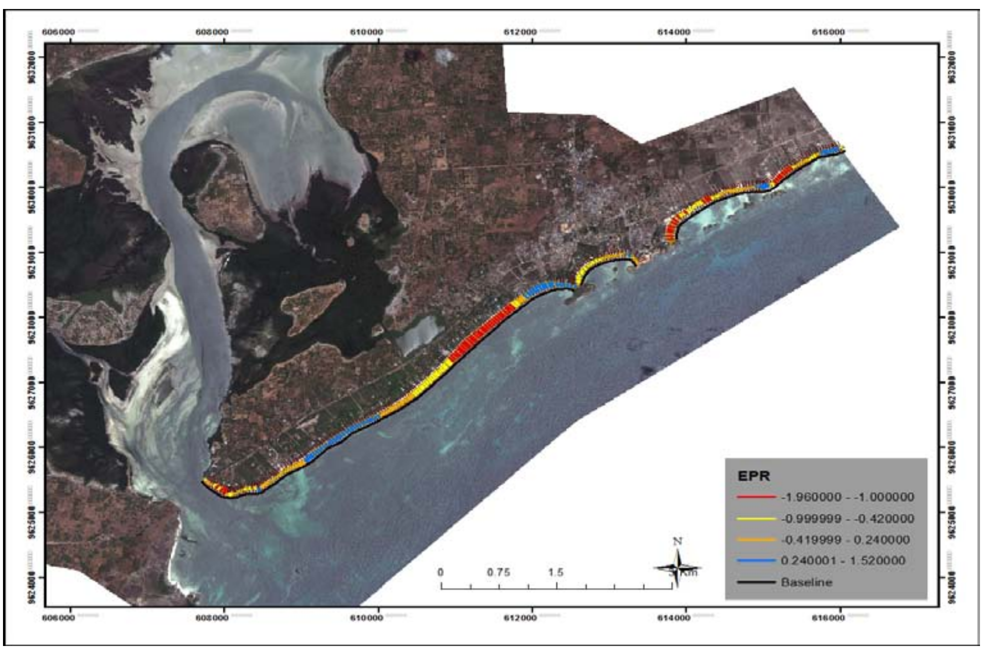

Figure 4: Rate of shoreline change (EPR m/year) along the shore from 1969-2010(all negative signs shows erosion, whereas the blue color shows accretion)

