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DECADAL SHORELINE CHANGES IN THE MUDDY COASTLINE OF ONDO STATE, NIGERIA

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Decadal shoreline changes in the muddy coastline of Ondo State, Nigeria

Temitope D. Timothy Oyedotun

Modifications du littoral décennales dans le littoral boueux de l'Etat d'Ondo, Nigeria. Les changements dans les positions du rivage à proximité du littoral boueux de l'Etat d'Ondo (sud-ouest du Nigeria) sont étudiés, entre 1972 et 2014. Les mouvements de l'eau (HW) rivage haut ont été étudiés en utilisant le système numérique Shoreline Analyse (DSAS), une extension ArcGIS développé par l'USGS. Les ensembles de données comprend plusieurs éditions de photographie de Landsat et le Nigeria Imageries satellite. le Shoreline délimitées les unes des images année inclus les positions de HW, qui ont été calculées à partir du rivage Mouvement net (NSM) et End Point Noter (EPR, le taux annuel de mouvement). Les résultats préliminaires montrent que les rivages de Ondo côte État ont connu un mouvement vers la terre constante au cours des quatre décennies. Ces changements sont attribués à des attaques d'onde, l'augmentation des niveaux des marées dans le golfe de l'Atlantique du Bénin, la récente hausse du niveau de la mer, canalisation de la rivière qui réduisent le transport de sédiments dans la zone côtière, l'extraction historique probable de sable et d'autres activités anthropiques dans la zone côtière.

Mots clé: Changement Shoreline, GIS, DSAS, l'érosion rivage, Hautes Eaux, niveau de la mer hausse

Decadal shoreline changes in the muddy coastline of Ondo State, Nigeria. Changes in shoreline positions in the vicinity of the muddy coastline of Ondo State (southwest Nigeria) are investigated, between 1972 and 2014. Movements of High Water (HW) shoreline were investigated using the Digital Shoreline Analysis System (DSAS), an ArcGIS extension developed by the USGS. Datasets includes multiple photograph editions from Landsat and Nigeria Satellite Imageries. Shoreline features delineated from each year images included the positions of HW, from which were calculated the Net Shoreline Movement (NSM) and End Point Rate (EPR, the yearly rate of movement). The preliminary results show that the shorelines of Ondo State coastline have experienced a consistent landward movement over the four decades. These changes are attributed to the wave attacks, increasing tide levels in the Atlantic Gulf of Benin, the recent sea-level rise, river canalisation which reduce sediment transportation to coastal zone, the probable historical sand mining and other anthropogenic activities at the coastal zone..

Keywords: Shoreline change, GIS, DSAS, shoreline erosion, High Water, Sea-level rise.

1. INTRODUCTION

The physical conditions, forms and morphology of the coastal and estuarine environments are far from being stable, especially as they respond in time and space to variations in sediments (and their movement/transport), geological constraints, wave, current or river processes, man-made structures/human activities and sea-level change. As a consequence, coastal and estuarine shorelines can progress through significant phases of erosion and/or deposition over time-scales of years to decades [1]. Quantitative analysis of shoreline changes at historic timescales is very important for understanding processes which drive coastal erosion and accretion [2], for computing regional sediment budgets [3], identification of hazard zones [4], or as a basis for morphodynamics modelling [5]. The dynamic processes of shoreline erosion and accretion are often attributed to hydrodynamic forces (e.g. river cycles, sea level rise), geomorphological changes (e.g. spit development), anthropogenic actions (e.g. port development, tidal power generation, construction, dredging) or other sudden forces (e.g. storm events, earthquakes and tsunamis, rapid seismic events) [5-7].

There has been increasing concern about the likely long-term impacts of changes in the natural/physical and environmental forcing factors and with those derived from human interventions on coastal environments [2-5], [8]. However, before any predictions about morphological responses to future changes can be made with strong confidence, it is necessary to understand the previous changes in the coast system, as well as determining the envelope of natural variability of any longer-term trends. The shoreline is perhaps the most basic indicator of changes in coastline interaction and, by implication, in erosion and deposition. This paper presents preliminary findings on the shoreline changes along Ondo State coastline between 1972 and 2014 and it aims at evaluating the sensitivity of High Water (HW) shoreline over the last four decades in the vicinity of the coastline. The targets of the study are: the examination of the temporal and spatial variability in coastal change, exploration of the geomorphic sensitivity and investigation of the likely processes forcing the morphological behaviour .

