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Spatio-Temporal Assessment of Shoreline Changes and Management of the Transgressive Mud Coast, Nigeria

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Abstract

This study investigated changes due to erosion and the consequences of rising sea levels on the Transgressive mud coast of Nigeria using multispectral Landsat images and ALOS PALSAR (AW3D30) elevation models with the view of proffering a management strategy for a sustainable coast. Endpoint Rate (EPR) and Linear Regression Rate (LRR) techniques within the Digital Shoreline Analysis System (DSAS) were used to assess the rates of changes along the shoreline between 1986 and 2021. Inundation models were developed in line with sea-level rise scenarios of the Green House Gas emissions (SSP5-8.5) with GIS to assess sea-level rise's impact on land and structures. Likewise, spatially disaggregated population and economic activity datasets projected to the year 2100 were overlaid on the inundation models to generate exposure indices for the coast. The study revealed that 49.8 km (64.67%) of the shoreline experienced retreat over the entire study period. This rapid rate of shoreline retreat has caused a land loss of 15.1 sq. km to the Atlantic over the last 35 years, which could trigger an additional 1.26 sq. km by the year 2032. Furthermore, the impact of sea-level rise is severe on the transgressive coast triggering submergence of the mud coast by inundation to the extent of 201 sq. km which will increase to 551 sq. km by 2100. Losses in terms of structures, population, and economic activity are recorded. To curtail the ongoing coastal changes, the study recommends the full adoption of the shoreline management plan (SMP) for sustainable

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shoreline management.

Keywords: Digital shoreline analysis system, inundation models, sea-level rise, shoreline change, shoreline management plan

Introduction

The coastal zone is the land area most affected by its proximity to the sea, as well as the part of the sea most affected by its proximity to land. The coastal zone is occasionally submerged, due to the action of tides and waves moving sediments inside, outside, and within the nearshore zone (Mentaschi et al., 2018). Coastal areas are some of the world's most productive and biologically diverse ecosystems (Badru et al., 2022). The shoreline is the interface between the land and the sea, and it is always in a state of flux due to sediment transportation and coastal/marine processes (Kankara et al., 2015). These processes possess the tendency to change shorelines on small-time scales ranging from days and years or long-time scales extending to decades or centuries (Fatima et al., 2017). Shoreline changes involve both erosion and accretion processes as well as changes caused by rising sea levels (Popoola, 2012).

Sea level rise (SLR) has been a major driving force affecting the stability of the shorelines as well as causing intense damage to coastal settlements (IPCC, 2021). SLR contributes to shoreline changes especially in low-lying areas, driving net long-term shoreline erosion over large spatial scales. This is accomplished through complex morphological adaptation and exposure to other drivers of morphodynamics (Nicholls & Cazenave, 2010). Coastal states in Nigeria are low-lying and vulnerable to the effects of climate change, including rising seas, inundation, coastal storms, and erosion (Popoola, 2014). Identifying areas vulnerable to erosion and inundation and quantifying their extent is essential for coastal planning and management (Kankara et al., 2015). As estimated by the IPCC's Sixth Assessment Report (AR6), there could be a global SLR of 1.01 m by the end of this century (IPCC, 2021) that could displace sizeable coastal settlements. IPCC (2019) included marine ice sheet instability and results for 2100 under the representative concentration pathways (RCP) 8.5 are higher than in AR5 (0.61-1.10 m). Other studies (Kopp et al., 2017; Wong et al., 2017) have predicted the RCP 8.5 process model estimates to rise to nearly 1.6 m by 2100. Likewise, Vermeer and Rahmstorf (2009) used a semi-empirical method linking temperature changes to SLR and suggested the possibility of a rise above 2 m. In Nigeria, the effect of a 1-meter rise in sea level could be enormous as about 18,000 sq. km of land area along the Nigerian coastal zone and 2,016 sq. km of the Transgressive mud coast will be inundated (French et al., 1995). More recent studies that used a space-borne digital elevation model reveal lower

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estimates of the effect of a 1 m SLR by 2100 as 2,869 sq. km of the Nigerian coast and 200 sq. km of the Transgressive mud coast will be inundated (Popoola, 2012; Popoola, 2014).

SLR will result in coastal recession and shoreline changes (Ranasinghe et al., 2012), coastal flooding (Aucelli et al., 2018), inundation, and subsidence (Popoola, 2012; Popoola, 2014). It will lead to declining water quality, decreasing fish cultivation, seawater intrusion into freshwater resources, the inundation of wetlands and estuaries, and severe impacts on coastal urban infrastructure (Koroglu et al., 2019). Factors responsible for the landward retreat of the coast include high wave energy, inundation due to low topography, little or no longshore sediment transport, lack of river deposits, sediment composition, clearing and harvesting of mangrove forest, and land subsidence due to oil exploration and exploitation (Dada et al., 2019; Oyedotun, 2015). Sea level rise is a major factor that contributes to the impacts of flooding on floodplains (Olokeogun et al. 2020). Indeed, a gradual rise in sea levels can rapidly increase the severity and frequency of coastal flooding (Vitousek et al., 2017). The impact of flooding events is usually exacerbated by human activities such as wetland degradation and depletion, building on floodplains, and improper siting of drainages for stormwater (Olajuyigbe et al, 2015). Assessing shoreline changes in coastal zones involves monitoring, modeling, prediction of coastal changes, and vulnerability analysis (Koroglu, et al., 2019). Many studies have adopted Remote Sensing and GIS techniques in shoreline and coastal change assessments to estimate erosion, accretion, and inundation and have adequately sufficed to produce results with high correlation and wieldy errors (Becerra et al., 2020; Griffiths et al., 2019). Statistical models such as End Point Rate (EPR) and Linear Regression Rate (LRR) as well as coastal vulnerability indices have been useful for the prediction of shoreline changes due to sea-level rise (Pendleton et al., 2004; Ozyurt and Ergin, 2010).

With increasing shoreline retreat rates per year, many developed countries have implemented measures and policies such as the shoreline management plan (SMP) to manage changes along their coastlines (Leatherman, 2018). SMP is a non-statutory, high-level planning document that involves longer-term strategic planning to reduce risks to people, the built, historic, and natural environment from coastal processes and anthropogenic forces that bring about changes in the shoreline through flooding and erosion (Environmental Agency, 2010). The SMP follows a proactive procedure starting from scoping the SMP, assessments to support policy development, policy development, public examination, finalizing the SMP, and plan dissemination (DEFRA, 2006). SMP has been adopted to manage shoreline issues globally, however, in Nigeria with increasing shoreline retreat, there has been little attention to shoreline management measures nor is there a

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shoreline management plan for the coast (Popoola, 2012). Research on the impact of shoreline changes on socio-economic indicators such as population that can be affected, economic activity loss, and wetland loss in the Transgressive mud coast is sparse. Hence, this study will attempt shoreline changes between 1986 and 2021, estimate the extent of sea-level rise on the Transgressive mud coast and its implications on various socio-economic indicators and proffer a shoreline management strategy for the coast.

Methods

Study Area

The Transgressive mud-beach coast is situated in the southwest of Nigeria in between the Lagos barrier lagoon coast and the arcuate coast of the Niger Delta. It lies approximately 5^{0}50’38’’ and 6^{0}38’45’’ North of the Equator and 4^{0}30’18’’ and 5^{0}30’18’’ and 5^{0}02’52’’ east of the Greenwich meridian. It is approximately 25 kilometers east of the boundary of Lagos and covers about 1,433 sq. km extending 77 kilometers along the coastline (Figure 1). The Transgressive mud coast is an undulating coastal plain with nearly two-thirds of the coast (64.5%) less than 5 meters and 89.4 percent within 10 meters (Figure 2).

