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Long-term determination of shoreline changes along the coast of Lagos

Peter C. Nwilo[1*], A. Chidi Ibe[2], Jimmy O. Adegoke[3], Jerry N. Obiefuna[4], Alfred S. Alademomi[1], Chukwuma J. Okolie[1], Olayemi O. Owoeye[1], Joel N. Nwokocha[1], Michael J. Orji[1], Abdulkareem A. Umar[1] and Olagoke E. Daramola[1]
[1]Department of Surveying & Geoinformatics, Faculty of Engineering, University of Lagos, Akoka, Lagos State, Nigeria
[2]Institute for Natural Resources, Environment and Sustainable Development, University of Port-Harcourt, Rivers State, Nigeria
[3]Department of Geoscience, Centre for Applied Environmental Research (CAER), University of Missouri, Kansas City, USA
[4]Department of Architecture, Enugu State University of Science & Technology, Enugu, Enugu State, Nigeria
*Email: [a]pcnwilo@unilag.edu.ng

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Abstract: Analysis of shoreline changes is an important indicator in the study of coastal erosion and/or accretion. It aids in understanding the spatio-temporal trends in the changes triggered by natural processes and human impacts. The construction of two breakwaters (East and West moles) between 1908 and 1912 at the entrance to Lagos harbor inhibited the natural flow of the longshore drift, hence it accelerated erosion rate especially in the Victoria Island area while areas on the west of the breakwaters were accreting. This study relied on archival maps of 1900 – 1964 and satellite imageries of 2001–2016 to determine and visualize the magnitude of erosion and accretion along the coast of Lagos State. The shoreline positions at various epochs were extracted from the maps and satellite imagery by vectorization. The magnitude of change was determined by calculating the differences in the shoreline positions measured along vertical line segments spaced at 200-meter intervals. Then, the shoreline positions were plotted graphically. The analysis shows a trend of accretion on the western side of the shoreline up to the West mole and massive erosion eastwards of the East mole. However, the high magnitudes of erosion in the Victoria Island axis have been checkmated by the Eko Atlantic City project along with the construction of coastal defenses. Notwithstanding, evidence from recent satellite imagery and analysis of the shoreline changes shows that these anthropogenic interventions have only succeeded in transferring the erosive actions eastwards to areas downdrift of these coastal defenses.

Keywords: Erosion, accretion, coastal defenses, coastline, shoreline change

1. Introduction

The world's coastal areas are believed to house about two-thirds of the global population (Hanson and Lindh, 1993). It is therefore very important to understand the processes at work in coastal environments. The processes that determine the physical configuration of a coast are both natural and anthropogenic (Williams, 1960; Ibe, 1988; Nwilo, 1995). The natural processes include among others the waves, tides and surges, currents, the presence of canyons, earthquakes, the amount of rainfall, drainage characteristics, sea level trends and natural subsidence (Nwilo, 1995). Also, human activities such as the extraction of fluids, construction on and away from the coast, deforestation and canalization make a substantial contribution towards determining the physical configuration of the coastal environment (Nwilo, 1995). Coastal shorelines are defined as the interface between the land and sea (Bird, 1993; WIOMSA, 2010; Akinluyi et al., 2018), and the immediate position of the land–water line at an instant in time (Boak and Turner, 2005; Akinluyi et al., 2018). These shorelines are subject to changes in response to morphological, geological or climatic factors (Carter and Woodroffe, 1994; Pidwirny, 2006; Akinluyi et al., 2018). The analysis of shoreline changes is crucial to lot of studies being conducted by coastal scientists, engineers and geomorphologists.

Shoreline changes depict how the position of the shoreline moves with time; the shoreline can move landwards through the process of erosion or seawards by sediment accretion. This combined action of erosion and accretion changes the shape of the coast over time. Coastal erosion as a worrying phenomenon along the coast of Nigeria is influenced by tides, waves, longshore currents and ocean currents. This retreat of the Nigerian shoreline is a threat to coastal settlements, recreational grounds and oil export handling facilities which are located in coastal towns (Ibe and Antia, 1983). Waves constantly crash against the shore eroding the loose sandy beaches and moving the coastline farther inland. This is predominant along the coast of Lagos and was the reason for the loss of the Lagos Bar Beach in Victoria Island area of Eti-Osa Local Council. Annual rates of erosion between 20-30m/yr have been recorded in Lagos (Ibe, 1988; Orupabo, 1990; Nwilo and Onuoha, 1993). Ibe (1988) estimated that over 1.5km of the coastline had been lost in Victoria Island due to coastal erosion. Similarly, Obiefuna et al. (2013) have reported that the Lagos coastline along Eti-Osa and Ibeju/Lekki Councils was rapidly eroding and measured annual erosion rates in Eti-Osa Local Council as high as 8.75-10.11m between 2006 and 2009. More recently, Obiefuna et al. (2017) showed that the maximum rate of erosion on the eastern stretch of Lagos coastline between 2001 and 2013 occurred mainly in Eti-Osa Local Council at about 22.75m/yr around Kuramo Waters.

Coastal erosion is further exacerbated by accelerated sea-level rise being experienced globally. A coastal area with a low-lying topography like that of Nigeria will be adversely affected by a small rise in sea level (Nwilo, 1995). The impact of sea-level rise on coastal/shoreline erosion in low-lying coastal regions has received some attention by coastal scientists such as van Rijn (2011); Zhang et al. (2004) and Smith et al. (2010). Other coastal scientists have also inquired into the vulnerability of the coastal area to wind and storm surges. In that regard,

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Harley et al. (2017) reported large-scale severe coastal erosion due to anomalous wave direction. Storms lead to coastal erosion and other changes in the shoreline due to high winds, an increase in the height of ocean water, and action of waves. IPCC (1992) has noted that the Nigerian coastal areas will be adversely affected by a small rise in sea level and from the accounts of Bruun (1962), a sea-level rise of 0.3m will cause a coastline recession of 30m on low-lying and flat coasts. Nwilo (1995) showed that the rate of sea-level rise along the Nigerian coast was 1mm/yr.