2. ONDO STATE COASTLINE

Of the four distinct geomorphic zones along the 800 km of Nigeria's coastline, Ondo State coastline is along the 75 km eastern boundary mud beaches which terminate at the Molume at the boundary with Delta State of the western flank of the Niger Delta [9]. Ondo State is between Latitudes 5° 45' and 8° 15' N and Longitude 4° 45' and 6° E with its south being the coastline bounded by the Atlantic Ocean (Figure 1). The coastline is predominantly medium to coarse, poorly sorted, finely skewed and platykurtic to leptokurtic silt beach [9]. It is also a mesotidal (2 – 4 m tidal range) beach with largely fine grained (0.18 – 0.34 mm) sediment and are of low gradient (< 80) [10].

Due to the low mean tidal range, the coast has a relatively high and consistent intensity of wave action. Large swell waves are , therefore, common in the area, which are generated by the prevailing south-westerly winds [9] and the flooding driven by high tides [11]. This low lying mud coastline has an elevation varying between 0.5 to 2 m above mean sea level [11] and persistent significant wave height (hs) of the order of 1.4 m – 2.5 m with the prevalence of longshore currents at the near shore zone [12]. The continental shelf in the study area is narrow, relatively gently sloping with bathymetric lines running generally in parallel to the coastlines [11]. Full and detailed description of the geology of Nigerian coastline, including the study site and the entire Niger Delta have been given extensive discussion in literature (See for example, e.g.,[9], [11], [13-21]). Evolution of the present-day physiography of the study sites are attributed to the separation of South America from the African plate, especially from the Upper Jurassic to the Lower Cretacous [22].

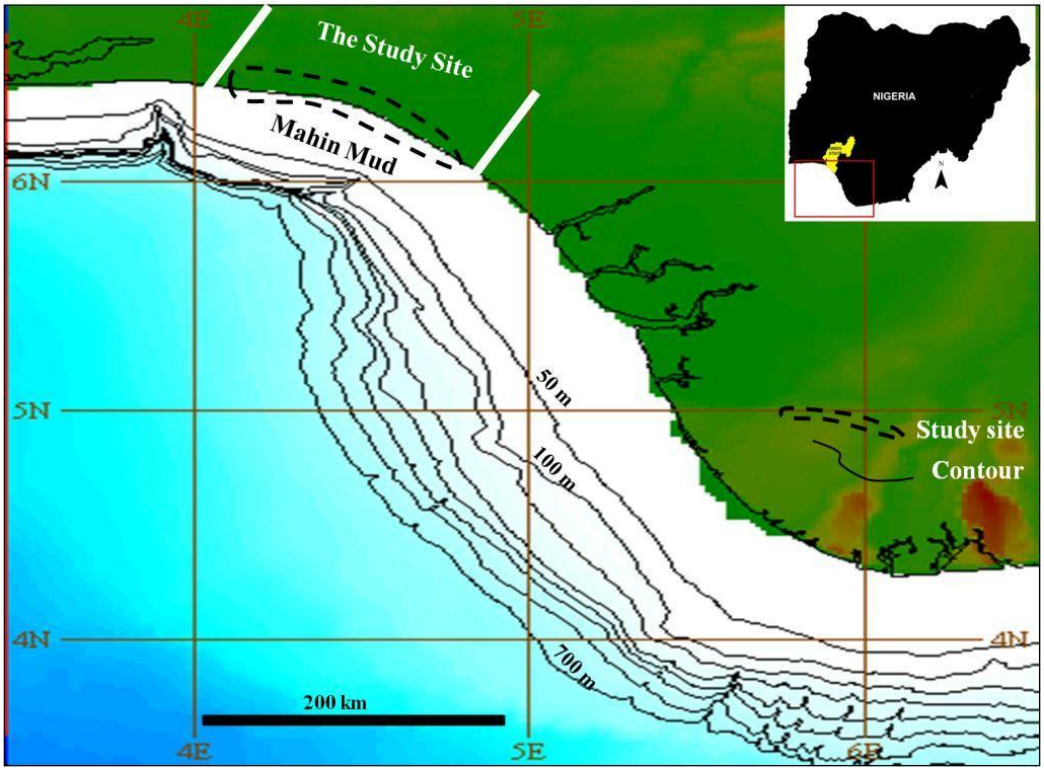

Figure 1. Nigeria's Atlantic Gulf of Benin showing Ondo State coastline (in black dashed line, background map courtesy of Awosika and Folorunsho, 2008 [23]) where the study is focused. Inset, The map of Nigeria highlighting Ondo State.