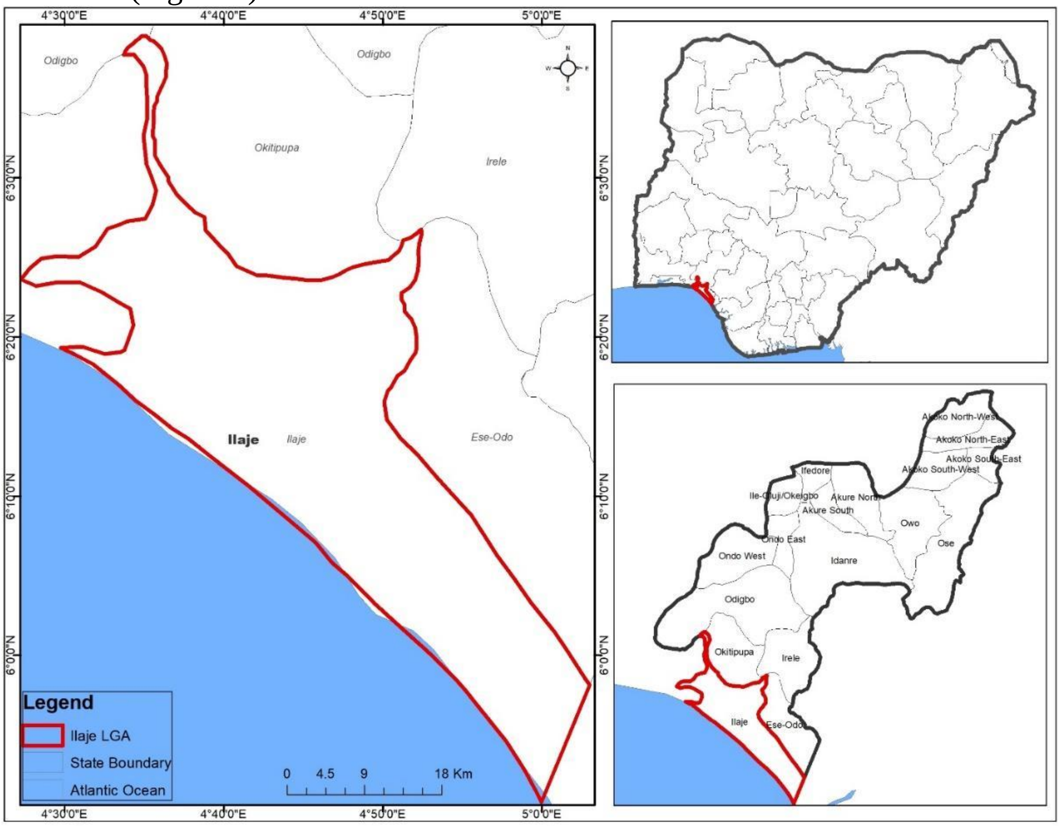

Figure 1: Map of Nigeria showing the Transgressive Mud Coast

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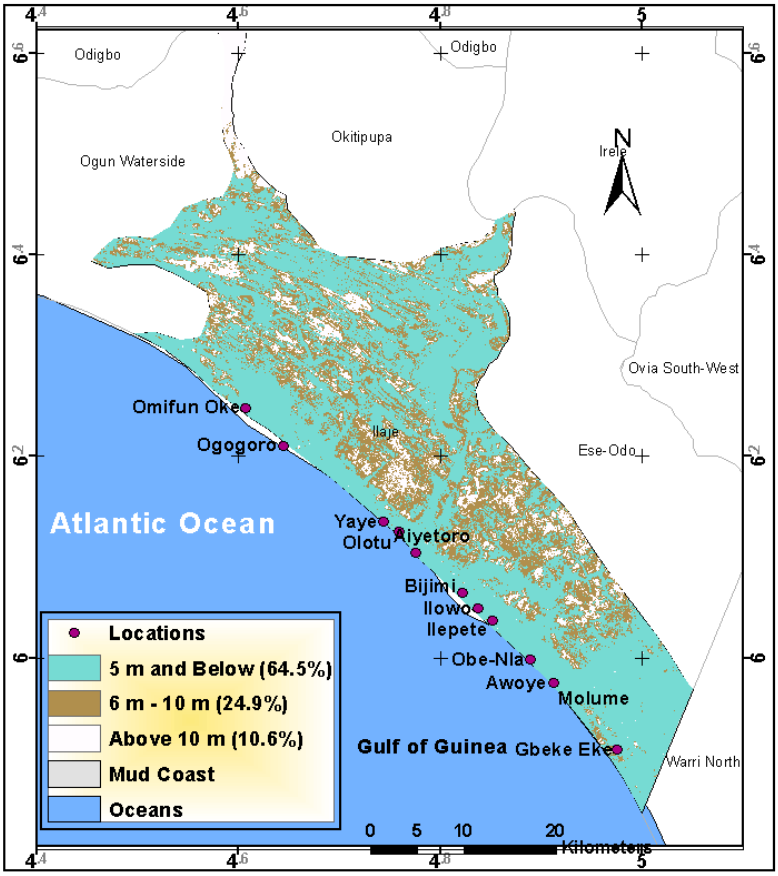

Figure 2: Elevation Map of the Transgressive Mud Coast
Source: Author's Analysis, 2022

The coastal plain is surrounded by 30 to 60 kilometers of freshwater marshes and freshwater swamps with an intricate network of interconnected creeks and lacustrine marshes (Olorunlana, 2013). The climate of the area is a tropical humid condition with an average annual rainfall of about 2,721 mm and an average annual temperature of about 27.8^{0}C (Fashae and Onafeso, 2011). Strong winds and dynamic waves characterize the wet season, which typically runs from May to October, whereas the dry season, which runs from November to April, is distinguished by mild winds and waves (Dada et al., 2019). Semidiurnal tides ranging between 1.5 and 1.8 meters are found within the transgressive mud coast (Ihenyen, 2003), however, the coast is dominated by waves generated by storms in the Atlantic Ocean with a wave period of 12 – 25 seconds. This generates swell waves with significant wave heights ranging from 1.2 to 1.5 meters (Popoola, 2012). This was based on the WaveWatch III data Recent studies (Kayode & Koya, 2019) recorded values for significant wave heights to range between 1.003 and 1.824 meters.

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Longshore currents are minimal along the coast, thus not significant in transporting sediments and fluvial deposits along the coastline (Ihenyen, 2003). However, ebb currents which is a semidiurnal type of reversing current predominate eroding the shore zone. Large stretches of the transgressive mud coast comprise loose clayey deposits, with steep mud and have been subjected to inundation, flooding, and shoreline erosion due to the extensive destruction of the mangrove forests and overgrazing of the salt marshes along the coast (Fashae & Onafeso, 2011; Olajide & Popoola, 2020; Olajide et al., 2020; Popoola, 2021). Rising sea levels are observed along the Transgressive Mud Coast and this is caused by wave run-up and astronomical tides (Dada et al. 2020). Likewise, flooding events on the coast are caused by the interaction of large wave run-ups and astronomical tides (Dada et al. 2020). In terms of socio-economic characteristics, the population presently stands at 543,259 using the RCP8.5 projections. The predominant socio-economic activity on the coast is fishing, farming, boat construction, lumbering, mat making, net weaving, and trading (Olajide & Popoola, 2020; Olajide et al., 2020). Several natural resources abound on the mud coast such as crude oil, petroleum, glass sand, and bitumen, likewise, there are also agricultural products such as palm oil, timber, raffia, rice plantations, and banana which are produced well (Olajide & Popoola, 2020).

Data and data sources

The study involves analysis of shoreline change and SLR using six multi-temporal and orthorectified Landsat imageries with path/row 190/056 and resolution of 30 m of 1986 and 2021 from the United States Geological Survey (USGS) server. The Landsat images include a Thematic Mapper (TM) for 1986 and 1991, Enhanced Thematic Mapper (ETM+) for 2001 and 2011, and Operational Land Imager (OLI) for 2016 and 2021. The coordinate system of the imageries was in World Geodetic System 1984 (WGS84) but was projected to UTM/WGS84 Zone 31. The imageries were used as proxies for shoreline extraction. ALOS PALSAR AW3D30 digital elevation model (DEM) was obtained from Earth Observation Research Center while spatially disaggregated population and GDP data were obtained from the International Institute for Applied Systems Analysis. The study also obtained data from stakeholders along the coast concerning management strategies. This was done by ascertaining the stakeholders which are mainly the Ministries, Departments, and Agencies responsible for shoreline management, and conducting a qualitative assessment using semi-structured interviews.

Shoreline change

These images were radiometrically calibrated and geographically referenced and selected at the same tidal period and based on the conditions,

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the cloud coverage was not significant. The images were subjected to geometrical correction using a set of ground control points (GCPs) made available by the United States Geological Survey (USGS). A reconnaissance survey was conducted to ensure that the GCPs and other features registered on the images tally with each other. For shoreline extraction, the Automated Water Extraction Index (AWEI) was used to delineate the land-water boundary represented by the high-water line as shoreline proxies for the different years using the band rationing and differencing algorithm as used by Feyisa et al. (2014). The Digital Shoreline Analysis System (DSAS) version 5.1 was used to calculate the rate of coastline change statistics from multiple historic shoreline positions by casting transects perpendicular to the baseline at a specified spacing along the coast. The study generated a baseline parallel to the shoreline buffered 1000 meters from the shoreline position for the year 1986 from which transects were cast perpendicularly. This was followed by setting transect parameters that split the shoreline into intervals, and then the rate of change for each transect was calculated. A spacing of 100 meters intervals perpendicular to the baseline was specified along the coastline thus making it 770 transects, covering the entire 77 km coastline of the mud coast. The values estimated from the transects were then used to estimate the rate of shoreline change using the endpoint rate (EPR) for short-term analysis and the linear regression rate (LRR) for long-term analysis (1986-2021). In forecasting future shoreline positions, the study made use of the Kalman Filter model which combines observed and model-derived shoreline locations to estimate future shoreline positions.

