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Assessment of Coastline Changes Along Lagos West Mole

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***Abstract*— assessment of coastline changes is crucial to coastal development and management. The Lagos coast is still prone to sediment trap and erosion to date despite the construction of the three moles to solve siltation challenges; moreover, their rates and distributions are yet to be adequately evaluated. This study examines changes along the Lagos West Mole and the possible degree of distributions along the coast between 1984 and 2018 for six epochs. Acquired Landsat imageries were processed to delineate water boundary using Modified NDWI and extract the respective coastlines from the classified waterbodies. Coastline changes were quantified using Digital Shoreline Analysis System (DSAS); the Relative Shannon Entropy (RSE) model was used to measure the degree of concentrations of accretions and/or erosions. Results revealed more profound coastal accretions than erosions; whereas RSE values portrayed dispersed accretions more than erosions. Hence, the outcomes can aid stakeholders' informed decisions concerning coastal protection and management.**

Keywords— accretion, coastline changes, DSAS, erosion, Lagos coast, tidal inlet, sediment siltation, Shannon entropy.

I. INTRODUCTION

Lagos coast is centered on a tidal inlet, which serves as the link between the Lagos Lagoon and South Atlantic Ocean that connects the Lagos Harbour through the Commodore Channel. This channel was observed to be heavily dredged, thus, the quest to protect and stabilize it necessitated the establishment of three moles (the West Mole, the Training Mole, and the East Mole) between 1908 and 1912, in order to guarantee the channel entrance position. Over the years, these anthropogenic actions have been reported to have the most profound effects on the Lagos coast that threaten not only the coast but its immediate environment [2].

Before the construction of the Lagos Harbour moles, there existed active coastal processes that are in a state of dynamic equilibrium between this tidal inlet and its adjoining beaches as well as the natural coastline in. Notwithstanding, there were also complex swell wave actions along the shore, particularly from the south-southwest direction due to exacerbated longshore sediment transport to the east. As a result, there is always an accumulation of an underwater sandbar that prevents easy navigation and access to vessels' entrance to the Lagos Harbour. In addition, aside from the accumulated sandbar, insistent infringement of oncoming waves on the shallow area impedes access to and entry into the Lagos Harbour. Moreover, the dynamic nature of the sandbar's position and depth over time makes navigations to the Lagos Harbour even more challenging than ever before [2, 3]; thereafter, resulting in a measure of uncertainty and fuzziness. It is therefore imperative to find a way of prioritizing the distributions and changing coastlines.

Consequently, after the construction, these moles became an impediment, obstructing the quantities of sediments transported along the west-to-east longshore sediment movement. It was thus noticed that there were dropped in the amount of the longshore current, thus, many materials were not effectively transported and became trapped at the West Mole, causing the Lighthouse Beach to expand to the seaward and the Bar Beach to be eroded; eventually, an ebb-tidal delta ensues and serves as the basis of sediments for the longshore current and the lagoon [2].

An evaluation of the coastline position and the historical changes of the coast over time, is, therefore, an essential issue for coastal management stakeholders in order to address its usefulness in the environmental studies [4-7], and concerning sediment volume and accumulations. Nevertheless, the risks and consequences of developing anthropical structures and coastal features seem very pertinent since two-third of the world's population is concentrated majorly on the coast [4].

Thus, there is always an interaction of gain in sediments (in form of accretion) and their loss (in form of erosion). Since the sediment volume that leads to accretion along the Lagos West mole expansion cannot be negligible compared to the volume of erosion that might be present at the mole; it is, therefore, necessary that studies to account for the coastline changes due to the presence of this mole should vigorously be undertaken to understand the natural processes, such as sea-level rise (S.L.R), changes resulting from storms and climate, intense weather events, as well as increased intensity and frequency of waves on the coastline that eventually serve as the driving forces for coastline change through which rates of coastline changes could be measured in ensuring better coastal management

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strategies.

Previous studies [4, 6-14] have examined several approaches in evaluating coastline changes, and currently, the most often used techniques include: airborne topographic LIDAR data [6] for estimating shoreline geospatial variations; geodetic and GPS (R.T.K) survey; orthorectified process as applied to aerial photography based on Digital Surface Model (DSM) and oblique scan images that are also orthorectified and geo-referenced; airborne videography, wherein qualitative recognition of changes than the quantification are achieved; video systems through which image and/or data with a resolution range from one-hundredth of meters to meters are captured [6, 15]. However, there are observed challenges with the highlighted previous procedures [16-19], such as: the single points data in the case of GPS, their acquisition processes are always costly with lower resolution and restricted spatial coverage; high possibility of mistakes, particularly with orthorectification and georeferencing processes. Moreover, there are other studies that centered on accretion and sedimentation of salt marshes along coasts [13, 20].

