



Assessment of Shoreline Change Along the Coast of Lagos, Nigeria

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Abstract

Shorelines and adjoining land remain an important site for the intensive interplay of socioeconomic development and natural processes. Unfortunately, the Lagos, Nigeria shoreline is always subjected to varied morphological changes in response to small (short term) and large-scale (long term) events as triggered by natural processes and human development. Thus, there is the need to accommodate these changes through a combination of the relative permanence of urban infrastructure and shoreline defense efforts. The study assesses the evolution of the Lagos coast over 20 years, with reliance on archived Google Earth imageries dated between 2001 and 2020 to estimate and visualize the magnitude of erosion and accretion along the Lagos coastline with a focus on sections extending from the east mole to Victoria Island end, which form part of the Eti-Osa Local Government Area (LGA). This was achieved using the Analyzing Moving Boundaries Using R (AMBUR) software package, an R programming language add-in. Over the 20-year period, the Lagos shoreline cumulatively records a mean rate of change of +0.93 m/year, mean erosion rate of −1.94 m/year, and mean accretion rate of +4.84 m/year. Focusing on Victoria Island where shoreline change is observed to be the highest, a mean shoreline change rate of +6.24 m/year, depicting accretion activities is observed. Victoria Island also recorded a mean erosion rate of −5.2 m/year and a mean accretion rate of 81.99 m/year. The high accretion rate and positive mean rate of change for Victoria Island and the entire Lagos coast results from land reclamation activities undertaken within the period of study. Further analysis of temporally segmented data into pre-reclamation, reclamation, and post-reclamation periods at Victoria Island reveals that eastward of Victoria Island is an active and unabated erosional activity resulting in disappearing beaches and urban developmental structures during the post-reclamation period. A post-reclamation period overall mean rate of −4.73 m/year, with maximum erosion rate of 51.25 m/year are recorded for Victoria Island over a pre-reclamation period overall mean rate of −1.41 and a maximum erosion rate of −11.8 m/year. Therefore, an appropriate land use and land cover management plan needs to be adopted along the Lagos shoreline region, especially for Victoria Island.

Keywords Coastal defense · Coastal erosion · Google Earth imageries · Lagos shoreline · Shoreline change

1 Introduction

The coast is a highly dynamic region continually shaped over varying degrees of space and time scales by the ever-changing shorelines, which respond to natural processes of periodic accretion and erosion. The processes of accretion and erosion may respond to small-scale (short-term) events like tides, storms, winds, and regular wave action. Large-scale events on the other hand can result from shoreline subsidence or emergence triggered by orogenic cycles or glaciation [1–4].

Shoreline erosion involves the landward movement of the water's edge and is generally concentrated in the most sensitive coastlines, backed by Aeolian dune complexes. This is usually along the sand or pebble gravel beaches or where

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unconsolidated sediments or weakly consolidated bedrock forms shoreline bluffs [5–7], resulting in cliffs receding, beaches and dune systems “migrating” or changing location [8–11]. It should be noted that there are tendencies for stable and currently eroding shorelines to wear down further and accreting shorelines to wane or stabilize due to the combined effect of global warming and sea level rise [6, 12].

Shoreline retreat poses a threat to coastal infrastructures such as roads and buildings, as well as human activities relating to fishing, agriculture, and transportation. The threat of change in habitat, resulting from loss of marshes, lagoons, mangroves, or sand dunes can also not be overlooked. The retreat is not always a continuous and steady process, but there are often dramatic incomplete recovery cycles [1, 5, 13].

Human activities along the shoreline (land reclamation, port development, aquaculture developments), within river catchments and watersheds (river damming and diversion), and offshore (dredging, sand mining) in fusion with natural forces, often exacerbate shoreline erosion and threaten socioeconomic and ecological opportunities of shorelines at a reasonable societal cost [4, 14, 15]. Thus, the vulnerability of the coast to climate-related risks increases as anthropogenic activities become enormous.

Rising global sea level remains one of the most certain consequences of global warming, which poses threats to coastal populations along with low-lying coastal sites due to the increased likelihood of flood events. The combined effect of sea-level rise and human interference is the most plausible causes of current issues of coastal erosion, since, as sea level rises, the high water line migrates landward in proportion to the slope of the shoreline area [16, 7, 17–20].

The problem of coastal erosion is widespread. It is however unfortunate that most often, the application of a perceived solution to the issue is mainly affected locally or with respect to national jurisdictional boundaries rather than solutions that target system boundaries in reflection of natural processes. A contributing factor to such local responses often points to insufficient knowledge of the dynamic processes that result in accretion and erosion, as well as the protective functions provided by shoreline systems [21–23].

The result of such local responses may include the application of hard or soft structures that may not be properly designed, constructed and maintained, or without the careful evaluation of the effects on adjacent shores, thus constituting inappropriate countermeasures.

The Lagos shoreline is a barrier-lagoon coastal complex comprising of beach ridges fronted by a narrow beach with a foreshore gradient of about 1:50 [24, 25]. Beach crest elevation is between 3 and 4 m above mean lower low water [24, 26].

The narrow and sandy beach ridges, which form a natural barrier island protecting the foreshore system that is aligned

parallel to the coast, are naturally unstable, eroding, migrating, and rebuilding in response to the natural and anthropogenic processes. These processes disturb the morphodynamic equilibrium of the low-lying beach system, resulting in erosion, flooding, and inundation of the beach and its environment.

Some areas along the beaches are almost at sea level; such low-lying beaches like Victoria Island and Lekki Bar Beach are easily flooded during high tides and storm surges. On every occasion that storm surges coincide with spring tides, most beaches at a maximum elevation of 3 m above sea level usually have high waves, resulting in flooding of the coastline [25, 27].

Threats to the natural resources on the Lagos shoreline are visible because of the interrupted long-shore transport of sand from the west mole to the east along the shoreline; this results in the trapping of about 0.5 and 0.75 million cubic meters of sand per year behind the west mole [22, 28].

Thus, this study aims to assess shoreline changes along the Lagos coastline, with a focus on locations downdrift of the east mole via the Victoria Islands-Ibeju-Lekki-Epe corridor. This is necessary in order to accommodate various changes induced by human activities through a combination of the relative permanence of urban infrastructure and shoreline defense efforts, extreme events, and sea-level rise.