Sea Level Rise Inundation assessment

The study performs an overlay analysis by draping the ALOS DEM on critical elements (land, population, GDP, buildings) of the coast with inundation zones of 0 m and projected for 1 and 2 meters SLR scenarios. The 1 and 2-meter scenarios were based on the Sixth Assessment Report (AR6) that sea levels could rise to 1.01 m by the year 2100 and that global mean sea level rise approaching 2 m by 2100 cannot be ruled out due to uncertainties in ice sheet processes (IPCC, 2021). The study mosaicked three grids of the ALOS DEM into a single seamless raster. Image analysis was performed to extract the mosaicked elevation data into the delineated feature class of the study area. Inundation zones were derived from the DEM by extracting the pixel value of 0, 1, and 2 from the raster in the elevation field. However, for the present relative SLR estimate which is 0.33 m (GLOSS, 2016), the Inverse Distance Weighted Interpolation tool was used to interpolate the pixels from 0 m to 0.33 m.

These scenarios were superimposed with the delineated coastal extent and the appropriate exposure dataset (critical elements) to extract vulnerable

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regions to inundation. In identifying the effect of the SLR on the socioeconomics on the coast, buildings within 5 km of the shoreline were digitized based on the scientific definition of the coastal zone (Kay and Alder, 2005). The study used ArcGIS 10.8.2 version to run a query dialogue to select all buildings that are within the extent of the impact of sea-level rise for each climate change scenario. The uncertainties embedded in the ALOS DEM are critical in estimating the impact of SLR on the critical elements. Indeed, best practices for inundation assessment include discussing derived maps and statistical summaries in terms of the elevation dataset's limitations, which include accuracies and reporting following accepted national and global standards (Gesch et al., 2009). With the ALOS DEM, the vertical accuracy (VA) ranges from 4.1 m to 4.95 meters (Ferreira and Cabral, 2021; Tadono et al., 2015; Santillana and Makinano-Santillana, 2016) and has been incorporated into the results of the analysis.

Stakeholders' assessment

The research conducted interviews with the agencies responsible for managing the coastal zone. These include the Niger Delta Development Commission (NDDC), Niger Delta Ministries (NDM), the Ministry of Environment, the Ondo State Oil Producing Areas Development Commission (OSOPADEC), and the Town Planning Department to assess management strategies employed for the planning and management of the Transgressive mud coast. Responses were transcribed and subjected to Content Analysis to identify patterns and context with regards to the management of the Transgressive Mud shoreline from which strategies of the Shoreline Management Plan emanated.

Results

Shoreline change analysis

The study made use of the EPR and LRR models of the DSAS to estimate short-term and long-term effects of erosion respectively along the Transgressive mud coast. The negative values denote erosion, while the positive values denote accretion.

Short-term variation of the shoreline

The short-term analysis of shoreline changes as used in this study includes 6 periodic intervals: 1986-1991, 1991-2001, 2001-2006, 2006-2011, 2011-2016, and 2016-2021 (Figure 3). The study reveals the erosional and accretional changes that have occurred along the shoreline over the 35 years considered.

Between 1986 and 1991, the shoreline experienced a high rate of erosion (Figure 4a). The EPR parameter shows that the shoreline experienced

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an average erosion rate of -22.11m/yr. and average accretion rate of +12.78 m/yr. with a shoreline change of -9.33 m/yr. In terms of extent, 61.87% (48 km) of the entire coastline experienced erosion during this period while 38.13% (29 km) experienced accretion, hence, erosion was predominant during this period. The highest erosion rate was observed in the eastern part of the transgressive mud coast.

From 1991 to 2001, the erosion rate stood at -22.56 m/yr. The accretion rate was 20.02 m/yr. This indicates a net change of -2.54 m/yr. for the shoreline. Results also indicate that 58.91% (45 km) of the entire shoreline experienced erosion in this period, and 41.09% (29 km) experienced accretion. Accretion was dominant in the eastern part of the coast and some sections of the western areas of the shore (Figure 4a).

Between 2001 and 2006, the shoreline erosion rate was -23.76 m/yr and the accretion rate was +18.22 m/yr. Approximately 48% (37 km) of the total shoreline extent was accreted, while 52% (40 km) eroded. As revealed in Figure 4a, erosion is dominant within this period with a net rate of -5.54 m/yr. Erosion was predominant in the central section of the shoreline while accretion was predominant in the eastern section and the western section.

EPR analysis between 2006 and 2011 shows that erosion rates were more intense in the central section of the coast. The erosion rate recorded was -24.17 m/yr. the accretion rate was 17.6 m/yr. The net rate of change was -6.57 m/yr. As shown in Figure 4a, some patches in the eastern sector also experienced low to high erosion within this period. These are noticeable in Awoye and Gbeke Eke communities. Erosion was also observed in the Ogogoro community in the western section of the coast.

During the 2011-2016 period, increased erosion was observed in the western section of the coast compared to the previous period. Erosion remains the dominant phenomenon alongshore with the central section comprising communities such as Yaye, Olotu, Aiyetoro and Bijimi mostly affected (Figure 4b). The erosion and accretion rates recorded rate was -22.27 m/yr. and 15.95 m/yr. respectively. 65.23% (50 km) of the shoreline extent experienced erosion in this period, 32% (23 km) experienced accretion while 4 km were stable. The net rate of change is -6.32 m/yr. indicating high erosion during this period.

In the 2016-2021 period, the erosion rate was -20.18 m/yr. accretion rate was 8.71m/yr. based on the EPR result. The net rate of change of erosion increased to -11.47 m/yr. As revealed in Figure 4b, some parts of the shoreline's central area that experienced erosion during the last period such as the Ilepete and Obe-Nla communities were seen to have experienced accretion. However, communities such as Omifun Oke, Molume, and Awoye experienced more erosion in this period compared to 2011-2016.

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Approximately 65.33% (50 km) of the shoreline extent experienced shoreline erosion in this period.

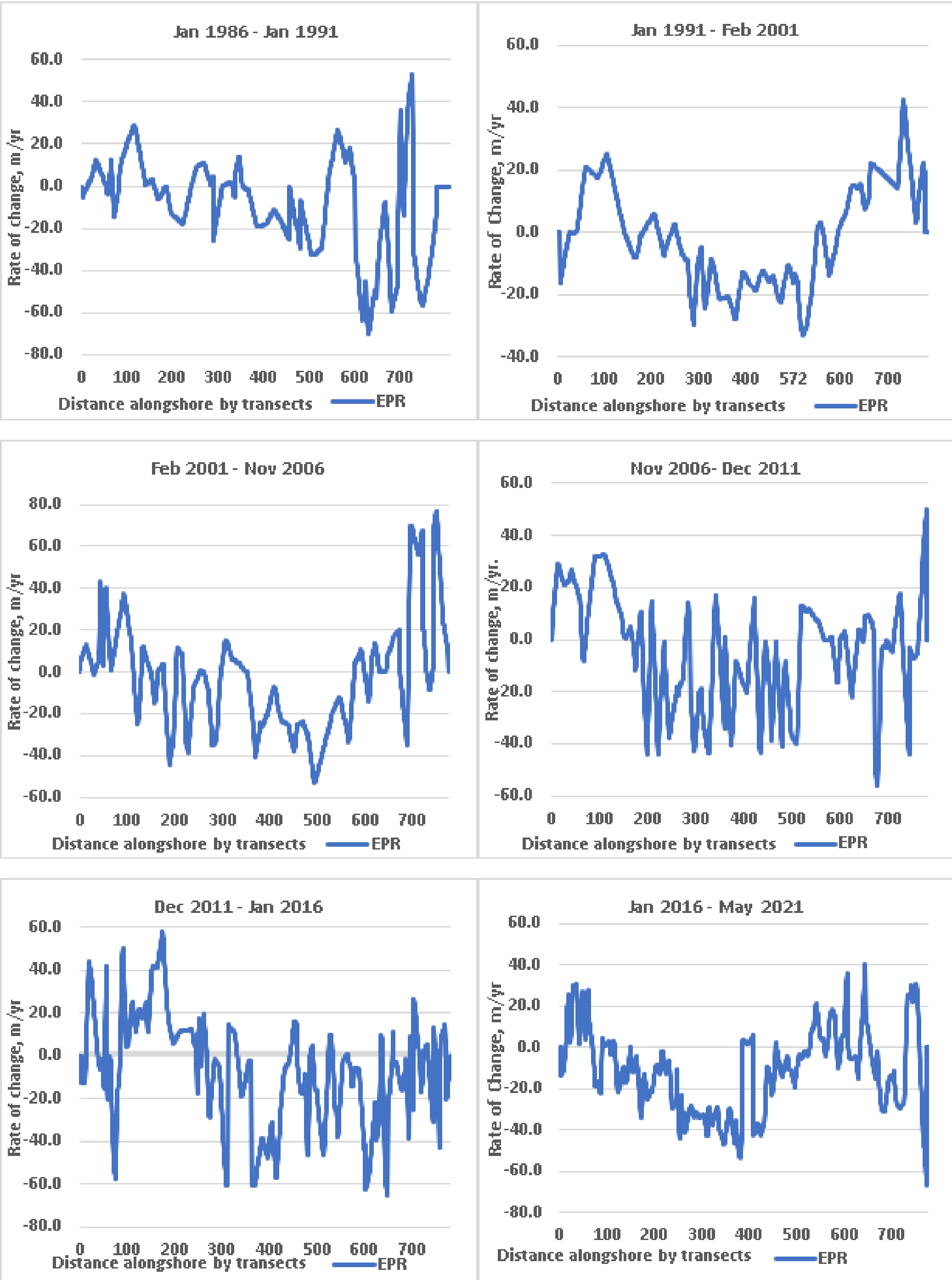

Figure 3: Shoreline Change rates for different periods
Source: Author’s Analysis, 2022