The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4) projected increased global sea-level rise rates between 1.5mm/yr and 9.7mm/yr in the 21st century (Meehl et al., 2007). The projections of sea-level rise in the more recent IPCC Fifth Assessment Report (AR5) are much higher than in AR4. According to the AR5 predictions summarised in Church et al. (2013), for the period 2081–2100, compared to 1986–2005, global mean sea level rise could be as high as 0.98m with a rate during 2081–2100 of 8-16 mm/yr. In furtherance to the observation of IPCC, the erosion issue in the Lagos coast is not influenced by sea-level rise alone. Other equally contributing factors are wave direction, storm surges, tides and lack of conservation of the coastal wetlands. In 2012, a storm surge coupled with erosion sheared off the entire Kuramo Beach and extended the Atlantic Ocean landward into Kuramo Waters, a hitherto partially landlocked waterbody. No significant study has been done on this storm impact since 2012. The recent Eko Atlantic City development that caused seaward sand filling of the ocean had mitigated erosion around the Bar Beach area. However, it is seemingly now causing severe erosion eastward of the beach.

Victoria Island in Eti-Osa Local Council has been the site of very active erosion following the completion in 1912 of the two stone breakwaters (stone moles) perpendicular to the shore purposely for protecting the entrance of dredged water into the Lagos harbor (Ibe et al., 1991). This inlet was known to be constantly silted thereby constituting navigational hazards to ships into Lagos harbor (Fowora-Ranardet Associates, 1981; Ibe, 1986, 1988; Nwilo, 1995). The construction of these stone moles impacted the normal flow of longshore sediment transport which was from west to east along the coastline. While the issue of siltation was remedied, it reduced the flow of sediments reaching the Victoria Island Beach on the east of the moles. As a result, while areas west of the West mole were experiencing accretion, there was acute erosion at Victoria Island east of the East mole. Figure 1 shows the positions of the East and West moles, and the direction of movement of the prevailing longshore current. This coastal erosion had destroyed the beach, constituted a threat to several high-brow developments on the frontage of Ahmadu Bello Way and infrastructures within the area. Kuramo Waters, a formerly enclosed water body in Victoria Island was breached by the Atlantic Ocean in 2012 (Obiefuna et al., 2017). Nwilo (2016) showed that its surface water area reduced by 0.24km^2 between May 2001 and December 2015; although the study did not consider the seasonal variations of water level in the rainy (wet) and dry seasons. Figure 2 shows observed changes in Kuramo Waters at five yearly periods – 2001, 2011, 2013, 2014 and 2015.

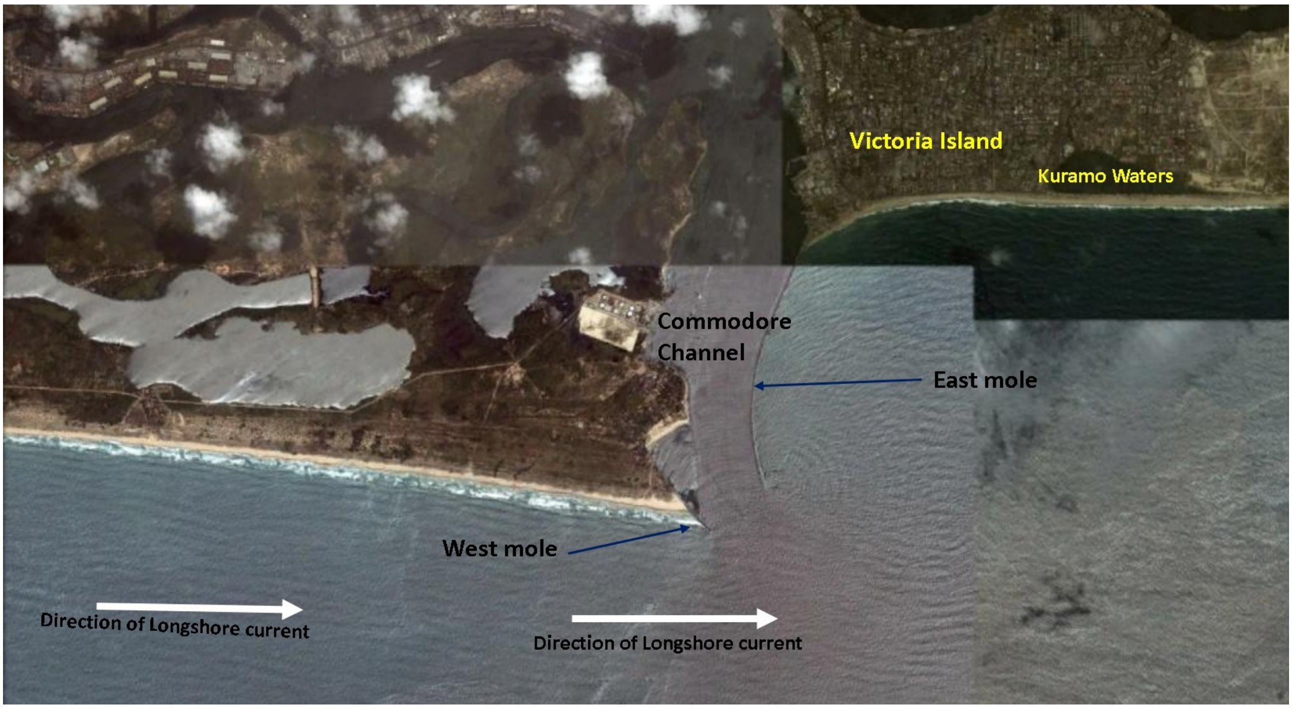

Figure 1: The positions of the East and West moles, and the direction of movement of the prevailing longshore current (Imagery source: Google Earth, October 2002)