2 Regional Setting

Lagos is located in the southwest of Nigeria (i.e., within 6° 23' N–6° 41' N, 2° 42' E–3° 42' E) contiguous to the Atlantic coast in the Gulf of Guinea, occupying an area of about 3577 km². It is currently the fifth-largest city in the world located [29]. Lagos has its borders as the Atlantic Ocean to the south, Ogun State on its north and east, and on the west by the Republic of Benin (Fig. 1). The study area covers the entire coast of Lagos with detailed analysis covering the Eti-Osa Local Government Area (LGA) of Victoria Island. The Eti-Osa LGA is between the Amuwo-Odofin, Lagos Island, and Ibeju-Lekki LGAs and is located east of the east mole in Victoria Island.

Lagos is characterized by a burgeoning population living in limited space close to the shoreline and threatened by sea level rise and unpredictable weather events that impend the future of coastal communities and natural resources therein [28, 30]. The region is the economic nerve center of the country with the highest concentration of Nigeria's wealth and commercial center. The Lagos Lagoon separates the varied linked and bounded islands like the Eko, Ikoyi, Victoria Island/Lekki, and Iddo. Developments within the coastal area have influx deliberate interest to resolve the coastal erosion issues in the region in an effort to restore coastal capacity. This

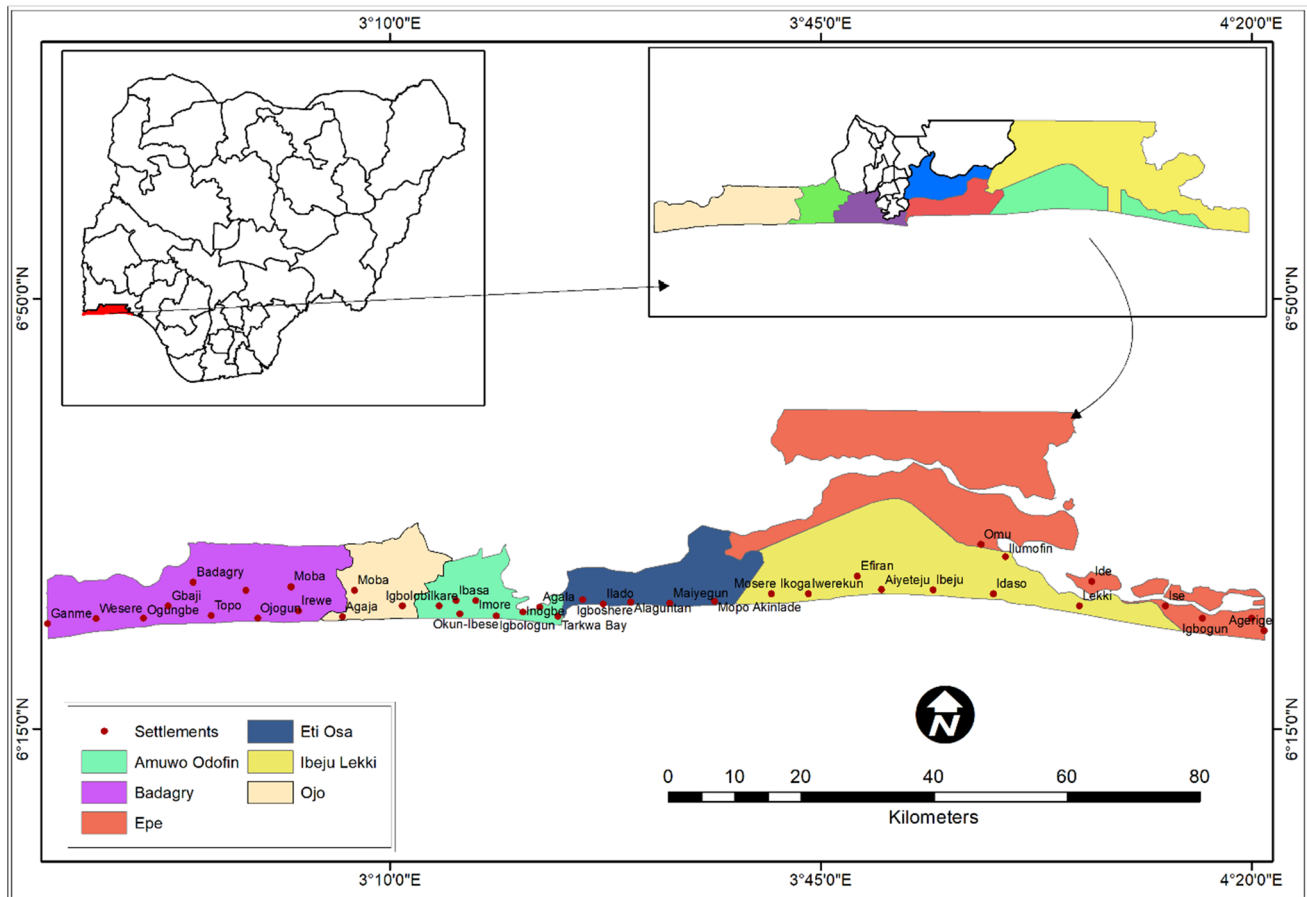


Fig. 1 Lagos shoreline with Nigeria map insert

fact accommodates short- and long-term changes induced by human activities, extreme events and sea-level rise through sand nourishment, beach restoration, and sea wall defense, among others [31, 32].

Protecting the Commodore Channel entrance (Fig. 2) from silting led to the construction of the east and west mole groyne system, which disrupted the longshore drift (west–east sand drift) that naturally distribute sediments along the coastline. Threats to the natural resources on the Lagos shoreline include the retreating Bar Beach due to erosional activities eastward of the east groyne system due to the loss of the lush vegetation. The designed groyne are to protect the Apapa port entrance from silting at the west of the inlet due to the preferentially concentrate sand (Fig. 2). Victoria Island is located along the extended coastline of Lagos State with loss of most of its lush vegetation (mixture of mangroves, swamp, and humid rainforest), resulting from land reclamation and further transformation into a huge resident district [22, 28, 33].