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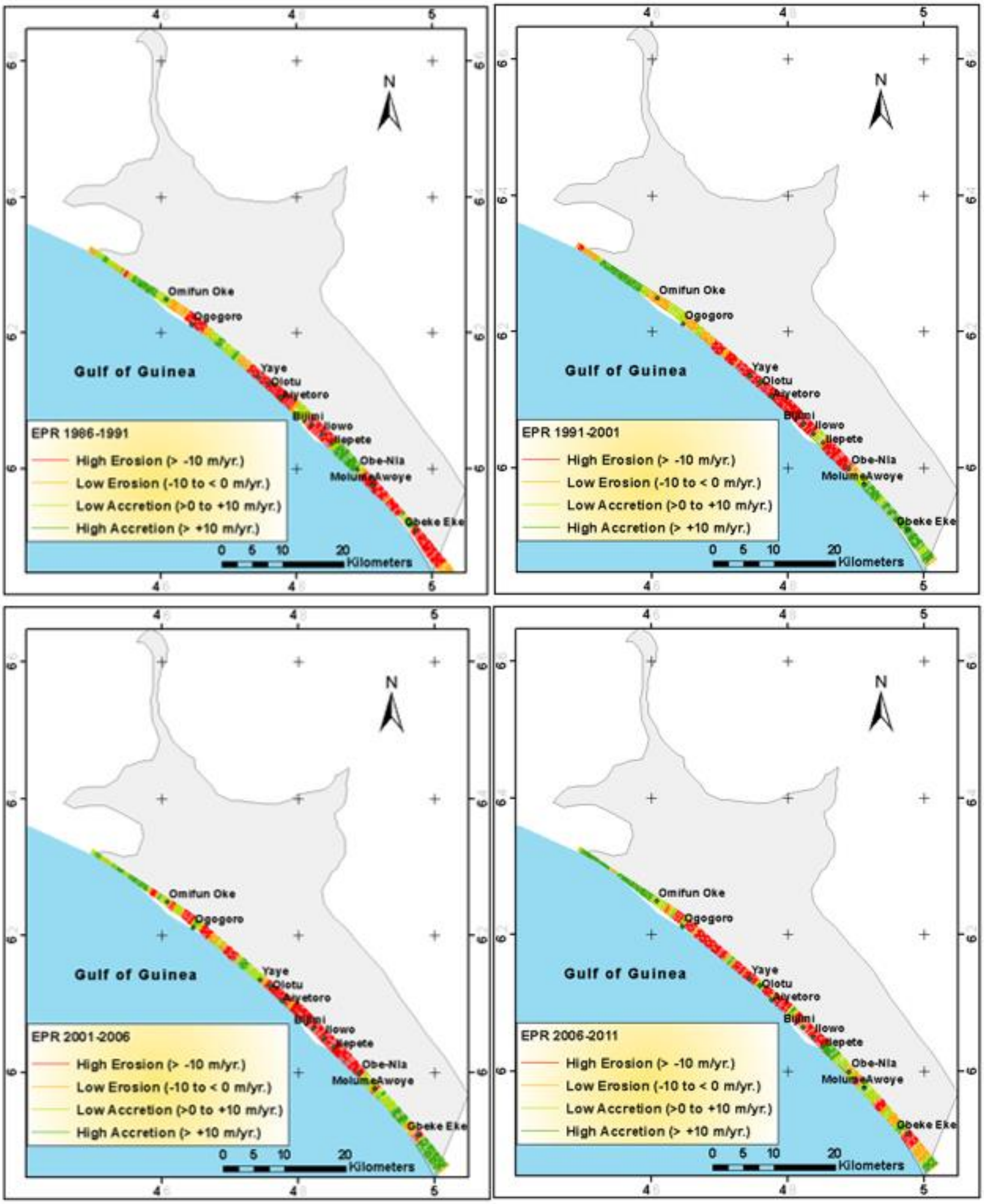

Figure 4a Short-term shoreline changes for different periods on the Transgressive mud coast (1986-1991; 1991-2001; 2001-2006; 2006-2011).
Source: Author's Analysis, 2022

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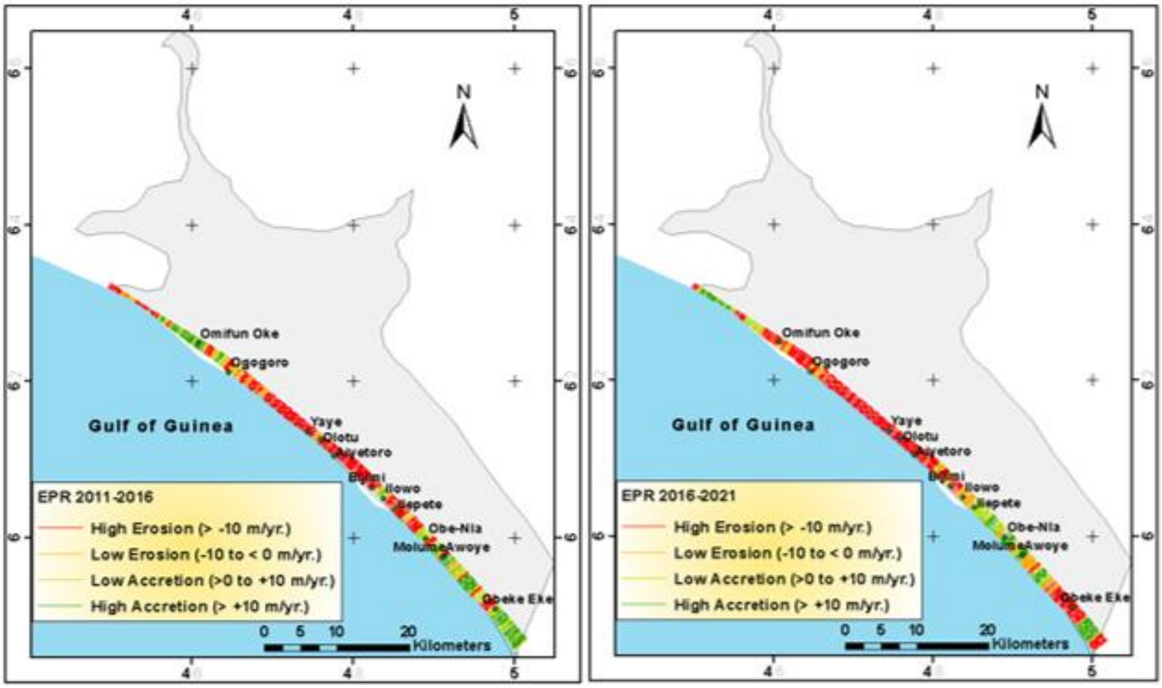

Figure 4b Short-term shoreline changes for different periods on the Transgressive mud coast (2011-2016; 2016-2021)
Source: Author's Analysis, 2022

Long-Term Shoreline Variation

The long-term shoreline variation assessment of the study area is dated from 1986 to 2021. The maximum shoreline change from 1986 to 2021 was 1042.34 m using the shoreline change envelope parameter (SCE). The SCE value represents the greatest distance among all the shorelines that intersect a given transect. Approximately 49.8 km (64.67%) of the entire coastline experienced erosion between 1986 and 2021, causing the retreat of the shoreline landward in those areas, and 27.2 km (35.33%) of the shoreline extent experienced accretion within this period. The LRR statistics suggest that the coastline is experiencing a landward retreat with erosion rates ranging from <0m/yr. to -22.48m/yr. thus triggering a land loss of approximately 15.1 sq. km to the Atlantic Ocean. As depicted in Figures 5 and 6, the results of the LRR show that the central part of the coastline has experienced high rates of erosion over the 35 years considered in this study. Communities affected include Yaye, Olotu, Aiyetoro, Bijimi, Ilowo, and Ilepete while the Obe-Nla community experienced low erosion rates. Results also indicated that the accretion process has been predominant in the eastern and some parts of the western zone of the coastline. Communities such as Molume, Awoye, and Gbeke Eke are seen to have gained more land between 1986 and 2021. Figure

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7 revealed the shoreline changes between the start date (1986) and end date (2021) of this study.