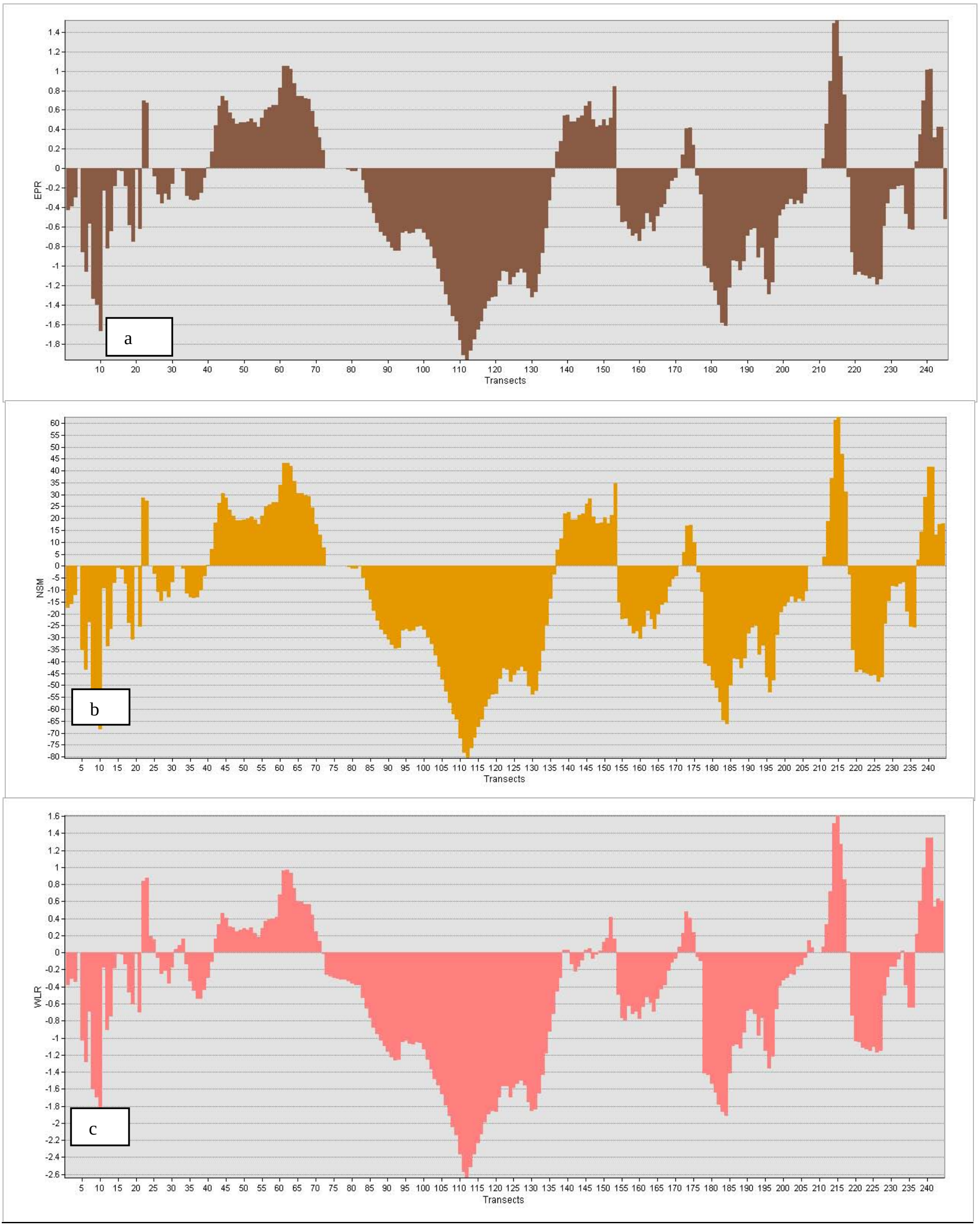

Figure 5 : Graphs of the shoreline changes 1969-2010, (a) End Point Rate (EPR), (b) Net Shoreline Movement (NSM) (c) Weighted Linear Regression (WLR). The EPR and WLR units are in m/year, while NSM is m/period. Most of the graph is in the negative area (i.e. below the line) which indicates shoreline erosion

b) Shoreline change trends

The result from the three shoreline analyses (EPR, WLR, and NSM) show that the shoreline has retreated (in general) along the Watamu beach over the last 41 years (Figure 6 and Table 2). The shoreline was divided in to sections comprising 50 transects each. Section S1 and S2 at the beginning of the Mida Creek entrance show a mean change of -0.25 and -2.1 m/year respectively (Figure 6 and Table 2). This result agreed with the EPR shoreline change analysis rates except that some of the area under EPR showed some accretions (Figure 6). Major erosion (retreat) was observed in S3 with the WLR mean of -1.32. The EPR analysis and the information gathered during ground truthing has shown similar shoreline erosion in this section (Figure 6). Section S4 and S5 also showed shoreline erosion though the rate of change is not as high as S4 (Figure 6 and Table 2). According to Thieler et al, (2009), the R^2 statistic has a dimensional index that ranges from 1.0 to 0.0, the smaller the variability of the residual values around the regression line, the better the prediction.

Table 2 : Weighted Linear Regression (WLR) from 1969 to 2010

Section number	Transect number	Mean	WR2 (R^2)	St. Deviation
S1	1-49	-0.25	0.5	0.57
S2	50-100	-0.21	0.4	0.69
S3	101-149	-1.32	0.5	0.82
S4	150-200	-0.65	0.8	0.61
S5	201-245	-0.01	0.6	0.77