3 Methodology

The methodological approach adopted in this study entails the need to assess areas susceptible to cross-shore coastal accretion/erosion along the Lagos coastline in Nigeria. This involved the acquisition of high resolution remotely sensed (composite Google Earth imageries) dataset of Lagos shoreline with focus on Victoria Island (Bar Beach) front shoreline from the Google Earth Pro version 7.3.3.7786 (64-bit) at a spatial resolution of 4800×2782 pixels at approximately 2-km eye altitude, for the periods 2001, 2006, 2012, 2018, and 2020. The process of vector layer extraction from the images necessitates the head-up (on-screen) digitizing method to capture multiple shorelines from the composite imageries, within the Google Earth Pro interface. The shorelines were generated within the Google Earth interface and exported into QGIS for further processing. Shoreline for the various periods was extracted and saved as KMZ files that were imported into



Fig. 2 A section of the Lagos shoreline highlighting the west and east mole constructions source: [34]

Table 1 Coordinates of ground control points for validating Google Earth images

GCP	GPS waypoint		Google Earth image	
	Longitude	Latitude	Longitude	Latitude
1	3.31515	6.45743	3.342258	6.430274
2	3.39334	6.48318	3.429530	6.501236
3	3.43325	6.46030	3.406132	6.478406
4	3.48279	6.43346	3.446602	6.415394
5	3.42396	6.42282	3.451109	6.449928
6	3.39175	6.43453	3.409861	6.470696
7	3.35969	6.44013	3.341578	6.412996
8	3.32452	6.44183	3.351663	6.468948
9	3.36381	6.45621	3.400011	6.492359
10	3.40808	6.45567	3.380932	6.437592

QGIS (version 3.6.0) for pre and post-data processing for shoreline change analysis. The validation and georectification of the Google Earth (GE) images were carried out with known ground control point (GCP) coordinates obtained from the field (Table 1 and Fig. 3), using Global Positioning System (Garmin GPSMAP 765) waypoints at accuracy positional error of ± 4 m.

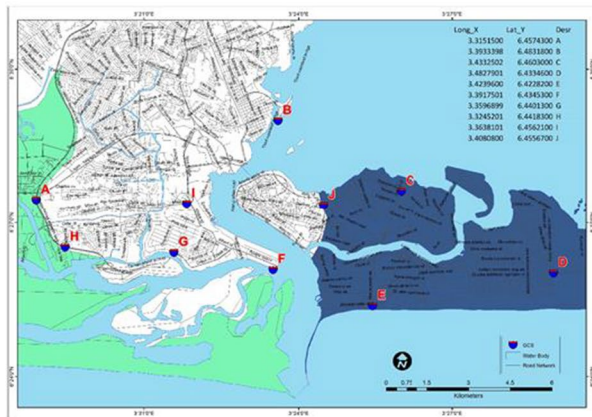
The performance measures of the estimated positioning were determined using the root-mean-square error (RMSE) as indicated in Eq. 1.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (GE_i - GCP_i)^2} \quad (1)$$

where N is the total number of validation points, GE is the coordinates from the Google Earth interface, and GCP is the coordinate from the ground control point measurement.

Shorelines imported into the QGIS environment were merged and saved as ESRI shapefile format for the shoreline change analysis, using the Analyzing Moving Boundaries Using R (AMBUR) software package (version 1.1.26). AMBUR is a user-friendly interface software used to calculate shoreline rate-of-change statistics from multiple historic shoreline positions as well as for predicting the position of future shorelines based on historical data. AMBUR package is an open-source package embedded in the R programming language environment and is compatible with most commercial and open-source GIS software. The package applies the definition of reference baseline and transects technique for quantifying distances and rate of shoreline change [35].

The measurements from the transects bounded by the most landward and seaward historical shoreline position for each site are estimated based on an array from the oldest to the most recent shorelines as dated. Shore-parallel baselines were also created towards attaining shore-perpendicular transects at 50-m intervals in order to capture the various developmental changes and microhabitats along the shoreline within short distances. Transect casting entails a single baseline casting of perpendicular transects based on an offshore (outer) location of the historical shorelines, while transects are measured from the baseline intersects of the shoreline vectors, and the points of intersection provide location and time information used in estimating the rates of change.



Goggle Map

Fig. 3 Ground control points on a Google Earth image of a part of the Lagos shoreline

The metadata was user-specific, while the output of calculated rates of shoreline change and other statistical information like distance changes are automatically performed. Change and associated statistics, such as rate of change, was calculated for the multiple shoreline shapefile data for the different years to estimate the coastline displacement over the specified period in the AMBUR interface [36, 37]. The rate of shoreline change was assessed using the linear regression rate (LRR) and end point rate (EPR) methods at a tolerance of 95% confidence interval. The pre-reclamation and post-reclamation periods of the Victoria shoreline front were analyzed using the EPR method since these periods consist of only two separate dates while the LLR was used for the reclamation period and the cumulative analysis since these comprised more than two different date times. EPR is a fast and effective technique while estimating changes and/or generating predictions between the oldest and the newest shoreline but is limited in use while estimating changes in magnitude or periodic trends of several shorelines.

In addition, the QGIS framework was used for the post-processing of the shoreline change mapping. The shoreline analyses were carried out for the entire Lagos coast, while the Victoria Island was segmented for the pre-reclamation, reclamation, and post-reclamation periods in reference to coastal developmental activities in the Eti-Osa LGA.

4 Results and Discussions

4.1 Lagos Shoreline Dynamics (2001–2020)

The Lagos shoreline positioning covers the period (2001 to 2020), with erosion and accretion constituting 2072 and 1523 transects, respectively, to make 3595 transects (Table 2).