Shoreline forecast

The Kalman Filter model was used in the study to forecast shoreline changes over 10 years. This model requires LRR, the confidence interval of linear regression and the standard error of the estimate. Results show that by the year 2032, an additional 1.26 sq. km would be lost to erosion. Hence, by 2032, the total land area that will retreat is 16.36 sq. km.

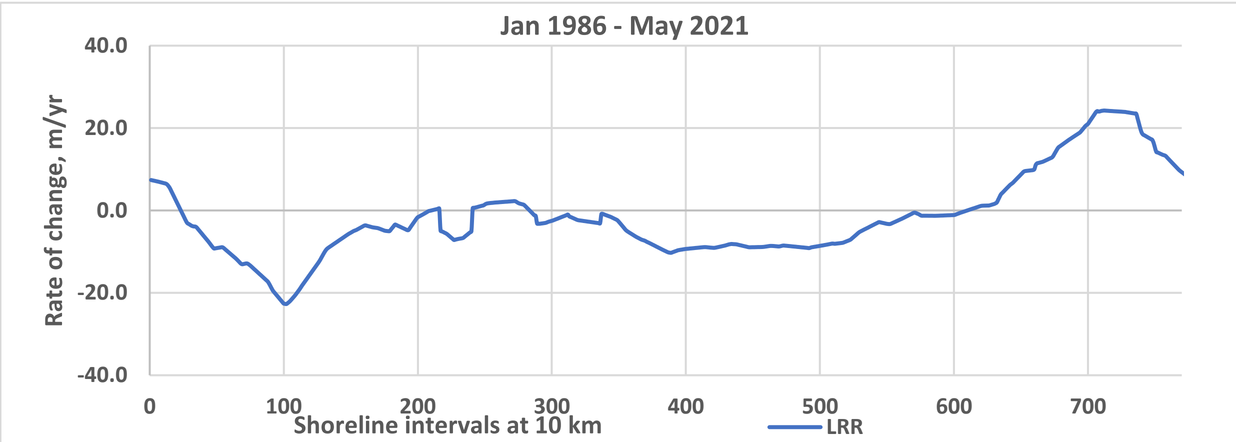

Figure 5: Shoreline change rate along the Transgressive mud coast between 1986 and 2021
Source: Author's Analysis, 2022

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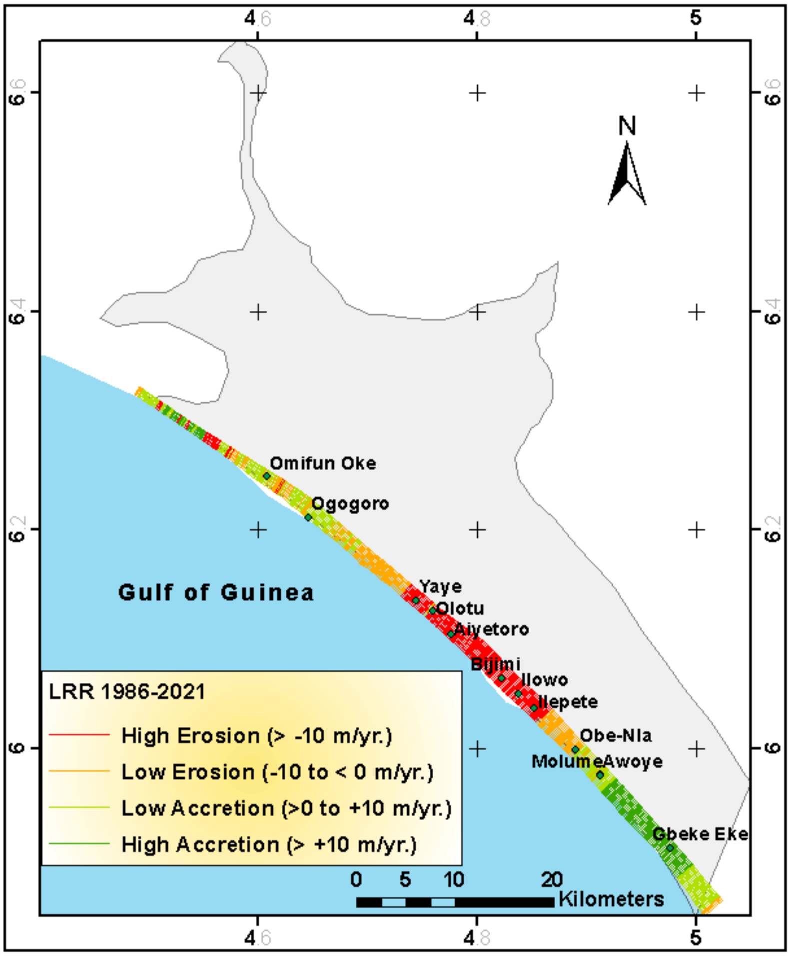

Figure 6: Shoreline change map for vulnerability to coastal erosion between 1986 and 2021
Source: Author's Analysis, 2022

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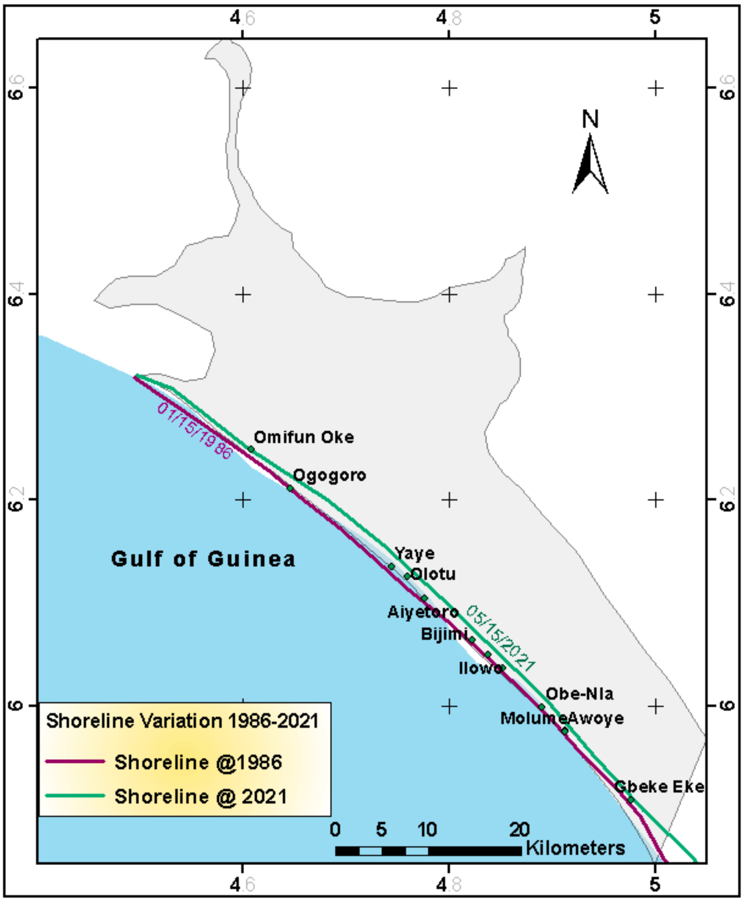

Figure 7: Shoreline change between 1986 and 2021
Source: Author's Analysis, 2022

Sea Level Rise Assessment

The study assessed and presented the results of the effect of sea-level rise (SLR) on the Transgressive mud coast using 0.33 m, 1-meter, and 2-meter SLR scenarios. Socio-economic implications such as population, buildings, and economic activity were also revealed. Results of the sea level rise assessment show that at the 0.33 m SLR scenario, 200.97 sq. km (13.93%) of the transgressive mud coast is already experiencing inundation (Table 1, Figure 8). In a 1-meter SLR scenario by the year 2100, 551 sq. km (38.18%) of the Transgressive mud coast will be submerged and will increase to 646.18 sq. km (44.77%) in a 2-meter SLR scenario. Results also show that 621, 1840, and 2032 buildings within 5 km of the shoreline will be affected in 0.33, 1, and 2 meters SLR scenarios respectively (Figures 9 and 10). For the population that will be affected, results indicate that at the present sea level situation, 75,675 inhabitants are already displaced along the Transgressive mud coast. With sea levels hitting the 1 m level by the year 2100, results indicate that

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461,491 inhabitants will be displaced out of the projected population of 1,208,726, while 541,146 inhabitants will be displaced in the event of a 2 m SLR by 2100. Economic activity expressed (GDP) for the mud coast for the year 2022 is $1,821,303 which will increase to $96,625,284 by the year 2100. This study finds out that with the present sea level rise scenario, $685,011 is already lost. If sea levels increase to 1 m by the end of the century, $99,607,139 is valued to be lost while $116,799,678 will be lost if sea levels increase to 2 m by 2100.