3. METHODS

Digital Shoreline Analysis System (DSAS, henceforth) with Environmental System Research Institute (ESRI)'s ArcGIS 9.3®, version 4.2 [24] was used to compute the rate of change statistics and the time series analysis of the changes in shoreline patterns. The shoreline changes (High Water, HW positions) along the coastline are the primary focus of this preliminary analyses. Two main approaches/methods were used (after [25]).

i. The first is the documentation of configuration of the High Water (HW) shoreline positions for over the 40 year period (1972 -2014). The spatial pattern of the HW are then analysed and presented in DSAS.
ii. The second approach involved the evaluation of historic changes and trends of two selected transects for in-depth examination and quantitative analysis.

Data Sources

The datasets used in the study are predominantly the remotely sensed images from Landsat (1972, 1999, 2002, 2004 and 2014) and Nigeria Sat 1 (2007) images. The positions of HW were identified and digitised from each of the images before being analysed for their movement and changes in a DSAS.

Shoreline digitisation and data quality consideration

The HW positions were extracted through manual on-screen digitisation. However, the DSAS analysis is not immune to the usual limitations associated with digitisation and synthesisation of variable quality and resolution materials derived from various sources as a result of irregular time sampling interval. Care was undertaken to ensure that the shoreline positions were accurately digitised as each of the digitised shorelines were consistently and continuously checked with the source data. As the calculated range of change provided by DSAS are only reliable as the sampling and measurement errors which was accounted for during compilation of each shoreline, the mapping errors as data uncertainty value estimate were +/- 10m for the pre-2000 images and +/-5 m for post-2000 photographs positions [26-29].

Shoreline analysis and interpretation

The spatial pattern of shoreline changes were evaluated first prior to the selection of transects for quantitative analysis. The DSAS methodology calculates the shoreline rates of change based on the measured differences between the shoreline positions through 1972 to 2014. The following parameters are presented in this preliminary result:

(i) Net Shoreline Movement (NSM): which reports the distance between the oldest (1972) and the youngest (2014) shorelines; and,

(iii) End Point Rate (EPR): derived by dividing the distance of shoreline movement by the time elapsed between the 1972 and the 2014 shorelines.

The above parameters were evaluated for the transects to show the spatial patterns of movements of the shorelines in the study site. To quantitatively measure the amount of shoreline shift along each transect (two transects were selected each from two communities, Aiyetoro and Awoye), the 1972 shoreline position was chosen as the baseline or zero position to which all other shorelines are referred. With reference to that baseline, positive measures indicate shoreline progradation while the negative ones show shoreline recession. The transect spacing adopted was 2 m with 10m simple baseline smoothing distance and the change statistics was based on 95% Confidence Interval.

4. RESULTS AND DISCUSSION

Decadal Shoreline Movement

In most applications, the shoreline rate-of-change is expected to reflect a cumulative summary of the processes that have impacted the coast through the time [30]. The spatial distribution for the rates-of-change (NSM and EPR) for the Ondo State HW coastline is presented in Figure 2. The spatial assessment of the change pattern shows the dynamic landward movement of HW shorelines in the study site. HW Shoreline change analysis (1972 to date) shows a large-scale and consistent patterns of retreat. This muddy coastline has experienced recession over the last four decades (Figure 2B) and the average net shoreline movements across all DSAS transects is – 25 m. The total erosion is not almost the same all over the coastline. The retreat of a little less than 20 m is observed in Awoye. Broad yearly rates of change in the position of HW are in the range of -2 to -5 m yr-1 before Aiyetoro and after Awoye (and towards the boundary of the Ondo State with Delta State) while around -2 to ±0.5 m yr-1 are observed in Awoye area (Figure 2C). The landward retreating are prominent at the coastline as no visible preventive structure or geological formation along the coastline (which could have checked the pattern of movement) are noticed. As the coastal regions are known to be complex systems subject to various marine and terrestrial influences, but are mostly controlled by a combination of hydro-dynamical conditions, the sedimentary environment, sediment supply, underlying geology and anthropogenic activities [8], [31]. The High Water erosion at the study are thought to be as a result of combination of many factors.