Table 2 Summary shoreline dynamics of Lagos coast and part of the Victoria Island coastline

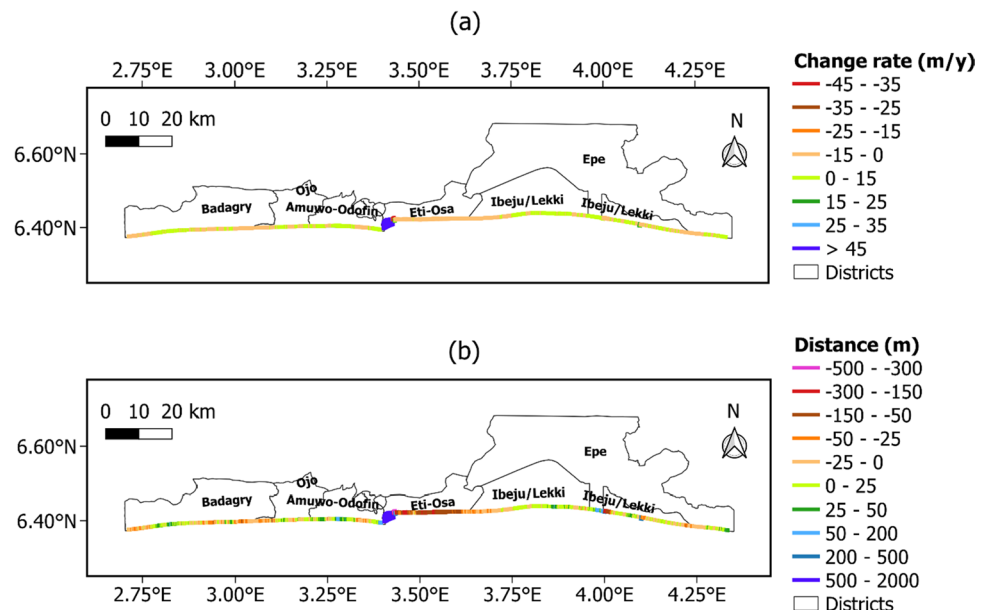
Criteria	Lagos cumulative
Oldest date	Dec. 2001
Youngest date	Dec. 2020
Number of transects	3539
Erosion transects	2072
Accretion transects	1523
Maximum erosion (m)	−490.81
Mean erosion (m)	−36.6
Maximum erosion rate (m/year)	−44.62
Mean erosion rate (m/year)	−1.94
Maximum accretion (m)	2019.51
Mean accretion (m)	91.61
Maximum accretion rate (m/year)	106.29
Mean accretion rate (m/year)	4.84
Overall mean change (m)	18.29
Overall mean rate (m/year)	0.93

The overall mean shoreline cross-shore dynamics (rate and distance change) along the Lagos coast depicts slight accretion (Table 2), with the rate at Victoria Island coastline being about seven (7) times that of the entire Lagos shoreline (Table 3). This is due to the massive coastal protection measures, which include several nourishment schemes to reduce the erosion threat to Victoria Island, most especially during the reclamation (2012–2018) period. These schemes significantly influence the advancement of the beach resulting in a higher mean cross-shore accretion rate along the east mole.

The cumulative shoreline change of Lagos (2001–2020) shows that on average, the cross-shore erosion and accretion rate along the beaches ranges from −15 to 15 m/year, the only exception being the Eko Atlantic City region. The city has an accretion rate of > 45 m/year, and at

Table 3 Summary shoreline dynamics of Victoria Island coastline for the various periods under consideration

Criteria	Cumulative period	Pre-reclamation	Reclamation	Post-reclamation
Oldest date	Dec. 2001	Dec. 2001	Dec. 2012	Dec. 2018
Youngest date	Dec. 2020	Dec. 2006	Dec. 2018	Dec. 2020
Number of transects	526	526	526	526
Erosion transects	457	381	361	376
Accretion transects	69	145	165	150
Maximum erosion (m)	−490.81	−58.99	−135.13	−102.57
Mean erosion (m)	−93.1	−15.75	−39.89	−18.94
Maximum erosion rate (m/year)	−44.62	−11.8	−22.53	−51.25
Mean erosion rate (m/year)	−5.2	−3.15	−6.65	−9.46
Maximum accretion (m)	2019.51	96.65	1582.59	108.52
Mean accretion (m)	1545.67	16.04	257.88	15.82
Maximum accretion rate (m/year)	106.29	19.33	380.51	54.22
Mean accretion rate (m/year)	81.99	3.21	43.89	7.91
Overall mean change (m)	121.87	−7.06	51.05	−9.39
Overall mean rate (m/year)	6.24	−1.41	8.95	−4.73

Fig. 4 Lagos shoreline change map: **a** change rate (m/year) and **b** distance change (m)

locations immediately after the city, the erosion rate of between -35 m/year to -25 m/year (Fig. 4) was evident. Regions of extensive erosion rate remain Badagry, Eti-Osa, and the corridor between the extreme end of Ibeju-Lekki and Epe LGA. The cross-shore erosion and accretion distance (m) ranged from -25 to 25 m except at Eti-Osa frontage and part of Ibeju-Lekki LGA, attaining a receding distance range of between -300 and -150 m, while accretion distance of 500 – 2000 m was attained at the Eko Atlantic City region.

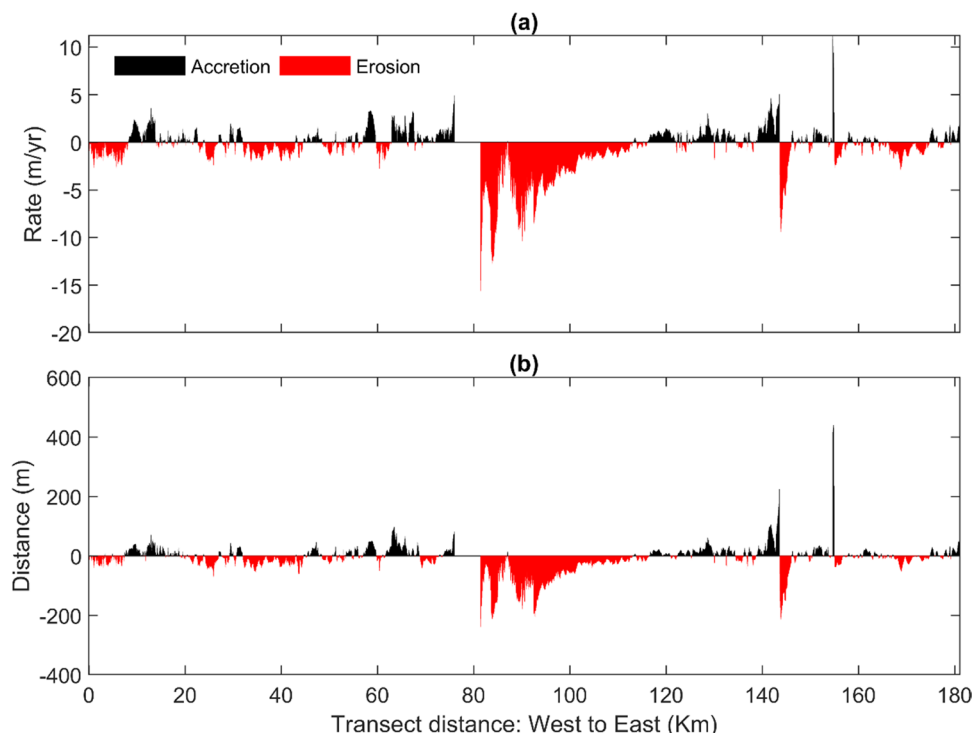
The alongshore transect distance (west to east) drift between 80 and 118 km depicts an extensive beach erosion at a maximum erosional rate of -18 m/year, at a receding distance of -200 km. The most outstanding accretion region