Table 1: Vulnerability of the Transgressive Mud coast to sea-level rise

	0.33 m +/- 4.95 VA	**1m +/- 4.95 VA**	**2m +/- 4.95 VA**
Impacted area (sq. km)	200.97	551.01	646.18
The land area inundated (%)	13.93	38.18	44.77
Buildings inundated @ 5km of coastline	621 (3.2%)	1840 (9.4%)	2032 (10.3%)
Impacted population @ 2022	75, 675	461,491	541,146
Economic activity (*GDP_{PPP}, US$)	685,011	99,607,139	116,799,678

Source: Author's Analysis, 2022 *GDP_{PPP} = GDP purchasing power parity

Discussion

As observed from the long-term shoreline variation, erosional processes dominate the central sections of the coast, as erosion rates as high as -65.67 m/yr were recorded in this section and -76.2 m/yr towards the eastern section. Previous studies have also recorded high erosion rates such as Daramola et al (2022) and French et al (1995) with over -100 m/yr. in some locations. Across the shoreline, the average erosion rate is between -1 and -25 m/yr. In previous studies, erosion rates are not far apart from this study with Dada et al (2019) recording rates between -1 and -30 m/yr. and Komolafe et al (2020) between -0.12 and -21.24 m/yr. The total land loss to erosion for the transgressive coast between 1986 and 2021 is 15.1 sq. km which will trigger additional land loss of about 1.26 sq. km by 2032. These rates are a bit higher than previous studies (Dada et al., 2019) which suggest 10.6 sq. km land loss and (Daramola et al., 2022) with 11.3 sq. km. The reasons for the variations include the period they considered to be shorter compared to this study, the duration of assessments, and the vegetation line proxy used in Daramola et al (2022). The noticeable accretion in the western section of the coast is due to the longshore drift of sediment from the Barrier-Lagoon coast from Lagos, rising sea levels, and the deposition of sand and other sediments along the shore. Little bits of erosion noticeable in the western section was due to human activities such as canalization and the deforestation of mangroves (Badru et al., 2022). The eastern sector of the shore zone even with little erosion experienced more land loss due to sea-level rise as the region's topography is low-lying ranging between 0.5 and 2 meters. Findings from previous studies suggest that elevation in the eastern sector of the coast especially in coastal

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communities of Awoye and Molume ranges from 0.8 to 1.8 m and are frequently inundated during high tides (Ebisemiju 1987; French et al., 1995).

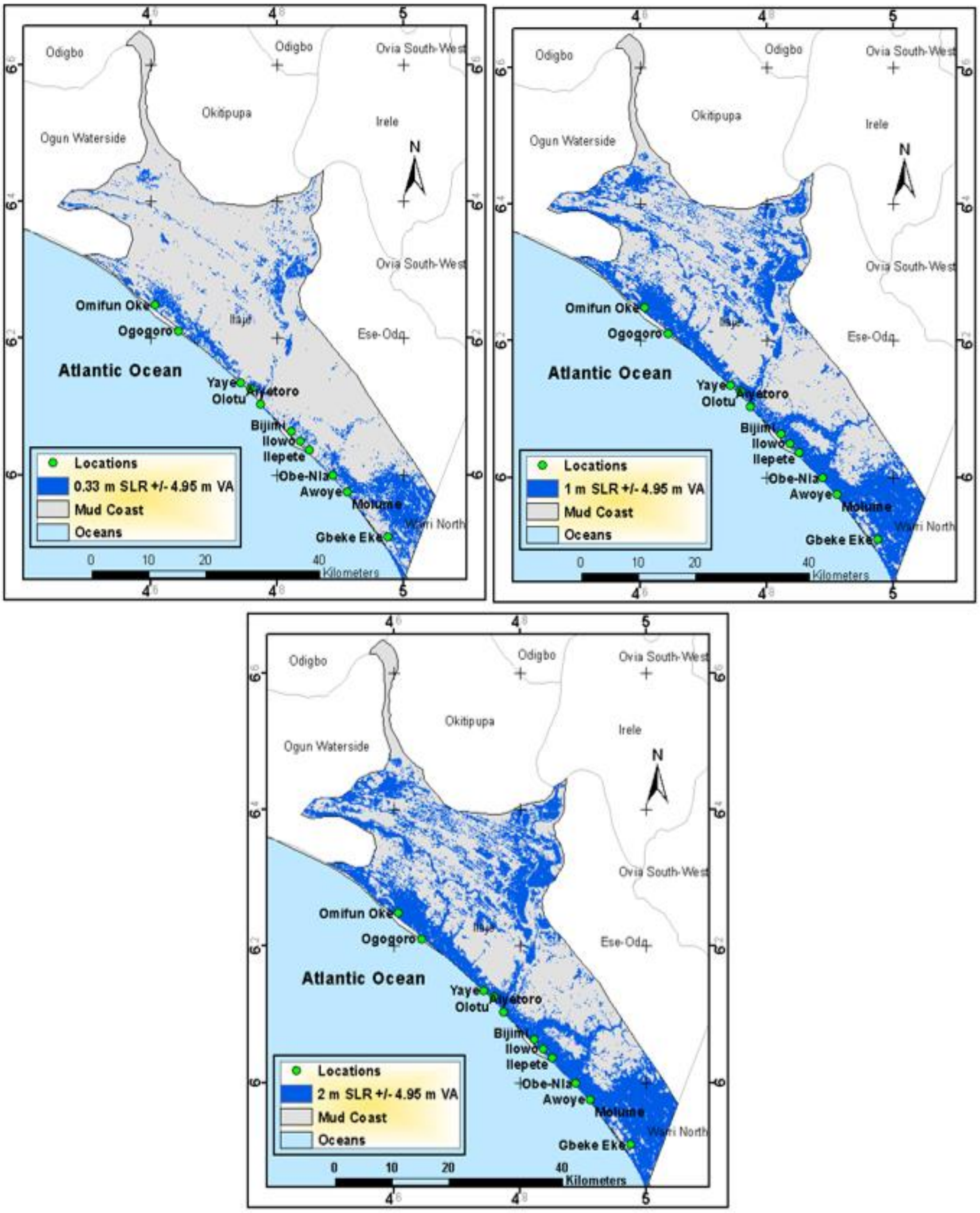

Figure 8: Transgressive mud coast inundated at different sea-level rise scenarios
Source: Author's Analysis, 2022

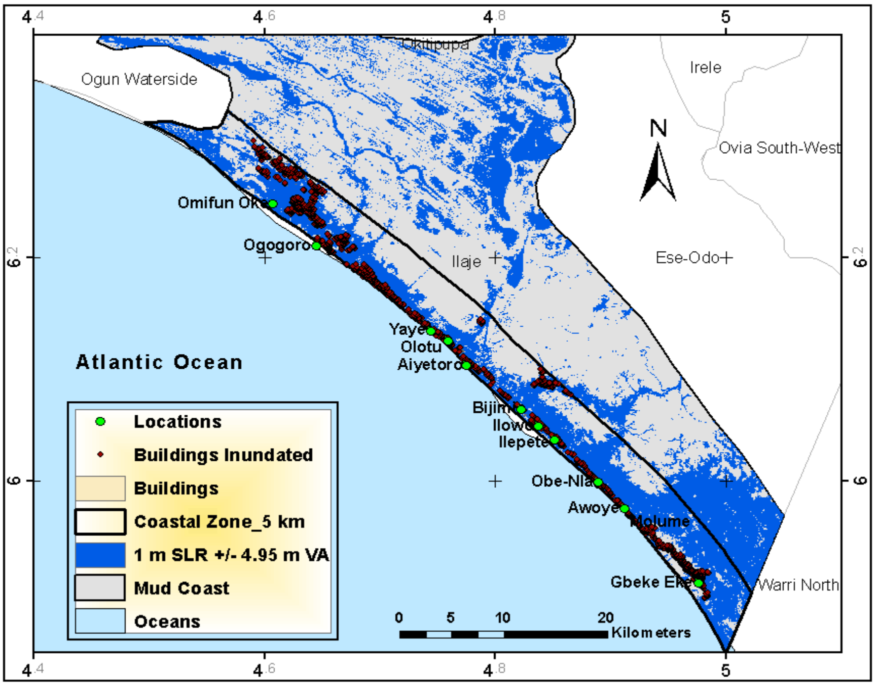

Figure 9: Map showing buildings along the shoreline inundated in a 1 m SLR scenario
Source: Author's Analysis, 2022