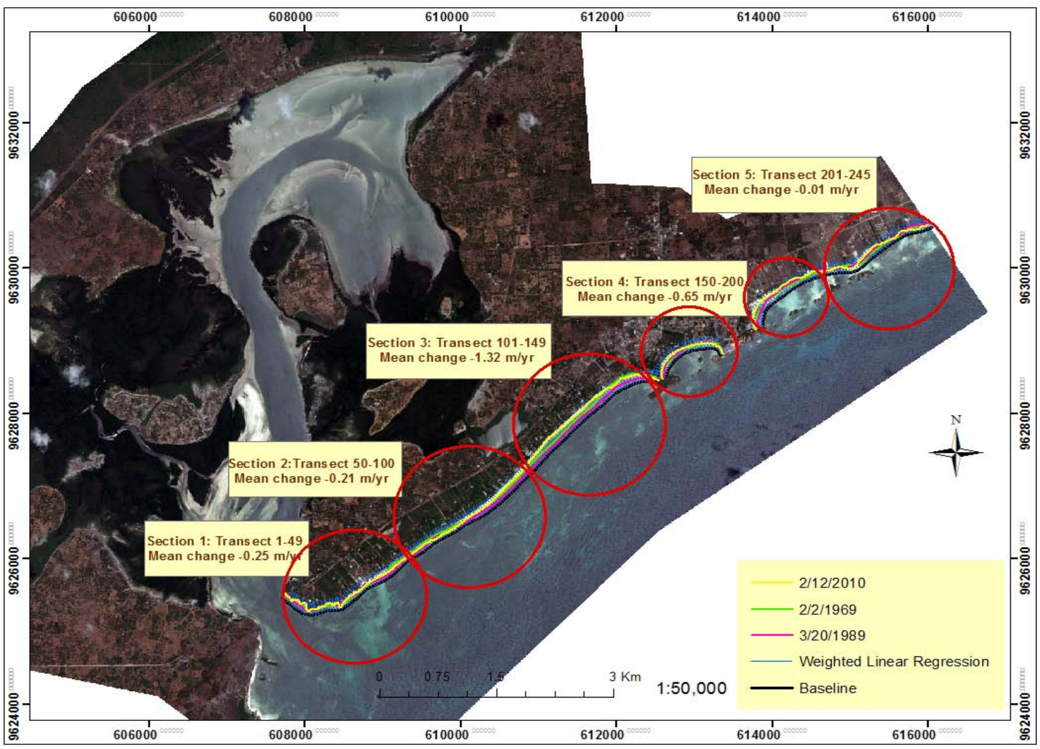

Figure 6 : WLR mean Shoreline change rates by sections (transects) from 1969-2010 (presentation adopted from Chaaban et al., 2012)

Numerous studies have used the ArcGIS extension DSAS to calculate long term shoreline erosion change rates (Borrelli 2009, Hapkeet al.,2010, Appeaning et al., 2011, Fletcher et al., 2012).In Kenya there was a research in Bamburi,Mombassa using an alternative methodology based on beach width measurements and a hydrodynamic parameters(Mwakumanya et al., 2009).

The outcome of the analysis from this study was similar with that of Fletcher et al., 2012. Based on Fletcher et al's., (2012) study on historical shoreline change in the Hawaiian Islands (1928-2006), long-term rates from all transects on the three islands are -0.11 ± 0.01 m/yr and 70% of transects indicate a trend of erosion.Another study in Keta, Ghana, using the same methodology came up with an erosion rate change ranging from 0.1 to 15.4 m/yr and accretion rates ranging from 0.1 to 21m/yrfrom a period of 25 years (Appeaning et al., 2011). However in each of these studies results from the analyses can differ depending on both the natural and human factors that cause variation in shoreline changes in each context.

IV. Discussion

Assessment of shoreline change rates showed a trend of shoreline erosion along Watamu coastline. Most of the beach underwent erosion while some part of the beach accreted during the study period. The observed patterns of erosion and accretion along the Watamu shoreline resulted from both natural and human impacts. Most of the shoreline was exposed to natural shoreline phenomena such as waves, tides and periodic storm surges. It was noted that during the southeast monsoon the shoreline showed signs of greater erosion, which was evidenced from uprooted trees and severely affected hotel and private property beachfronts (Figure 6 &7).The shoreline from Section 1 to Section 3 (S1-S3), as shown (Figure 6 above) was exposed during the southeast monsoon where the waves exert a strong alongshore influence on the beach causing movement of shoreline materials from one location to another. These findings confirm, a wider trend along the Kenyan coast, concerning the southeast monsoon as reported (Government of Kenya, 2010 (a)).

Figure 7 : Indicators of shoreline erosion in the study area. Pictures taken in; 2012, 2013 and 2014

Another natural factor which attributes to shoreline erosion in the study area isthe fine sandy nature of the beach material which makes it easily susceptible to erosion during periodic surges (Figure 8). Watamu beach has a fringing reef coast consisting of sandy beaches and reef limestone (Government of Kenya, 2010(b)).Coastal areas which are dominated by unconsolidated sediments are more susceptible to coastal erosion (IOC-UNEP- WMO-SAREC, 1994).