lies within 119 – 145 km at a maximum rate of 6 m/year at an advancing distance of 185 km (Fig. 5).

4.2 Victoria Island Front Shoreline

The Victoria Island front shoreline (downdrift location) to the reclaimed Eko Atlantic City suffered enormous rates of erosion, resulting in massive loss of beach width. Victoria Island front (a subsection of Lagos shoreline) coastlines have 526 transects consisting of 457 erosion transects and 69 accretion/stable transects (Table 3). The shoreline exhibit an annual mean erosional magnitude of 2.68 and an accretion rate of 16.94 m/year, higher than the entire Lagos shoreline, due to the massive volumes of sediment

Fig. 5 Lagos shoreline change by transect: **a** change rate (m/year) and **b** distance change (m)



supplied to the Bar Beach nourishments plan and flood defense wall, as well as large scale land reclamation (Eko Atlantic City). The massive sand deposit created a reemergence of the cross-shore eroded bar beaches located along the east mole downdrift. Unfortunately, massive washing away of locations and beaches downdrift of the defense walls of the reclaimed land occur due to the transfer of the erosion beyond the walls. The land reclamation is to meet up with the large space demands for residential, commercial, and recreational activities.

Comparative analysis of the Victoria Island front shoreline for the pre-reclamation, reclamation, and post-reclamation period of the Eko Atlantic City depicts a significant lateral change (Table 3). Victoria Island's pre-reclamation period had the highest total erosion transects (381) and the least accretion transect (145), followed by the post-reclaimed period. The reclaimed period had the least erosion transects (361), this might be due to the continuous nourishments of the enormous volumes of sediment against the erosional rate. The mean erosion rate (m/year) of the post-reclamation period is three times higher than the pre-reclamation period, while the mean accretion rate (m/year) during the reclamation period is 13.67 higher in magnitude than the pre-reclamation period. The overall mean shoreline rate dynamics shows that the pre-reclamation and post-reclamation period suffer massive cross-shore beach losses. The loss is about four (4) times higher during the post-reclaimed period compared to the pre-reclaimed period. Meanwhile, the reclaimed period (8.95 m/year) remains the period of massive accretion

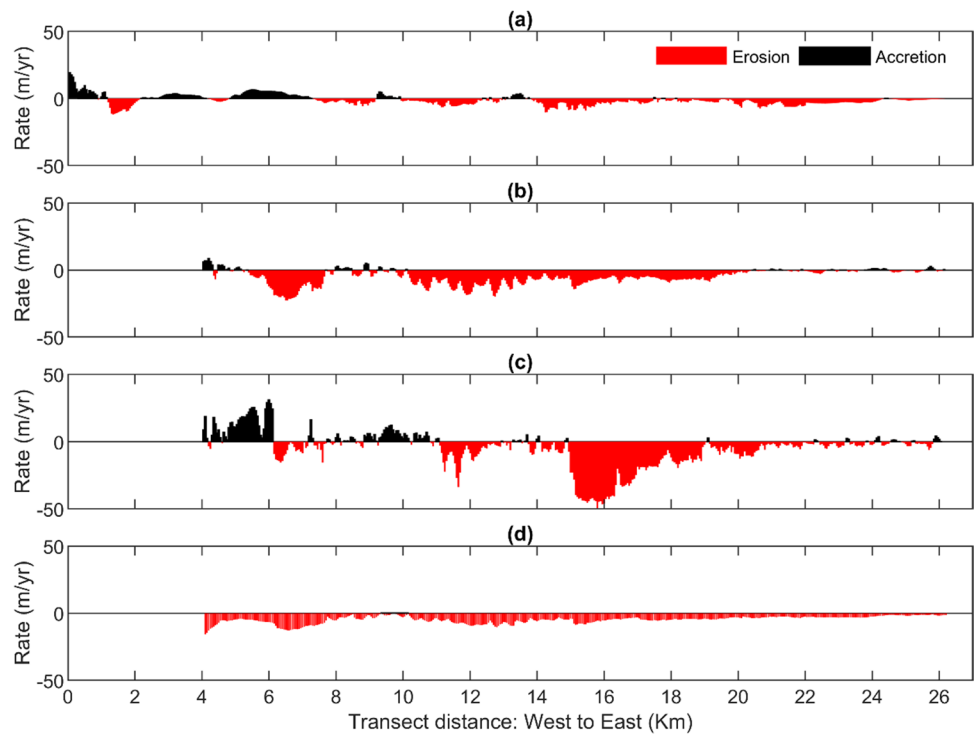
and beach restoration (advance) along the Victoria Island shoreline.

The cross-shore change of Victoria Island shoreline (Fig. 6), for the pre-reclamation period (2001–2006) depicts that across transects, accretion rate ranges between 5 to 10 m/year while erosion rate ranges between –5 to –10 m/year. The maximum accretion and erosion rates during the period were 30 m/year and –10 m/year, respectively. Extensive accretion and erosion across transect locations fall between 4.5 and 7.7-km and 7.8 and 24.5-km sections, respectively, of the Victoria Island shoreline (Fig. 6a).