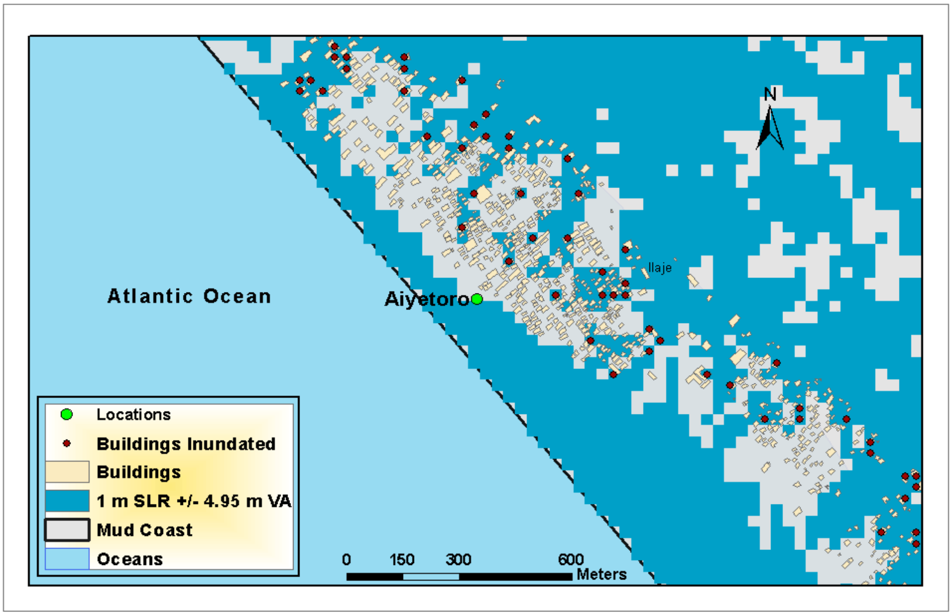

Figure 10: Map indicating specific buildings that will be inundated in a 1 m SLR scenario
Source: Author's Analysis, 2022

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Sea level rise has aggravated land loss in the transgressive mud coast and brought about damages to coastal settlements along the coast (Figure 12). As revealed by Dada et al (2020) the coast experiences regular flooding due to large wave run-ups and astronomical tides. This has weakened the coast's interparticle bonds thereby making the sediments unconsolidated and more vulnerable to erosion by high-energy waves and tidal floods (Ebisemiju, 1987). As found out, 201 sq. km (13.93%) of the mud coast is already inundated with floodwaters which will increase to 551 sq. km by 2100 if the AR6 RCP8.5 projections are anything to go by. Indeed, the AR6 predicted with high confidence that low-lying coasts will experience increased frequency and severity of flooding and erosion throughout this century. Comparing these results with previous studies (French et al., 1995; Popoola, 2012) shows variations. Findings of French et al. (1995) that used the Aerial Videotape-Assisted Vulnerability Analysis (AVVA) technique indicated that with a 1-meter SLR, 2,016 sq. km of land in the Transgressive mud coast will be inundated, which is greater than the results of this study. The dataset obtained with the AVVA technique is not detailed as the resolution range is between 100 and 500 m with a wider range of uncertainties. The findings of Popoola (2012) whose result is smaller than what was obtained in this study indicated that in a 1-meter SLR scenario, 199 sq. km of land in the mud coast will be lost. This result grossly underestimates the impact of SLR along the coast. Reasons attributed to this include the resolution of the elevation dataset used and the non-reporting of its limitations regarding the accuracies of the derived maps and statistical summaries of the mud coast as suggested by Gesch et al. (2009). The resolution of the elevation dataset used by Popoola (2012) is 90 m and the vertical accuracy is +/- 6.13 m whereas the ALOS DEM used in this study possess a 30 m resolution and vertical accuracy of +/-4.95 m. Besides that, this study incorporated this uncertainty into the derived maps and statistical summaries produced which was not done in Popoola (2012) for the coast.

Presently, there is displacement along the coast as the residents must move away from the advancing sea waters. The displacements of the residents have affected communities such as Aiyetoro, and Olotu due to increased wave action and storm surges in the central section of the coast, and Awoye and Molume in the eastern section of the coast which is not unconnected with the presence of the Awoye estuary and the rising tides of the sea. Indeed, most of the previously inhabited areas especially in the eastern section are now flooded which will aggravate with a 1-meter SLR (Figures 7 and 8). The implication of this will be enormous causing more loss of lives, properties, land loss, displaced population with its associated emotional trauma and psychological effects, destruction of the marine life and economy, vegetation loss and loss of livelihoods and income-generating activities of the inhabitants. In an

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overlay analysis of the inundation assessment and shoreline change using the LRR (Figure 11), it was evident that erosion was more evident in the central section of the coast coupled with the inundation of the coastal land. In the western section, mild erosion was evident and lower inundation effects compared with the central locations. The eastern locations experience less erosion presently but more land loss due to the low elevations in the region and rising seas from the Atlantic and rising tides from the Awoye estuary.

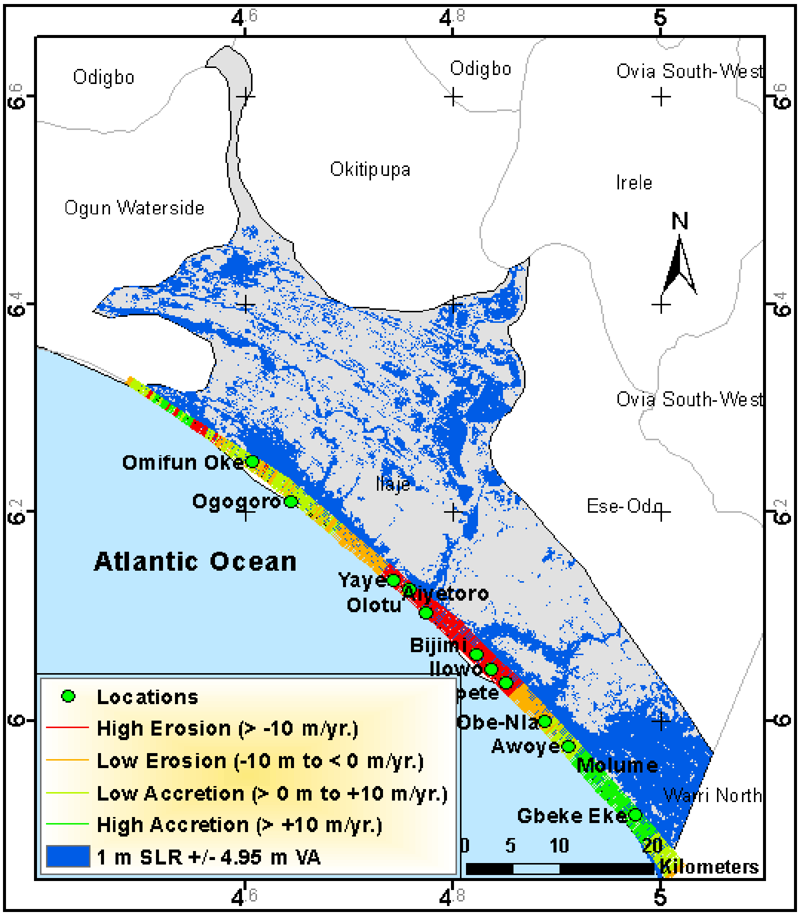

Figure 11: Overlay of shoreline change on coastal vulnerability to sea-level rise
Source: Author's Analysis, 2022

Existing shoreline management challenges

Findings from interviews conducted with relevant stakeholders which include officials of NDDC, NDM, Ministry of Environment, OSOPADEC and the Town Planning Department reveal that there has not been any coastal/shoreline management plan except for some piecemeal approaches which are unveiled in failed government efforts. In a bid to safeguard the shoreline, the Federal Government of Nigeria through the NDDC contracted

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out a multimillion-dollar shoreline protection project using geotextile tube technology in 2004 to Gallet Nigeria Limited for USD16 million, and then to Dredging Atlantic in 2009 for USD43 million, however, they both failed to meet their intended purpose. Findings revealed the reasons for its failure to include inadequate knowledge of the dynamics of the mud coast due to the unavailability of historical data that can assist in informed decision-making for shoreline management. The contractors for the project were purely limited to their field of expertise in water and maritime engineering, hence, they could not carry out holistic planning, appraisal, and execution of the project. The pre-contract feasibility study was not adequate, and this was reflected in insufficient sand for the geotextile tube revegetation project. Non-payment of workers on-site and the practice of providing only a 25% mobilization fee for the project contributed to its failure. Lack of cooperation from community members is a factor as they continuously made claims to get undue compensation; and when their demands are not met, they sabotaged the contractors' efforts leading to the abandonment of the project (Figure 12 g&h). There is poor preparation, institutional failure, and corporate negligence. Hence, the need for an integrated shoreline management plan (SMP) for the transgressive mud shoreline is essential for proper monitoring and protection of the shore.