Figure 8 : Watamu beach front along the Long beach where the beach is covered by natural riparian vegetation and few tree species including Cocos nucifera, Casuarin equisetifolia and Pomoeapes-caprae,(photo taken during southeast monsoon period)

Human impacts such as;areas where the riparian vegetation was cleared to expand the recreational beachfront and to get a better view of the sea, construction of sea walls to control shoreline erosion, and building developments near the HWM are all considered to be major contributors to shoreline erosion (Figure 9 &10). Along the beach several tourist hotels and expensive residential/holiday houses were observed, withsome of these being built just a few meters away from the High Water Mark (HWM)making them susceptible to flooding during spring tides(Figure 9).Studies conducted by IOC-UNEP-WMO-SAREC, (1994), indicated that; Diani, Shelly beach, Nyali, Bamburi, Kikambala,Watamu and Malindi coastal tourist centers are located on level (I) that is 0-5 meter above sea level and level (II) 5-10 meter above sea level.

Figure 9 : Some of expensive investments near the HWM

The Survey Act (Cap 299) of Kenya, provides a set-back of not less than 60 meters above HWM (Government of Kenya, 2010(a)).However the reality on the ground proved that this set-back was not appliedto some of the tourist hotels and houses (Figure 10). As reported in the shoreline change rate analysis Section 3 (S3) demonstrated marked erosion, this result agrees with other similar shoreline studies. For example a study in the Caribbean revealed that the shoreline has been significantly altered by human action such as coastal infrastructure (Restrepo et al., 2012). Another study in Ghana confirmed the impact of increased population along the coast followed by rapid urban development has been the main driving force for coastal erosion (Appeaing et al., 2011). A study of Bamburi beach, Kenya, also confirmed the anthropogenic activities such as recreational activities resulting in a trampling effect of the beach sediment aggravates shoreline erosion as the sediment gets loosened and carried away by the stronger waves (Mwakumanya et al., 2009).