During the reclamation (2012–2018) period (without the reclaimed Eko Atlantic City), the average cross-shore accretion rate of 11 m/year and erosion rate of about –20 m/year was observed, with an extensive erosion along transect falling between 10- and 20-km sections of the shoreline (Fig. 6b). Locations of massive erosional activities fall between 5.4 and 7.9 km at the highest magnitude of 22 m/year, with a significant accretion location falling within a 4 to 5.4-km range and a mix-up of minor accretion and erosion activities beyond a 20-km section of the shoreline.

The post-reclamation period (2018–2020) experienced a mean cross-shore accretion rate of 22 m/year and an erosion rate of –30 m/year, with insignificant alterations between accretion and erosion at a receding distance of about 15 m (Fig. 6c). The period along-track location between 15 and 16 km shows evidence of extensive erosion rate, and between 11 and 21 km along track, massive erosion rate at the peak of 50 m/year was evident. The extensive accretion region is

Fig. 6 Shoreline change rates (m/year) of Victoria Island: **a** pre-reclamation period; **b** reclamation period; **c** post-reclamation period; and **d** cumulative change

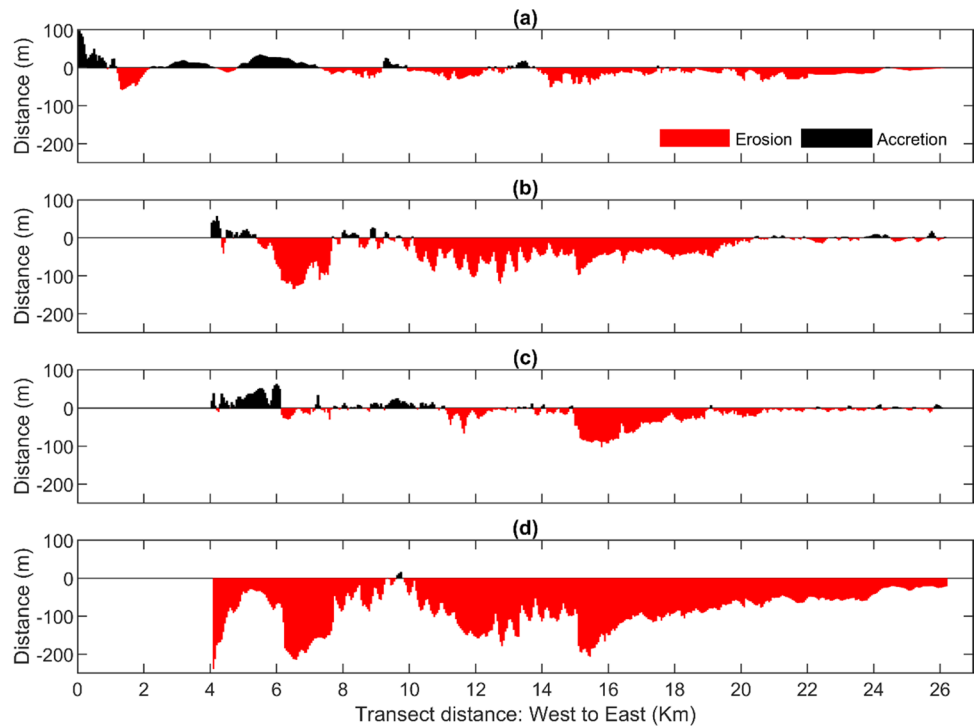


between 4 and 6 km, along track, reaching a maximum of 30 m/year. Beyond 21 km, there is a mix-up of minor erosion and accretion.

The cumulative shoreline change for Victoria Island (2001–2020) depicts a receding trend with an average

erosion rate of about -12 m/year; the rate of change during the period shows massive beach loss along the track with the most extensive losses occurring between 4 and 7 km and 10 and 16 km along-track (Fig. 6d).

Fig. 7 Shoreline change distances (m) of Victoria Island: **a** pre-reclamation period; **b** reclamation period; **c** post-reclamation period; and **d** cumulative change



The dynamics of the cross-shore distance with the transect distances for the Victoria Island shoreline is shown in Fig. 7. During the pre-reclamation period (Fig. 7a), the shoreline change of Victoria Island (2001–2006) depicts an accretion rate, advancing at a maximum distance of 100 m, while the average erosion ranges from a receding distance of –5 to –50 m. Accretion distance ranges from 25 to 75 m at a maximum distance of 100 m along with a transect distance of 0.5 km.

The shoreline change of Victoria Island for the reclamation period (2012–2018) shows that the length of accreted beach width ranged from 25 to 65 m, while an eroded distance of –20 to –80 m was observed (Fig. 7b). Alternations between erosion and accretion occurred at a distance of 20 m.

The post-reclamation period shoreline change of Victoria Island (2018–2020) depicts on average, accreted distance ranges of about 15 to 85 m and an average eroded distance of about –65 m, with an insignificant erosion activity at a receding distance of 10 m (Fig. 7c). Alongshore distances between 15 and 17.5 km had the most extensive receding distance with a maximum of about 85 m. The regions between 4 and 6 km constitute the most extensive accretion at a maximum distance change of 85 m. The mix-up of regions of minor erosion and accretion between 21 and 26 km is at a distance of –5 to 5 m.

The cumulative change for Victoria Island (2001–2020) depicts a receding shoreline, ranging between 25 and 185 m, with an average receding distance of 65 m, and a maximum receding distance of 225 m, at 4.2 km along-track section, with the most extensive receding beach losses falling within a 10 to 26-km section alongshore (Fig. 7d).

In all, the Lagos cumulate and Victoria front shoreline are experiencing a varying degree of changes from both natural and anthropogenic driving forces, starting with the disruption of the natural longshore drift which has alleviated the issue of siltation along the harbor entrance but reduced the flow of sediments down-drift of the east mole [38]. The west and east stone mole constructions obstruct the normal flow of the longshore sediment transport.