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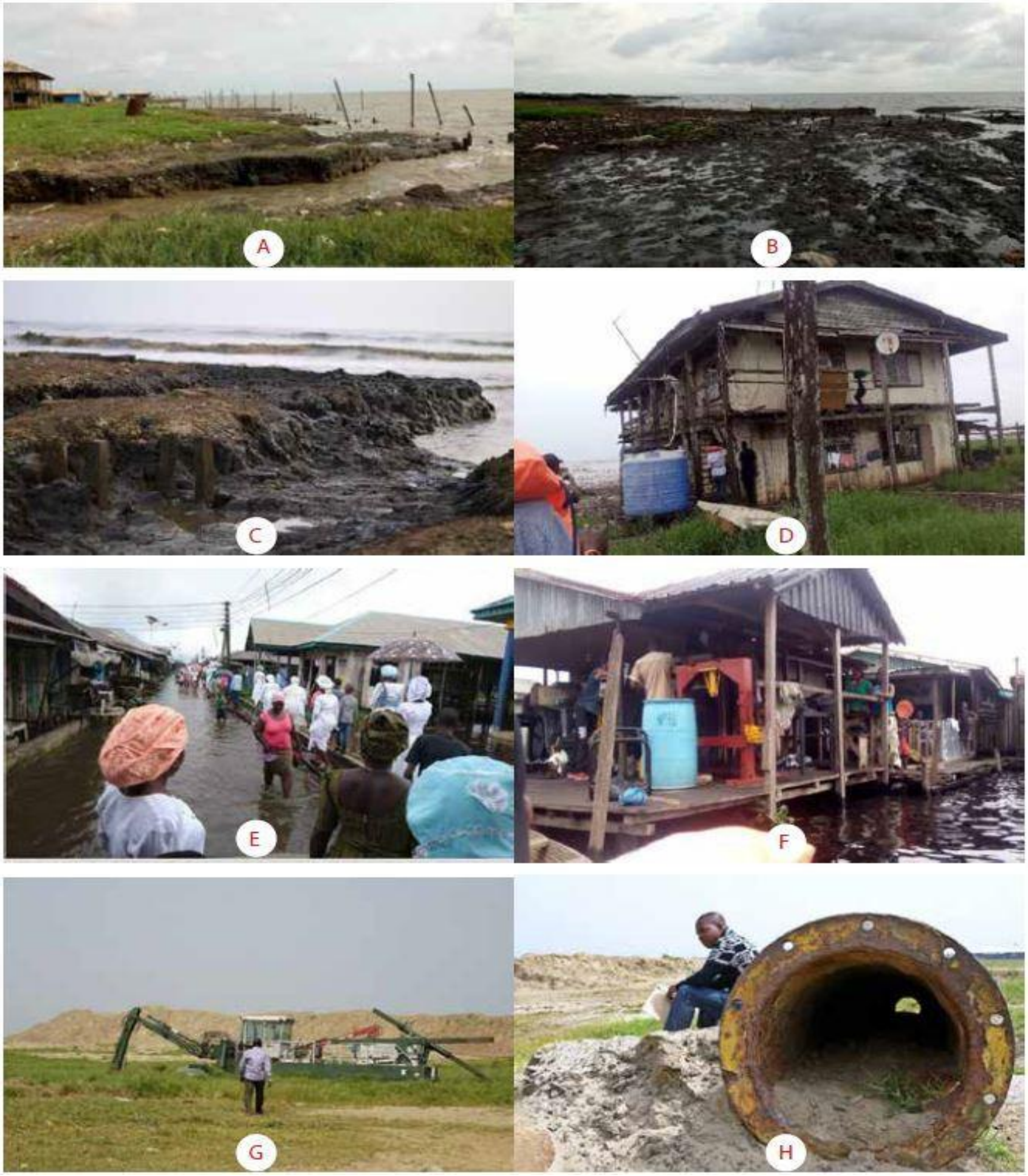

Figure 12: (A.) A typical seashore with broken pieces of houses already submerged by the rising sea. (B.) Happy City College is completely inundated. (C.) Other parts of the seashore with fragments of houses destroyed and submerged. (D.) A typical building being destroyed due to wave action, storm surges and rising sea levels (E.) The aftermath of a sea surge left Aiyetoro flooded. (F.) People already adapted to living on the waters. (G.) A dredger was abandoned by contractors. (H.) Geotube project for revegetation of the Aiyetoro seashore.

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Shoreline Management Plan (SMP)

This study has been able to show that coastal retrogradation has been a recurring occurrence along the Transgressive mud coast over the last 35 years through shoreline change and rising sea levels. Many intervention approaches have been suggested for managing the Transgressive shoreline such as identification of potential threats to hazards, flood defenses, land use management, community education and evacuation plan, and the adoption of the managed realignment approach (Daramola et al., 2022; Komolafe et al., 2020). These approaches are good, but unless they are integrated with a planning framework such as an SMP, they are not sufficient for effective shoreline management. With the SMP, long-term balanced sustainability of the shore zone is achievable which will form a basis for sustainable shoreline management policies (Environmental Agency, 2010). This type of high-level planning is essential for the management of shorelines in Nigeria. To date, Nigeria is yet to have a shoreline management strategy as coastal issues are managed sector-by-sector, thus complicating the sustainable management of coastal zones (Famuditi et al., 2014; Popoola, 2012). Managing the Transgressive mud shoreline will involve identifying the best ways to manage risks to people, built and natural environment and how to put these into practice by adopting the full implementation of the SMP process. Such a proactive approach will necessarily require an understanding of the natural coastal processes, coastal defense needs, environmental considerations, and planning issues that involves current and future land use (Ballinger & Dodds, 2020; Cooper et al., 2002).

In adopting the SMP for the Transgressive mud coast, six stages are essential. The first stage is Scope the SMP (DEFRA, 2006). Scope involves initiating SMP by the Ministry of Environment along with the Town Planning department, organizing Client Steering Group committees in determining the scope of work to produce the SMP. The purpose is to identify requirements for the SMP. The next step is identifying key stakeholders and involving them in the SMP. This will then be followed by data collection, management, and review. The second stage is situation assessment. This stage involves a baseline understanding of coastal dynamics, developing baseline scenarios, defining features, benefits and issues, defining objectives, identifying flood and erosion risks, and assessing objectives. The third stage is policy formulation wherein defining scenarios and drafting SMP documents are undertaken by the stakeholders. The four major policy options for SMP include holding the existing defense line, advancing the existing defense line, a managed realignment, and no active intervention (Environmental Agency, 2010). At this stage, the SMP considers policies that will assist with shoreline stabilization and beach nourishment through vegetative plantings, wetland enhancements, and preservation of beaches and natural shorelines (DEFRA, 2006). Stage four is the Public Examination which involves gaining approval from the public, confirming the consultation strategy, producing SMP draft documents for consultation, and conducting consultation activities with the public as it relates to managing the shoreline. The fifth stage is Finalize Plan. This involves determining revisions to the draft SMP, developing an Action Plan, and finalizing the SMP. The last stage is Plan Dissemination. This involves the publication of the SMP and the implementation of the Plan. Coastal Managers and Planners are to drive this process. Hence, the Town Planning Department and the Ministry of Environment should coordinate the SMP process for effective shoreline management.

Conclusion

The study assessed changes along the Transgressive mud coastline using remote sensing and GIS techniques. Specifically, the study assessed shoreline retreat and sea-level rise-induced changes along the coast during the last 35 years. The results showed that the study area has experienced retrogradation, with a retreat of over 64% (49.8 km) of the 77-km long coast. This is due to insufficient sediment supply to prevent the landward retreat of the shoreline which in part is due to rising sea levels. This rapid rate of shoreline change indicates that retrogradation has triggered a land loss of 15.1 sq. km to the Atlantic over the last 35 years with the central sector of the coast the most vulnerable.

Climate change influences are also significant in changes across the shore zone as places inhabited by people before are now being inundated. Going by the AR6 RCP8.5 climate model that indicates that sea-level rise will exceed 1 m by the end of the century, this study established that 551 sq. km (38.18%) of the Transgressive mud coast will be inundated with floodwaters. This will trigger the submergence of 1,850 buildings within 5 km of the shoreline. The population that will be affected is approximately 461,491 while the cost of livelihood and economic activity expressed with GDP will be USD 99.6 million (N57.8 billion). The observed patterns of shoreline changes in the study area are due to waves, rising tides, and anthropogenic forces along the coast which corroborates with findings from Dada et al. (2020) and Daramola et al. (2022). The Landsat dataset used to generate proxies for the shorelines and the ALOS PALSAR digital elevation model may not have sufficient spatial resolution, but they are useful for monitoring coastal changes due to erosion and sea-level rise along the transgressive mud coast.

Temporal analyses of shoreline variations and the effects of sea-level rise are required for the development of a strategic plan for effective management, which an SMP provides. The relevant authorities and especially the Town Planning Department and the Ministry of Environment should coordinate the SMP process to safeguard the coast and improve the socio-

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economic development of the coastal area. Spatial planning regulations (such as land-use planning, and development control) that regulate human activities are already embedded in the SMP and they are to be enforced. The SMP when fully adopted will be able to give a clear understanding of the dynamics of the coast with different scenarios, produce and establish the best policy response for different stretches of the coast, and provide measures for monitoring developments around the coast as well as defense measures to mitigate coastal retrogradation and inundation. The SMP will also allow for flexibility as the members of the public and stakeholders can contribute to it and will understand their roles and responsibilities. The decision to award a project for shoreline protection should already be well analyzed and documented within the SMP as this will lessen the expenditure of public funds on vulnerable infrastructure and response mechanisms. Finally, the SMP supports natural beach stabilizations more than engineered coastal barriers.

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