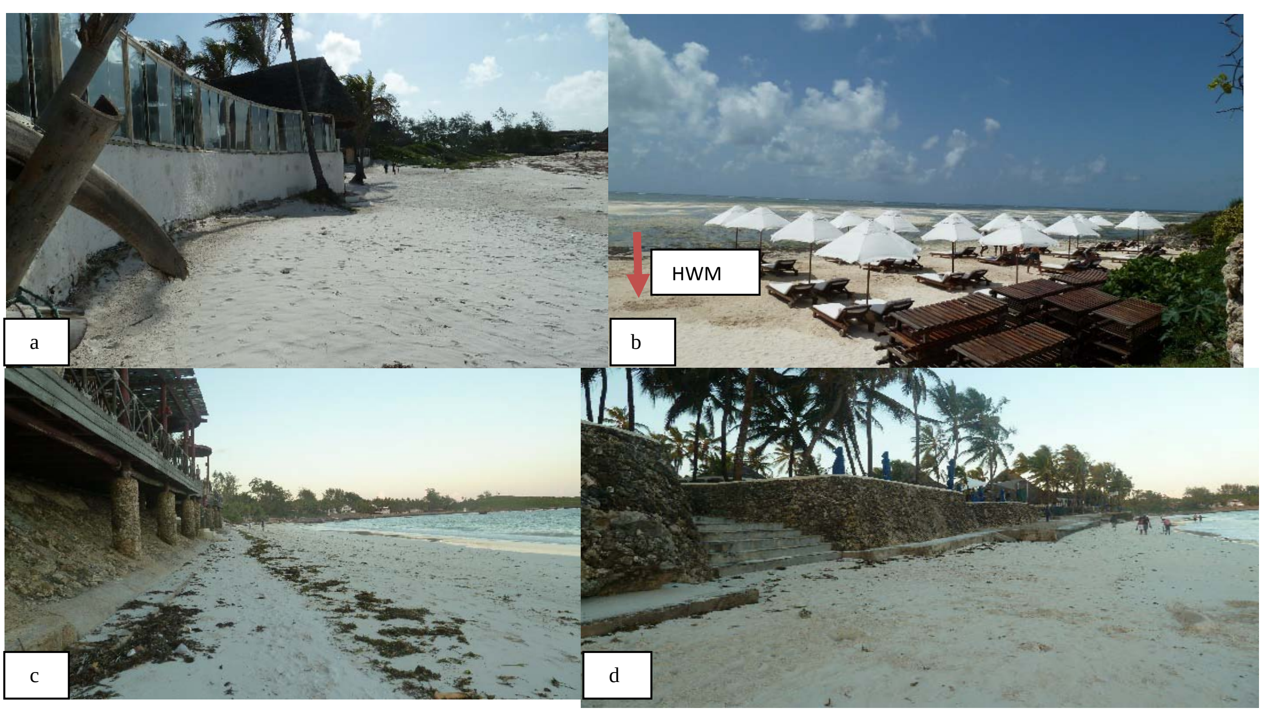

Figure 10: (a) Construction near HWM, (b) Impact of recreational activities along the beach, (c,d) construction of sea walls ,(e) (2007),(f) (2014)clearing of riparian vegetation and natural dune

It was observed during field verification the construction of sea walls to combat shoreline erosion has caused major shoreline erosion and property damage in adjacent plotson the beachfront (Figure 11). Other studies have also confirmed the impacts of such sea walls, for example a study in Diani, Bamburiand Kikambala, revealed beach erosion and rapid degradation of the beach resources as the result of sea walls (IOC-UNEP- WMO-SAREC, 1994). Astudy by Kairu and Nyandwi (2000) reported the impact of sea walls as the cause for the increase in reflected wave energy leading to the erosion and flattening of adjoining beach areas. A study in America by Hapke et al., (2010) indicated that the emplacement of shoreline protection structures such as; seawalls, bulkheads, and barrages can result in erosion of the beach.

Figure 11 : Adjacent properties affected by erosion displaced by sea walls and other fortifications

Information gathered during Focused group discussions with community representatives and longtime residents (through key informant interviews) confirmed how different human induced activities and developments along the beachfront have caused shoreline erosion as well as destruction of turtle nesting grounds. Respondents also mentioned that the night lights from some tourist hotels have disorientated newly hatched sea turtles, leading to lower survival rates. Watamu beach is a high priority turtle nesting area (Figure 12), and according to a report by the UNIDO COAST project (2014), five species of sea turtles can be found in the study site.

Figure 12 : (a)Turtle nesting areas marked by Kenyan Wildlife Services (b) turtle nesting site on a private beach plot (c, d) A good example of beach bank rehabilitation in Watamu

V. Conclusion

Watamu beach is one of the key tourist beach destinations in Kenya with a stunning white beach and a large variety of bird and marine life. The livelihood of the people also largely depends on income generated from different touristic activities. This study has demonstrated that almost 69% of the beachfront has undergone erosion in the period 1969-2010. The use of DSAS to calculate long term shoreline change was found to be very useful. A study of this kind is very valuable in helping to prepare a strategic coastal management plan and for future policy intervention.

Both natural and anthropogenic factors were observed to contribute for shoreline erosion and accretion. However the influence of human actions on accelerating shoreline erosion is a major concern. Construction of hotels or houses near the High Water Mark, sea defense structures or sea walls to combat beach erosion, high trampling effects due to orientated touristic activities, and destruction of vegetation along the beachfront were all observed to be aggravating shoreline erosion. These can all be easily observed when comparing areas covered by; indigenous coastal vegetation, under rehabilitation, and without coastal defensive structures.

In Kenya there are several parliamentary Acts and supporting legislation to protect and conserve riparian areas and marine environments. However, there is a problem of law enforcement and lack of regulation specifically on the 60 meter set-back regulation to prevent construction within such areas. Therefore, it will be advantageous if all institutions with responsibilities for such coastal areas to work in collaboration so as to keep the coastline and its marine life and resources from further damage and erosion. Rehabilitation of the shoreline with indigenous coastal vegetation is a good practice which needs to be replicated along the beach where major shoreline erosion is a problem. There should be a multi stakeholder discussion on the aesthetics of Watamu as a major tourist destination focusing on different shoreline protection practices, namely building of sea walls or, rehabilitation using natural vegetation protection techniques.

VI. Acknowledgement

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