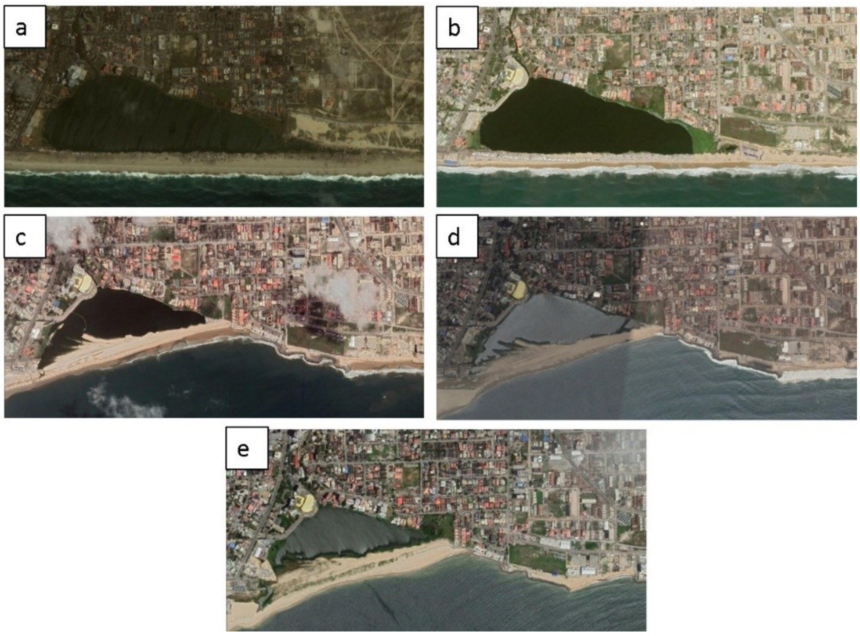

Figure 2: Observed changes in Kuramo waters at different periods – (a) May 5, 2001 (b) May 5, 2011 (c) October 20, 2013 (d) April 19, 2014 (e) October 12, 2015 (Imagery source: Google Earth).

Although several attempts including beach nourishment in the past (Ibe, 1988; Awosika, 1993) and in the subsequent years were made to rein in on the erosion menace on Victoria Island Beach, none was effective until the recent emplacement of coastal defenses and development of the Eko Atlantic City project. For effective coastal planning and management, it is desirable to continuously monitor both the developments on the Lagos coast along with the effects of emplaced coastal defense structures. Equally, it is worthwhile to undertake a historical evaluation of the impacts of these actions periodically to assess their effectiveness. This paper, therefore, addresses a long-term determination of shoreline changes in Lagos State. This is to understand the current situation of the shoreline since the construction of the moles as well as provide preliminary insights into the effectiveness of recent actions in taming the erosion menace on the affected parts of the Lagos coastal area.

1.1 Coastal morphology and wave regime

According to Obiefuna et al. (2017), the Lagos coastline is rimmed in its entirety by barrier islands. These barrier islands include the Badagry Island/Lighthouse Beach which is backed by Badagry Creek and Lighthouse Creek, the Victoria Island backed by Five Cowrie Creek, and Lekki Peninsula which is backed by the Five Cowrie Creek, and the Lagos and Lekki Lagoons. Geomorphologically, Ibe (1988) sees these barriers as part of the low-lying Barrier-Lagoon Complex which extends from the Nigeria/Benin border eastwards for about 200km. According to Ibe (1988), the morphology of this complex was determined by coastal dynamics, the drainage and a set of inter-related coastal processes. First, characterized by erosive beaches, there is the absence of 'exoreic' rivers which would have replenished from the hinterland sand lost from the longshore current action. This according to Ibe (1988), explains the absence of spits and barriers developing presently. Secondly, the longshore current is active in the area moving in a west-east direction. Thirdly, there is a steep and narrow continental shelf (approximately 30km wide), that is indented by submarine canyons such as the Avon Canyon and Mahin Canyon, and gullies (Ibe, 1988; Obiefuna, 2015). This narrow continental shelf enables waves to reach the shore at higher heights and promotes the loss of nearshore sediments to the gullies and canyons. Lastly, there is intense wave action along the beaches, which is caused by the influence of the prevailing south-westerly winds. Also, Ibe (1988) notes that the barrier islands vary in width from ½ km to 21km and are generally aligned parallel to the Atlantic Coast. The barrier beaches form a narrow belt of largely sandy accumulations with width varying between 2-8km and average altitude of 0.75-5m above sea level (Abegunde, 1988). Features of the Lagos coastline which largely negate accretion and enhance beach erosion have been enumerated in Ibe (1988). These include high-intensity wave action, large swell waves with spilling breaker wave type as the most common, strong longshore currents, steep and narrow beach profile, erosive beaches, the steep and narrow continental shelf of 25km, presence of gullies and canyons and longshore transported sand of about 0.7 to 0.8million m^3/yr. Incessant high-energy swell waves, impacting the Lagos coast with a mean direction of 188°, induce a mean eastward longshore transport of sediments (van Bentum, 2012). According to Ibe and Antia (1983), "the angle at which the moles were constructed did nothing to mitigate the effect of waves on the coast. In fact, the eastern mole, by promoting eddying, accentuated the destructive impact of the waves which have continued to move sand eastwards from the Victoria Beach thereby precipitating the continuing erosion problem."

The waves have a south-westerly component driven by the south-westerly winds. Along the Lagos Bar Beach, waves are predominantly about 1 to 2 m high. However, during the rainy season, waves swell up about 3 to 4 m along most areas. The longshore currents are the predominant currents generated by the south-westerly breaking waves. Tides occurring on the coast of Nigeria are semi-diurnal with two inequalities. The tides arrive in a south-westerly direction. Tidal range varies from 1m at Lagos and increases progressively eastwards to about 3m at Calabar (Awosika and Folorunsho, 2009). The action of the hydrodynamic forces makes the region vulnerable to storms in the rainy season (Busari and Osman, 2017).