The Atlantic City reclamation project along the Victoria axis, as well as the construction of the Lagos Great Wall (groyne) as coastal defense, also contributes to the anthropogenic driving force for the coastline dynamics. The Lagos cumulate shoreline has a mean shoreline rate of change of +0.93, a mean erosion rate of –1.94 m/year, and a mean accretion rate was +4.84 m/year. The mean shoreline rate of change depicts accretion activities for the study period with the mean shoreline rate of change of +6.24 m/year, a mean erosion rate of –5.2 m/year, and a mean accretion rate of 81.99 m/year, for Victoria front shoreline.

The overall mean change rate for pre- to post-Victoria Island reclamation front shoreline depicts erosion during

the Victoria pre-reclamation period (–1.41 m/year) and Victoria post-reclamation period (–4.73 m/year), and accretion during the Victoria reclamation period (8.95 m/year), with extensive erosion during the Victoria post-reclamation period. The mean erosion rate was also higher during the Victoria post-reclamation period (–9.46 m/year), followed by the Victoria reclamation period (–6.65 m/year), and the Victoria pre-reclamation period (–3.15 m/year). The mean accretion rate was the highest during the Victoria reclamation period (43.89 m/year), followed by the Victoria post-reclamation period (7.91 m/year), and Victoria pre-reclamation period (3.21 m/year).

Coastal erosion along the Lagos coastline destroyed the Victoria Island Bar Beach and constituted a threat to several urbanization developments on the frontage of Ahmadu Bello Way and infrastructures, including the disappearance of Kuramo Beach on the east of the moles before the newly constructed groynes. The extensive land reclamation practice, and the uncompleted coastal defenses and groynes off the Lekki Peninsula, has also blocked the sediment transport drift by the breakwaters. The rate of erosion eastwards of Victoria Island has intensified towards the tail end of the last constructed groyne (Figs. 8, 9, and 10) [39].

Nwilo et al. [34] noted that the erosional rate on the eastern side of the Lagos coast between 2001 and 2012 and 2012 and 2016 depicts a maximum erosional rate decrease of about 0.68 m/year between the east mole and around Victoria Island. Meanwhile, the maximum erosional rate increase of about 1.83 m/year was recorded between the period 2001–2012 and 2012–2016, from Victoria Island to Orimedu within the Ibeju-Lekki LGA.

Eastward of Victoria Island, Obiefuna et al. [40] reported an annual erosion rate of between 8.75 and 10.11 m between 2006 and 2009, while along the eastern stretch of Lagos coastline within Ibeju/Lekki area, between 2001 and 2013, this has increased to about 22.75 m/year around Kuramo Waters [26].

Thus, morphological processes along the Barrier-Lagoon coastline of Lagos [28] have raised concerns on the vulnerability of infrastructures and coastal services within the coastline. This calls for the integration of a coastal protection plan for developmental processes along the coastal region with detailed local, regional, and global dimensions. Such processes are needful, considering the enormous disruption of the littoral drift and magnitude, through upstream river dam construction, port developments, and other coastal disruptions, such as shipwrecks, which have resulted in the redistribution of the sand and sedimentary materials over space and time, along the Lagos shoreline.