Cummulative Shoreline Positions (HW)

In order to quantitatively examine the cumulative rate of change at some locations along the HW in the coastline, two transects are selected from Aiyetoro and

Awoye areas for examination. The cumulative change in the shoreline positions along the same transects are plotted in graphs with 'year' plotted along the X-axis and the corresponding cumulative change in shoreline positions with respect to 1972 shoreline plotted on the Y-axis. In the graphs, presented in Figure 3, the positive values indicate accretion trend where as the negative trends as erosion. From the cumulative graph time series, it is observed that there is a period of no stability in the early and later parts of the series, with interval of severe erosion in the 1970s and 1980s. The cumulative HW shoreline movement indicate the landward migration of the HW to ~ 20 km from their original position in 1972.

The findings from this study has shown that the persistent scale of erosion which have been reported in the past literatures on the Nigerian coastlines (for example, [32-42]) have not abated yet. Several reasons have been given to be accountable for increasing erosion of Nigeria's coastline, the study site inclusive. Notable are the increasing socio-economic activities primarily driven by oil exploration, seaport development and activities, oil exploitation [43]; increase in sea-level (sea-level rise), canalisation of rivers which reduce the sediment loads of rivers and thereby decrease sediment deposition along the coasts, and river/coastal dredging [44]. The impacts of erosion on Nigeria coastal zone have also been highlighted to include but not limited to: depletion of vital marine resources, the washing away of human population and settlements; the incursion and intrusion of saltwater onto the freshwater thereby polluting the freshwater, siltation and sedimentation of fluvial channels from the deposition of eroded materials, frequent and acute flooding, loss of beaches and its direct effect on recreational and other socio-economic benefits [41], [44].

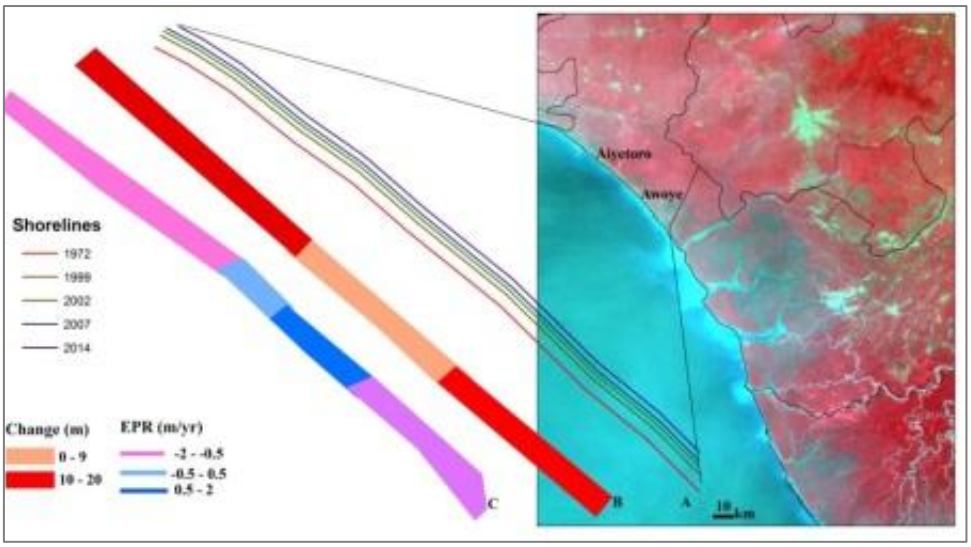

Figure 2. Shoreline change analysis of Ondo State coastline showing (A) the digitized shoreline positions, (B) Net Shoreline Movement, and (C) decadal yearly rate of change (End Point Rate)