1.2 Study area

The study area is the shoreline of Lagos state in Nigeria. Lagos is a low-lying coastal state and is Nigeria's center of commerce. It is located between Longitudes 2°41'15" - 4°22' 00" E and Latitudes 6°20' 10" - 6°43' 20" N. The study area falls within the Barrier-Lagoon Complex of the Nigerian geomorphological units. This coastal unit starts from the Nigeria-Benin Republic border and extends about 200km to the east. It is within the chain of barrier-lagoon complexes from Cote d'Ivoire through the mouth of the Volta River in Ghana, through Benin Republic and finally into Nigeria (Nwilo, 1995). As stated earlier, the Lagos coast consists of west-east trending barrier islands backed by the Badagry Creek, the Lagos and Lekki lagoons as shown in figure 3. The Lagos Lagoon has a direct link to the Atlantic Ocean through the Commodore Channel. Due to this link, the salinity of the Lagos Lagoon is higher than that of Lekki Lagoon (Ibe, 1988). Furthermore, along the Lagos coast, sediment transport by the longshore drift is controlled by the prevailing wind direction (Awosika and Folorunsho, 2009). Sediment transport by this drift is blocked by the breakwaters, the coastal defenses and groins of the Eko Atlantic City project. The erosion force is deflected inwards towards Victoria Island and areas on the downdrift side of the coast. Based on the old Local Government set-up, Lagos has 20 Local Government Areas (LGAs) or Councils. Over the years, accelerated migration from other parts of Nigeria and neighboring countries has resulted in a rapidly expanding and diverse population within Lagos State.

2. Materials and Methods

2.1 Data acquisition and analysis

The maps for the years 1900, 1946 and 1964 and a set of satellite imageries for the years 2001, 2012 and 2016 were compiled. The coverage of the 1900 and 1946 map does not extend beyond the Lagos harbor area. The imageries were downloaded from Google Earth using El-shayal software. Table 1 shows the characteristics of the datasets used in this study. In ArcGIS Software, the maps were georeferenced. The satellite imageries required no georeferencing since El-shayal maintains their rectification during download. All the datasets were re-projected from geographic coordinates to a Universal Transverse Mercator (UTM) projection referenced to the WGS84 datum. This transformation helped to overcome linear measurement difficulties, preserve geometric properties, and ensure harmony in the coordinate system and datum properties of the datasets. Following the approach of Zollini et al. (2019), the maps and imageries were manually vectorized to extract the shoreline positions within ArcGIS software. Two baselines were drawn along the east and west sides of the coast. Perpendicular line segments were projected from the baselines to intersect all the shorelines at intervals of 200m (183 segments on the eastern side of the coast and 191 segments on the western side). Figure 4 shows the baselines and extent of areas measured (A, B, C and D) drawn on the western and eastern sides of the coast. The categorization of the coastline into four areas, A, B, C and D aided the sub-division of the coastline into smaller portions with similar characteristics for more detailed analysis. The distances from the baseline to each shoreline along the segments, and the magnitudes of change between shorelines were then measured and compiled in a tabular form. The analysis was also supported by a field survey of the area to acquire photographs of some of the groins as well as to observe the effects of the erosional action.

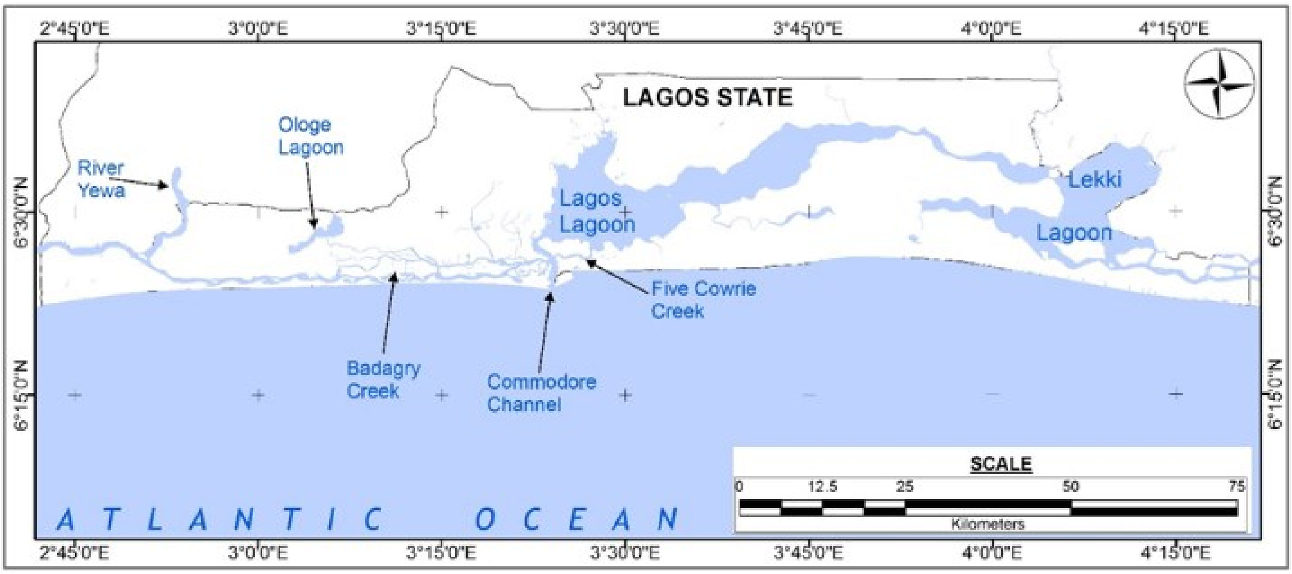

Figure 3: Map showing the Lagos coastal area

Table 1: Characteristics of the datasets used

S/N	Data	Source/Publisher	Acquisition Date
1	Earth observation data	Google Earth	2001, 2012, 2016
2	Map of Lagos harbor area	National Institute for Oceanography and Marine Research (NIOMR)	1900
3	Nigeria City Plans, Edition 1-AMS (1:12,500)	US Army Corps of Engineers Army Map Service (USACE-AMS), Office of the Surveyor General of the Federation (OSGOF)	1946
4	Topographic maps (1:50,000)	Office of the Surveyor General of the Federation	1946, 1964