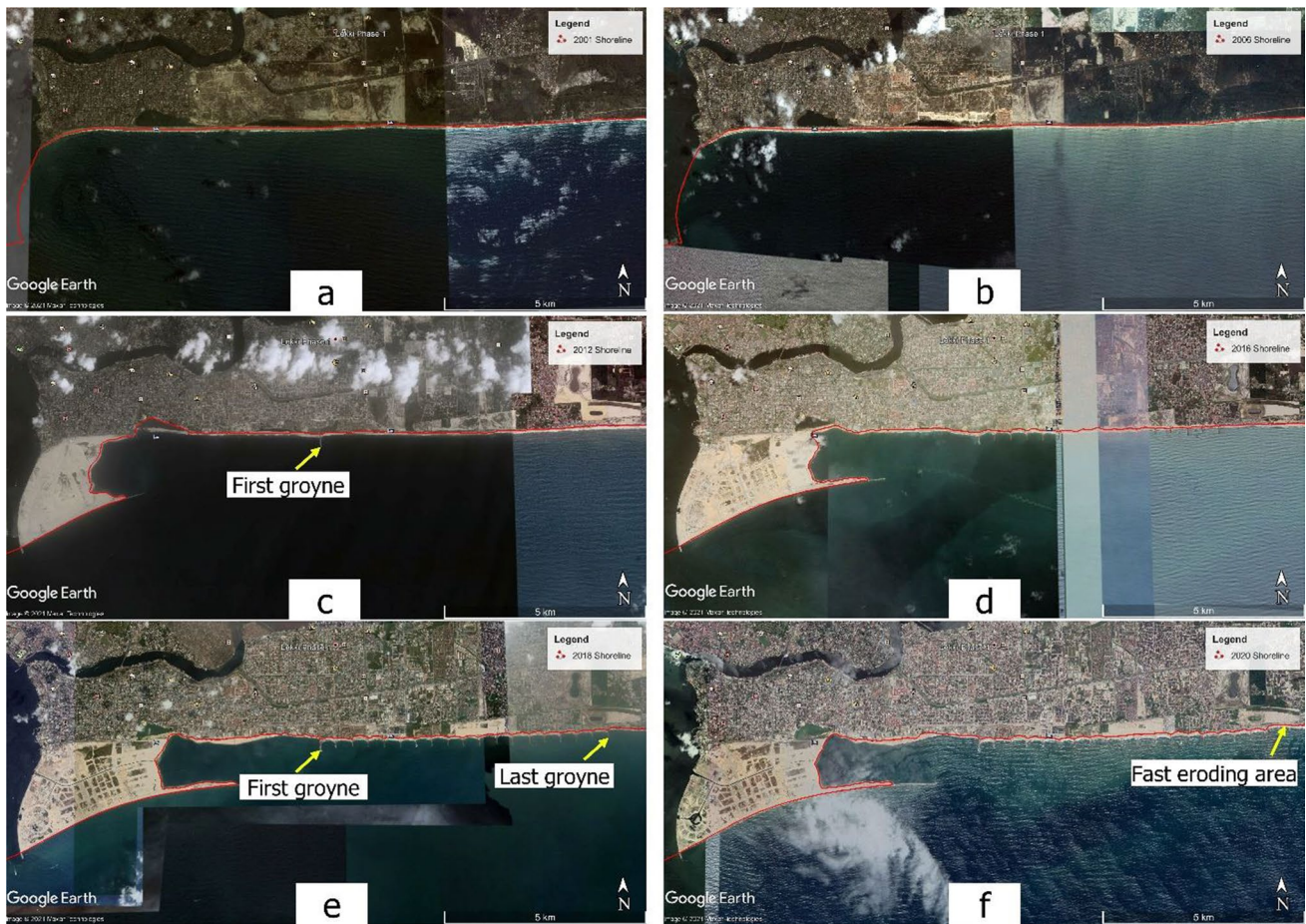


Fig. 8 Evolution of the coastline of Victoria Island from 2001 to 2020. **a** 2001; **b** 2006; **c** 2012; **d** 2016; **e** 2018; and **f** 2020

Fig. 9 Estimated Victoria Island coastline dynamics: **a** shorelines indicating the evolution of reclamation with very fast eroding area highlighted; **b** eroded shoreline areas (red) and reclaimed area (light green) with the very fast eroding area highlighted; and **c** very fast eroding area after the last constructed groyne as highlighted in **a** and **b** showing respective shoreline positions

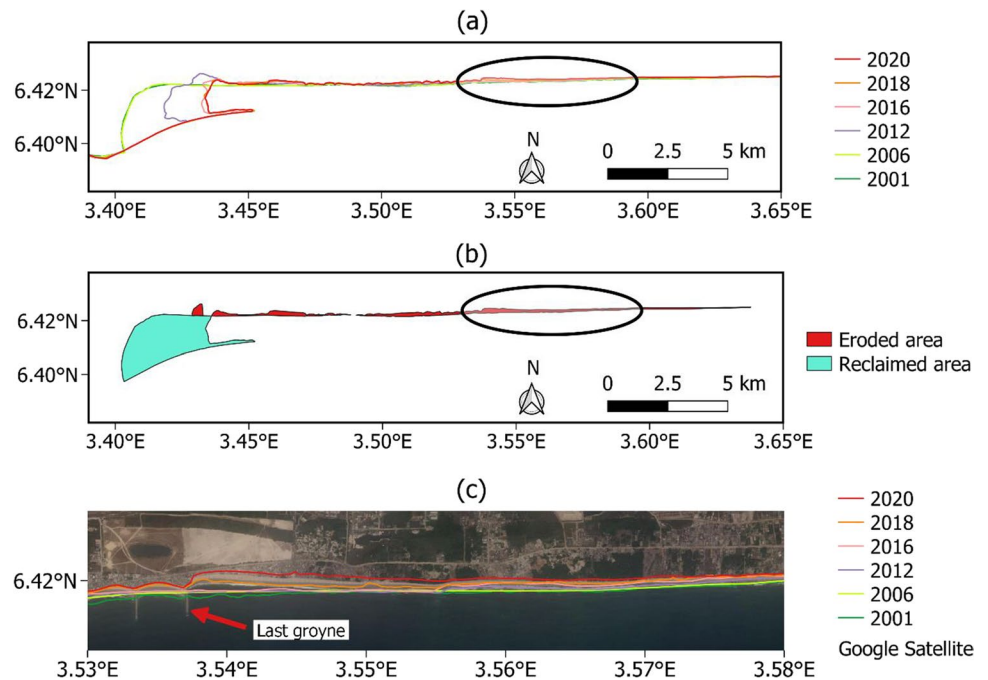




Fig. 10 Overview of the Eko Atlantic Project Lagos (source https://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/Nigeria_Eko_Atlantic_ESIA_ESMP_Summary.pdf)

5 Conclusion and Recommendation

The study assessed shoreline dynamics of the Lagos coastline with a focus on Victoria Island frontage downdrift location, based on remote sensing techniques, using data from Google Earth. The study demonstrated a simple but efficient approach for monitoring shoreline changes over extended periods using high-resolution satellite imagery and open-source tools in assessing the coastline dynamics (coastal erosion and accretion) along part of the Lagos shoreline.

In the study area, both natural and anthropogenic factors contributed to shoreline erosion and accretion while locations of extensive erosion rate remain Badagry, Eti-Osa, and the corridor between the extreme end of Ibeju- Lekki and Epe LGA. The land reclamation project of the Eko Atlantic City and seawall construction activities result in the deflecting of the erosion force inwards towards Victoria Island downdrift, an area known for its real estate development with numerous socioeconomic activities. Thus, sites like Eleko Beach, Alpha Beach, and the Apese community among others are now the shadow of their earlier existence.

The need for careful and sensitive management of the Lagos shoreline calls for an intensive and robust investigation into the recent developments along the coast and their impacts on the coastal dynamics of the Lagos shoreline. There is also the need to have a more holistic plan of action towards addressing the issue of coastal erosion beyond the present coastal defenses being implemented, to involve

soft path management plans, most especially in the area of physical spatial planning of the Lagos coastal region. This is necessary since coastal erosion is part of the physical processes expected in the barrier-lagoon complex of Lagos and its environs, with strategic development and management towards the immense benefit of all stakeholders.

Thus, proper coastal land use management strategies need to entail sustainable land reclamation practices along the coastal area and across Lagos Lagoon. There is also the need to provide adequate beach profiling surveys toward monitoring the shoreline dynamics, in order to protect the massive socioeconomic activities along the coast against the consequences of coastal erosion.

The government should take urgent steps to protect the coastal communities from total destruction by erosion. Furthermore, proper consideration of the geomorphology and sediment characteristics of the Lagos coast is needed while determining an appropriate coastal defense system that can promote the sustainability of the coastline. Above all, there is the need to promote an integrated coastal management strategy with a continuous monitoring plan along the Lagos coastline. In addition, there is the need for national, regional, and international cooperation among institutions toward research, funding, and monitoring as well as management of the Lagos shoreline.

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Data Availability Google Earth imageries via Google Earth Pro version 7.3.3.7786.

Code Availability None.

Declarations

Competing Interests The authors declare no competing interests.

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