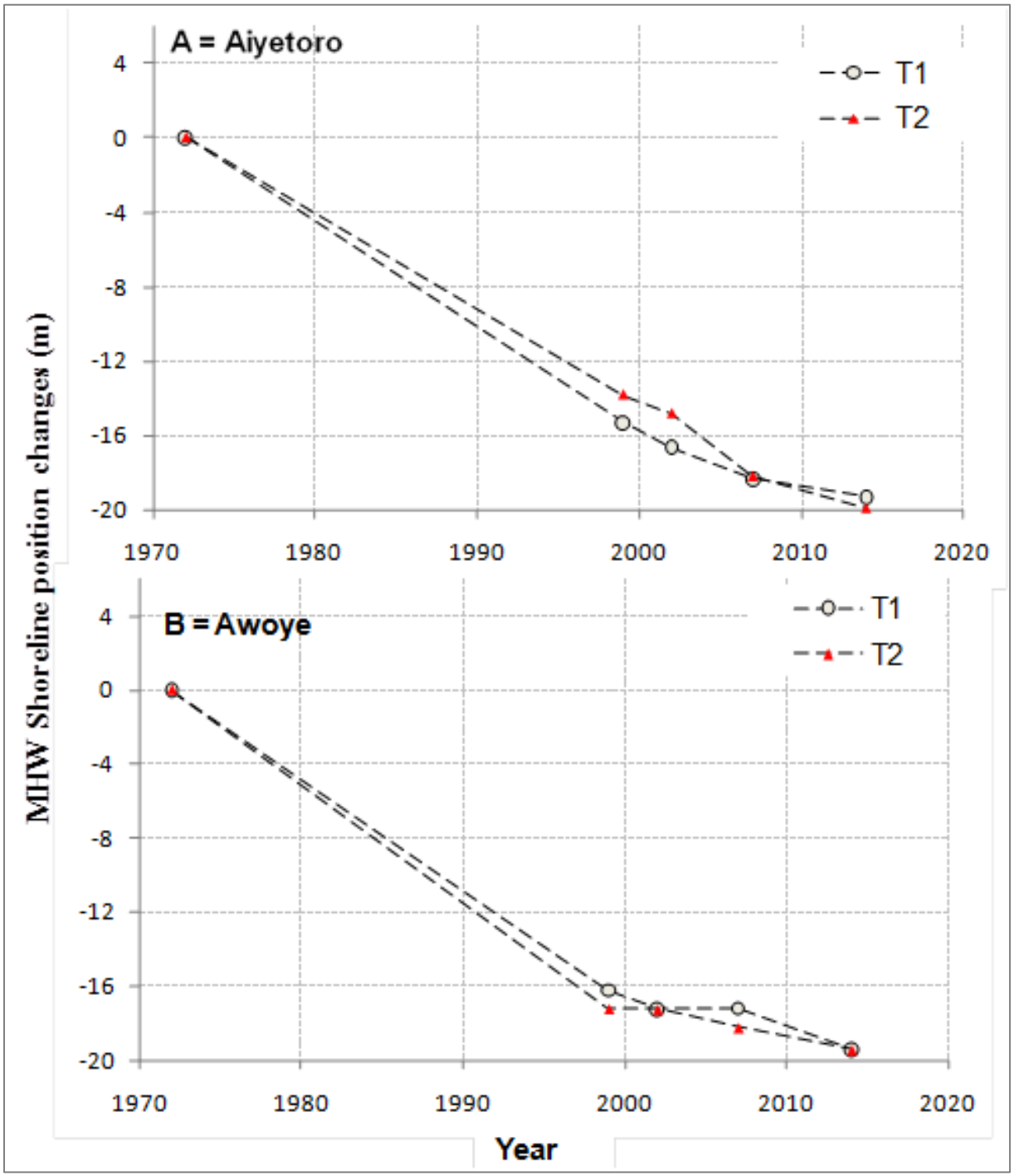

Figure 3. Cumulative volume of change of two transects in two sample locations, Aiyetoro and Awoye

5. CONCLUSIONS

The primary objective of this paper is to presents preliminary findings related to the HW shoreline movement along Ondo State coastline between 1972 and 2014 with the focus of evaluating the sensitivity of the shoreline over the last four decades. This paper has, therefore, examined the temporal and spatial variability in coastal change,

explored the geomorphic sensitivity and discussed the likely processes forcing the morphological behaviour of HW at the study site.

The trend of HW indicates a landward movement, it is suggested that variable environmental and anthropogenic factors might have been responsible for the instability in the shoreline positions. The sea level rise is the likely environmental factor postulated as being responsible for the landward movement, while port development, dredging, training wall construction, canalisation, etc are considered as the probable factors which influenced the pattern of shoreline trend in the study site.

Based on the preliminary result from this ongoing research, it can be concluded that much of the coastline itself is characterised by long-term shoreline recession, corroborating what have been observed/identified in literatures.

The trend of this shoreline erosion is expected to continue except there is urgent intervention in curtailing the effect or there is a decrease in sea level rise, wave attack or human mining of sand, etc. Over the decadal timescales, shoreline erosion is evident in the patterns of change in the HW movement, the ongoing further study of the coastline is expected to fully document and characterize the historic behaviour of the shoreline pattern in the study site.

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