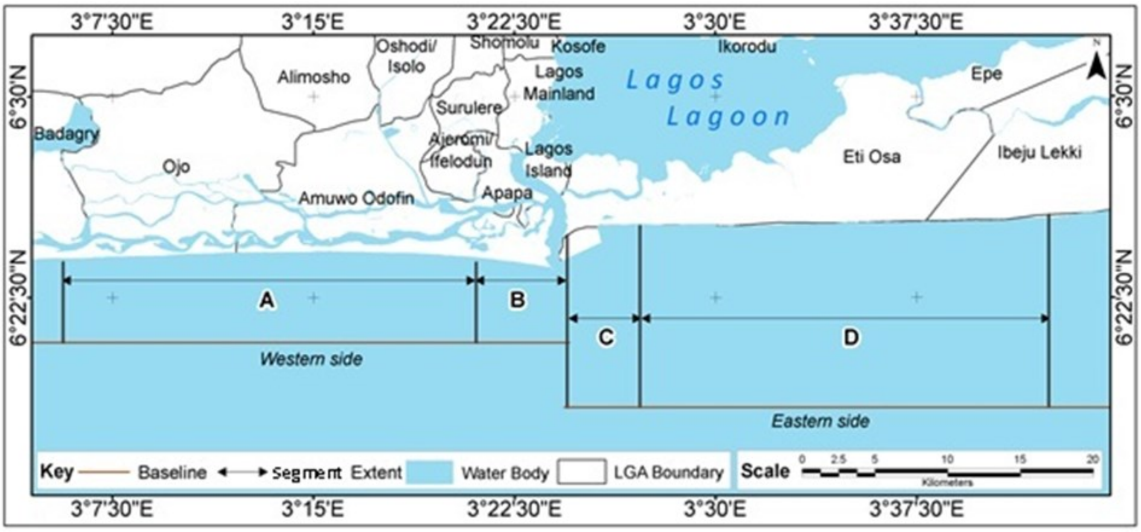

Figure 4: The two baselines and extents of measured areas (A, B, C and D) drawn on the western and eastern sides of the Lagos coast

3. Results and Analysis

The 191 line segments drawn on the western side of the coast (A and B) were spread over a total distance of 37.8km while the 183 transects drawn on the eastern side of the coast were spread over a total distance of 36.4km (C and D). For the western side of the coast, table 2 shows the vertical distance between shoreline positions on the western side of the Lagos coast (A) – an 8-kilometer section starting from Igbooja Beach at 510434mE and going eastwards. Table 3 shows the vertical distance between shoreline positions on the western side of the Lagos coast (B) - From Apapa at 538834mE to end-point at the West mole. For the eastern side of the coast, table 4 shows the vertical distance between shoreline positions on the eastern side of the Lagos coast (C) - a 5-kilometer stretch at Victoria Island from the East mole going eastwards. Table 5 shows the vertical distance between shoreline positions on the eastern side of the Lagos coast (D) – an 8-kilometer section starting from Victoria Island at 552097mE and going eastwards. Positive changes indicate erosion while negative changes indicate accretion. A few data gaps were observed in the tables at areas where there were gaps in imagery/map coverage.

There is evidence of erosion and accretion on the eastern and western sides of the coast respectively. However, the general trend on the eastern side shows erosion is more predominant while on the western side, accretion is predominant. Thus, the rate of accretion statistics measured on the western side was extracted and summarised in table 6 while the rate of erosion statistics was extracted and summarised in table 7. On the western side, the highest rate of accretion of 15.91m/yr occurred between 2012-2016 close to Siku village in Amuwo Odofin LGA while the lowest rate of accretion of 0.02m/yr was measured at two areas – at Igboeseyore in Amuwo Odofin LGA between 1964 and 2001; and at Olomometa in Ojo LGA between 2001 and 2012. On the eastern side, the highest rate of erosion of 26.5m/yr occurred at the area previously inhabited by Apese community in Eti-Osa LGA between 2001 and 2012. Apese community has since been submerged by water.

The positions of the shorelines as vectorized from the datasets are presented graphically in figures 5 to 8. In the 37.8km western section, figure 5 shows shoreline changes from Igbooja Beach, Ojo LGA to Apapa while figure 6 shows shoreline changes from Apapa to end-point at the West mole. On the 36.4km eastern section, figure 7 shows shoreline changes at Victoria Island from the East mole going eastwards while figure 8 shows shoreline changes from Victoria Island to Orimedu, Ibeju Lekki LGA. In figure 8, two downward spikes are observed close to the 2200m mark. These spikes take the shape of groins constructed on the coast.

Table 2: Vertical distance between shoreline positions on the western side of the Lagos coast (A) – an 8-kilometer section starting from Igbooja Beach (510434mE) going eastwards

Line Seg. ID	Line Segment Easting (mE)	Distance (m)		
		1964-2001	2001-2012	2012-2016
1	510434.62	-153.36	12.23	18.37
2	510634.62	-119.98	6.54	19.93
3	510834.62	-147.45	22.04	21.64
4	511034.62	-118.11	24.47	19.18
5	511234.62	-114.90	14.90	19.04
6	511434.62	-112.95	10.96	20.02
7	511634.62	-117.58	11.80	27.46
8	511834.62	-131.27	23.60	19.11
9	512034.62	-131.85	30.57	2.21
10	512234.62	-135.15	32.85	0.91
11	512434.62	-78.27	14.36	3.87
12	512634.62	-62.44	18.12	2.25
13	512834.62	-111.26	13.19	17.93
14	513034.62	-113.53	6.99	21.04
15	513234.62	-140.25	15.05	16.54
16	513434.62	-118.39	6.11	16.20
17	513634.62	-81.63	17.53	11.60
18	513834.62	-122.86	4.91	10.65
19	514034.62	-34.83	-0.22	8.31
20	514234.62	-99.41	0.21	15.05
21	514434.62	-82.00	-16.27	13.47
22	514634.62	-81.46	-15.44	13.12
23	514834.62	-84.79	-23.45	10.20
24	515034.62	-96.75	-29.07	17.20
25	515234.62	-52.00	-73.75	23.27
26	515434.62	-197.49	35.74	27.24
27	515634.62	-203.90	53.75	29.93
28	515834.62	-202.42	47.13	21.74
29	516034.62	-216.13	46.66	28.39
30	516234.62	-233.00	35.77	21.09
31	516434.62	-202.47	34.12	21.75
32	516634.62	-196.15	29.46	19.31
33	516834.62	-146.27	13.49	20.02
34	517034.62	-187.86	9.92	20.16
35	517234.62	-179.02	0.86	15.83
36	517434.62	-177.29	-0.90	10.52
37	517634.62	-159.62	4.89	7.14
38	517834.62	-158.57	-12.24	12.33
39	518034.62	-171.53	-16.61	15.58
40	518234.62	-176.14	-19.31	20.59
41	518434.62	-183.41	-12.55	25.31

On the western side, the predominance of accretion is very evident thereby causing sediment accumulation at the West mole, while on the eastern side, the predominance of erosion is evident. On the eastern side, high erosion is observed at an area previously inhabited by Apese community in Eti-Osa LGA between 2001 and 2012. Apese community has since been submerged by water. The wave pattern along the coast contributes to the accretion and erosion variation. Observations have shown that waves at the Victoria Island Beach are mainly swells caused by the prevailing westerly winds, with a long ocean fetch, having a wave period between 8 – 13secs while the longshore currents move eastwards (Afiesimama, 2003; Egberongbe et al., 2006). Between 2001 and 2012, there was an area with no observable change with no erosion and accretion (stable) at Orimedu in Ibeju Lekki LGA. There were also several areas without any observable change along the Eko Atlantic City wall where the position of the wall has remained stable within that same period. The unusually high magnitudes of erosion observed here between 2012 and 2016 seem to be occurring after the construction of the Eko Atlantic City especially as Ibe (1988) noted some accretion and minimal erosion previously in this area.

Figure 9 shows some of the newly constructed groins along the coast. These groins were constructed perpendicular to the coast to interrupt the water flow and limit the movement of eroded sediment being transported away from the Victoria Island area. This led to accretion/deposition on the upper end and erosion on the lower end. The areas between the groins are observed to be u-shaped or crenulated. This shape is a result of despoliation by erosive forces acting within the groin fields (Figure 10).

Table 3: Vertical distance between shoreline positions on the western side of the Lagos coast (B) - From Apapa (538834mE) to end-point at the West mole

Line Seg. ID	Line Segment Easting (mE)	Distance (m)			
		1900-1964	1964-2001	2001-2012	2012-2016
1	538834.62	376.92	37.87	40.77	28.34
2	539034.62	380.38	41.77	37.57	43.04
3	539234.62	350.02	38.72	43.79	45.41
4	539434.62	341.77	54.64	33.64	63.64
5	539634.62	366.79	75.37	17.51	61.57
6	543434.62	345.44	25.23	52.66	47.35
7	541834.62	323.53	36.20	31.49	42.92
8	542034.62	344.49	41.80	26.70	47.94
9	542234.62	338.17	45.82	45.00	32.48
10	542434.62	495.56	22.82	49.12	38.86
11	539834.62	515.98	45.58	27.02	15.00
12	540034.62	540.19	26.19	37.76	37.70
13	540234.62	537.97	40.55	26.98	46.68
14	540434.62	562.33	34.97	34.06	62.26
15	540634.62	596.19	16.09	34.65	33.85
16	540834.62	617.45	8.02	37.47	57.04
17	541034.62	634.31	14.92	29.11	43.34
18	541234.62	654.46	38.55	28.32	46.69
19	541434.62	647.90	75.91	25.85	51.12
20	541634.62	547.75	40.12	40.32	42.41
21	542634.62	618.43	26.96	14.03	51.21
22	542834.62	650.37	57.07	9.64	49.49
23	543034.62	734.86	96.96	15.52	49.87

Table 4: Vertical distance between shoreline positions on the eastern side of the Lagos coast (C) - a 5-kilometer stretch at Victoria Island from the East mole going eastwards

Line Segment ID	Line Segment Easting (*mE*)	Distance (m)				
		1900-1946	1946-1964	1964-2001	2001-2012	2012-2016
1	545097.38	-1009.92	223.06	-475.62	2044.28	0.19
2	545297.38	-928.20	-26.96	-274.03	2051.38	-0.02
3	545497.38	-837.80	-63.75	-251.64	2025.35	0.00
4	545697.38	-737.77	-79.11	-	-	0.00
5	545897.38	-675.57	-65.55	-	-	0.00
6	546097.38	-556.87	-69.26	-302.71	1917.55	0.00
7	546297.38	-481.80	-84.62	-289.56	1852.66	0.00
8	546497.38	-415.57	-98.61	-264.46	1777.11	0.47
9	546697.38	-412.29	-60.99	-258.09	1708.48	0.00
10	546897.38	-369.44	-37.95	-237.12	1622.82	0.00
11	547097.38	-351.19	-15.14	-220.71	1538.16	0.00
12	547297.38	-349.24	18.61	-212.87	-74.93	1535.58
13	547497.38	-327.03	29.19	-216.45	-110.48	1511.65
14	547697.38	-311.11	25.27	-204.03	-167.02	1501.79
15	547897.38	-299.72	26.72	-203.18	-211.86	1514.67
16	548097.38	-299.88	24.75	-184.63	-282.69	1551.73
17	548297.38	-284.18	-1.92	-160.39	-291.48	1525.70
18	548497.38	-274.93	-3.22	-155.22	-255.86	1458.36
19	548697.38	-261.18	-3.19	-143.58	-200.97	1360.63
20	548897.38	-263.79	-11.18	-150.90	-112.71	1279.08
21	549097.38	-266.70	-12.60	-	-	1197.14
22	549297.38	-247.87	-11.56	-	-	1194.36
23	549497.38	-223.51	-22.64	-	-	1162.42
24	549697.38	-201.57	-7.92	-146.88	-65.31	1130.13
25	549897.38	-209.75	-1.28			-34.00

Table 5: Vertical distance between shoreline positions on the eastern side of the Lagos coast (D) – an 8-kilometer section starting from Victoria Island (552097mE) and going eastwards

Line Segment ID	Line Segment Easting (*mE*)	Distance (m)		
		1964-2001	2001-2002	2012-2016
11	552097.38	-213.01	12.78	159.09
12	552297.38	-209.89	-68.91	-6.87
13	552497.38	-218.47	-35.61	154.94
14	552697.38	-240.82	-46.84	-34.48
15	552897.38	-233.80	-37.67	-22.19
16	553097.38	-252.55	-36.03	-46.12
17	553297.38	-242.32	-24.03	-14.31
18	553497.38	-228.25	-35.16	-41.66
19	553697.38	-265.75	-5.66	-4.70
20	553897.38	-241.90	-15.74	-25.99
21	554097.38	-232.79	-3.41	2.36
22	554297.38	-237.15	-3.32	-11.60
23	554497.38	-195.79	-13.10	6.88
24	554697.38	-211.45	-12.40	-58.10
25	554897.38	-192.70	-13.33	-39.54
26	555097.38	-148.79	-31.23	-72.52
27	555297.38	-117.17	-21.76	-39.89
28	555497.38	-100.44	-16.17	-63.34
29	555697.38	-133.30	-17.43	-42.85
30	555897.38	-123.10	-22.44	-73.29
31	556097.38	-115.19	-26.58	-51.73
32	556297.38	-105.50	-24.56	-96.14
33	556497.38	-98.84	-45.35	-73.23
34	556697.38	-122.35	-38.02	-61.00
35	556897.38	-115.16	-48.56	-38.80
36	557097.38	-125.83	-45.52	-55.87
37	557297.38	-140.94	-31.21	-51.76
38	557497.38	-127.14	-38.53	-62.75
39	557697.38	-153.16	-37.70	-57.26
40	557897.38	-	-	-61.61
41	558097.38	-	-	-66.22
42	558297.38	-173.80	-11.46	-48.14
43	558497.38	-165.81	-21.99	-48.51
44	558697.38	-163.50	-28.75	-38.45
45	558897.38	-169.95	-32.95	-34.92
46	559097.38	-181.77	-24.41	-34.55
47	559297.38	-171.23	-19.04	-20.16
48	559497.38	-169.15	-13.92	-15.66
49	559697.38	-137.76	-23.30	-8.94
50	559897.38	-143.48	-12.62	4.03
51	560097.38	-143.88	-13.86	6.85

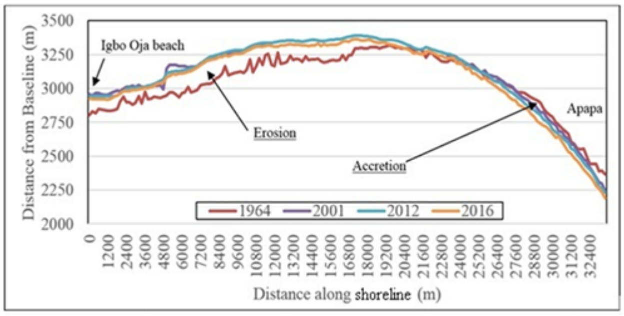

Figure 5: Shoreline changes from Igbooja Beach, Ojo LGA to Apapa (A)

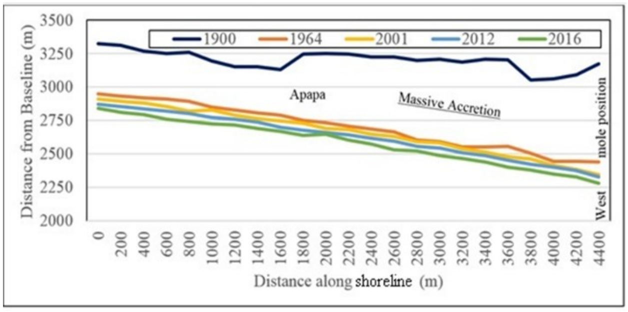

Figure 6: Shoreline changes from Apapa to end-point at the West mole (B)

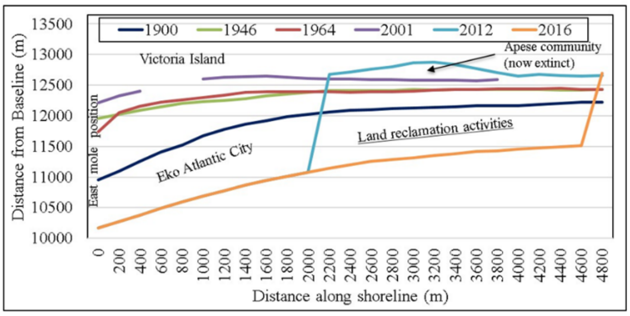

Figure 7: Shoreline changes at Victoria Island from the East mole going eastwards (C)

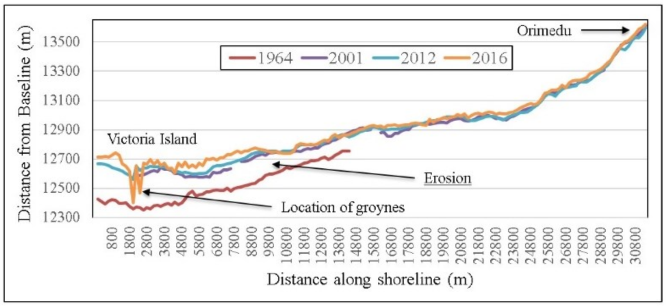

Figure 8: Shoreline changes from Victoria Island to Orimedu, Ibeju Lekki LGA (D)

Table 6: Rate of accretion (m/yr) on the western side of the Lagos coast

	From Apapa (538834*mE*) to end-point at the West mole				From Igbooja Beach (510434*mE*) to Apapa		
	1900 - 1964	1964 - 2001	2001 - 2012	2012 - 2016	1964 - 2001	2001 -2012	2012 -2016
Min	5.06	0.22	0.88	3.75	0.02	0.02	0.23
Max	11.48	2.62	4.79	15.91	3.27	4.89	15.91

Table 7: Rate of erosion (m/yr) on the eastern side of the Lagos coast

	From the East mole (545097*mE*) going eastwards					From Victoria Island (550097*mE*) to Orimedu, Ibeju-Lekki LGA		
	1900 - 1946	1946 - 1964	1964 - 2001	2001 - 2012	2012 - 2016	1964 -2001	2001 - 2012	2012 -2016
Min	4.38	0.07	1.97	5.94	0.00	1.24	0.00	0.08
Max	21.95	5.48	12.85	26.50	8.50	7.18	9.24	26.17

Figure 9: Newly constructed groins off the Lagos coast (Imagery source: Google Earth, December 2015)

Figure 10: (a) A view down the length of one of the groins (b) Ongoing erosion alongside one of the groins constructed on the Lagos coast (Field survey, October 4, 2017)

4. Discussion

The findings confirm accretion on the western side of the coast. For example, in the measurement from Apapa to the end-point at the West mole, the maximum rates of accretion of 11.48m/yr and 15.91m/yr were obtained during the 1900-1964 and 2012-2016 periods respectively. The accretion is caused by the withdrawal of sediments from the longshore drift and subsequent accumulation which is very pronounced at the West mole area. The findings also confirm a general increase in the trend of landward erosion on the eastern side of the Lagos coast. From the East mole going eastwards, maximum rates of erosion of 21.95m/yr and 26.50m/yr were measured during the 1900-1946 and 2001-2012 periods respectively. The natural factors propelling this rapid erosion include the low coastal plain topography, intensive or high wave energy which generates destructive littoral currents; the 'microtidal' and 'mesotidal' nature of the coastline, vulnerable soil conditions; the semi-diurnal tides that set up near-permanent reversible currents which transport sediments away from the coastline at steep angles. Ibe (1988) also identified that anthropogenic activities ranging from harbor protection structures with jetties, beach sand mining and deforestation, all aid coastal erosion. He further stressed that the construction of dams on some rivers prevents the normal delivery of sediment thereby starving the coastal zone of sediment nourishment.

The recent and on-going development of the Eko Atlantic City project on the eastern side aimed at checkmating the erosion problem in Victoria Island appears to have reduced the acute erosion here. The possible factors that may be responsible for this could be the change of wave direction, longshore current, inappropriate coastal defense measures, the impact of large-scale land reclamation on the Atlantic Ocean at the west, and weak environmental safeguards. However, as evident from literature (Watson and Adams, 2011; Obiefuna et al., 2017), hard engineering coastal defense structures tend to deflect erosive action to unprotected areas downdrift of their location. Consequently, increased erosive action has been witnessed in recent years eastwards in the Lekki Peninsula, areas previously known to be either accreting or experiencing minimal erosion (Ibe, 1988). For example, on the eastern side of the coast from Victoria Island going towards Orimedu, erosion rates as high as 26.17m/yr were measured during the 2012-2016 period. This has been somewhat confirmed by the construction of several perpendicular groins downdrift on the Lekki Peninsula since 2013. According to Obiefuna et al. (2017), these newly constructed groins are apparent confirmation of existing serious erosion.

It is important that the nature of the coastal defense measures to be applied should depend very much on the nature of the coast, the processes that determine the nature of that coast and the level of development on it. The tendency is for a nation or state to protect areas with very high economic values as against areas that are sparsely developed. This is what is playing out in Lagos State. It is evident that the intervention measures introduced in Victoria Island were able to slow down erosion in the vicinity. However, on the coast towards Ibeju Lekki LGA, erosional action is still active and unabated. For instance, it was observed that Apese community located close to Victoria Island was submerged by water. The coastal defense measures put in place on the eastern side of the coast along the Eko Atlantic City and the groins constructed off the Lekki Peninsula appear to have wrought some adverse effects downdrift and even within the groins stemming from the coupled destruction of the aesthetic quality of the beaches in this corridor. The steady erosion of the Lagos shoreline portends long-term danger to the teeming inhabitants of this area. The shorelines of Ibeju/Lekki and Eti-Osa Local Councils are fast eroding. Despite this, these councils are parts of the barrier island of Lekki Peninsula that are experiencing rapid development. Within the area are many luxury housing estates, recreational centers and beaches, a proposed seaport and a Free Trade Zone that are all serviced by one single access, the Lekki/Epe Expressway.

5. Conclusion

In furtherance of the understanding of the coastal dynamics along the Lagos coast, this study integrated high-resolution satellite imagery and historical maps to determine the magnitudes of coastal erosion and accretion along the shoreline. The study has demonstrated a simple, stepwise and repeatable approach for monitoring these changes over extensive periods. The results provide a vast knowledge base and spatial information to inform the relevant stakeholders charged with the oversight and management of the coastal resources and infrastructure in Lagos State and Nigeria.

6. Recommendations

The shoreline is a sensitive zone that requires careful and sensitive management. The need to understand the coastal processes at work on the Lagos coast cannot be overemphasized. With the recent developments along the coast, there is the need for intensive and robust investigation of their impacts on the coastal dynamics of the Lagos shoreline. The findings draw attention to the loss of socio-economic livelihoods of the dwellers along this coastal corridor. An example is the Apese community which has been completely uprooted and submerged by water. The government should take urgent steps to protect the coastal communities from annihilation by coastal erosion. Also, since coastal erosion is part of the physical processes inevitable in the barrier-lagoon complex of Lagos regardless of the coastal defenses being put in place, a more holistic plan of action should be taken by the Government in addressing the issue. Understanding the processes will be of immense benefit in the management and development of its coastal environment. Continuous monitoring of the Lagos coast is vital in addressing the issue of coastal erosion and accretion. In the planning of future coastal defense measures by the Government, it is advised that the geomorphology and sediment characteristics of the coast should be considered in determining the nature of the defenses to be emplaced. This will promote an integrated coastal management strategy and not just one influenced by economic benefits.

Continuous monitoring of the Lagos coast is vital in addressing the issue of coastal erosion. The Government should produce a deliberate institutional and funding policy for monitoring of the state's shoreline. The Federal Government should set up a Coastal Management Commission under the Ministry of Environment. This Commission should have the power to implement an integrated coastal management plan for the entire country without delay. The coastal management program should include the following steps: identification of the problems to be addressed; identification of the priorities among these problems; an analysis of specific processes that cause these problems; identification of specific management techniques designed to mitigate these problems; and a set of organizational arrangements and administrative processes for implementing a management program. Also, a vulnerability assessment of some major towns, installations and infrastructure in the country to coastal erosion should be undertaken. Lastly, national cooperation on the issue of coastal erosion should be established. The problems of coastal erosion have no state boundaries. Some response actions applied in one state can trigger off problems in a neighboring state. Cooperation and coordination are vital.

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