Remote sensing techniques have also been portrayed to supersede the others mentioned techniques (Alesheikh *et al.*, 2007; Gens, 2010; [18]; [17]; [19]). It offers improved comparable competitiveness to them, especially concerning high-resolution satellites imageries. It is a faster method when compared to the photogrammetric technique, can capture more geospatial scenes from several spectral bands, providing considerably more information than those obtained from the visible bands, and could generate thematic maps of a region using the multispectral classification of the acquired imageries at different epochs for environmental monitoring studies.

Consequently, a remote sensing technique was adopted in this study; moreover, multi-temporal satellite data were utilized to characterize coastline changes in the West Mole from 1984 to 2018, thus, the rate of coastline change and the defined drivers responsible for coastline accretion and erosion along the Lagos West Mole in that period were assessed.

Furthermore, to evaluate the measure of coastline uncertainty and fuzziness, the concept of Shannon Entropy was employed. It is an effective tool to prioritize the concentration and distribution of occurrences of the sediments transport, and the coastline changes, as there is an observed dearth of researches on this integrated approach adopted in this study to coastline changes; most previous studies are reported to be on the urban environment. The study, therefore, aims at an integrated approach for the evaluation and distribution of accretion and/or erosion along West Mole, using Remote Sensing techniques and the application of the Relative Shannon Entropy (RSE) model.

The remaining part of this manuscript is therefore structured as follows: The materials and methods employed including the study area, and the stages of data collection for coastline delineation, extraction, and application of Shannon entropy model are described in the next section (i.e., section 2). In section 3, the results obtained are presented followed by the discussions in section 4. The conclusion is then provided in section 5.

II. METHOD

A. Study Area

Lagos West Mole (Figure 1) is a breakwater situated at southeast of Tarkwa Bay, close to Commodore Channel, and falls under the barrier-lagoon complex of the Lagos coast. It also depicts the Lagos coast, which comprises of west-east trending barrier islands supported by the Badagry Creek as well as the Lagos and Lekki lagoons. Through the tidal inlet Commodore Channel, the Lagos lagoon gets direct access to the Atlantic Ocean; thus, the Lagos Lagoon's salinity is higher than that of Lekki Lagoon [21, 22]. Table 1 shows the nearby features around Lagos west Mole.

This barrier-lagoon complex is among the four main zones of the Nigerian coast as shown in Figure 2. It encompasses the Lagos coast that is geographically situated between Longitudes 2°41'15" - 4°22' 00" E and Latitudes 6°20' 10" - 6°43' 20" N [22] and consists of several interconnected lagoons, creeks, lakes, rivers, and channels. The other regions are the Mahin transgressive mud coast, the Niger Delta, and the strand coast [23-26].

In 1908 the natural coastal system was affected due to the building of the West mole (Study Area), the East Mole, and the Training mole at the tidal inlet (known as commodore channel today). At the end of the construction, the Lighthouse Beach at updrift of the inlet, has extended about 800 meters over approximately a century due to sediment ensnaring at the West Mole [2].

B. Data Source

Imageries (Table 2) which cover the study area were acquired from the United States Geological Survey (USGS) at 30m spatial resolution respectively for six different epochs and geographically referenced to WGS-1984 / UTM Zone 31N. 1984 coastline was obtained from Landsat 5 thematic imagery; 1999, 2004, and 2009 were obtained from Landsat 7 imageries whereas 2014 and 2018 coastlines were obtained from Landsat 8 imageries. These imageries depend on the availability and level of cloud cover, while the tidal height was not considered; though, it has been established [27, 28] that range of tidal height at the satellite overpass time normally affect the accuracy of extracted coastline position from satellite imageries. Hence it is essential to evaluate the tidal height (h) at the time of image acquisition (t) but the effects of tidal variations on satellite images depend on their spatial resolution. So, the Lagos West Mole coastline was extracted from a 30 m spatial resolution Multispectral Landsat imageries by excluding the effect of the tidal factor but the tidal effects must be taken into account with higher spatial resolution imageries which are comparable to the tide induced errors are being utilised as sources of coastline extraction [11]**.**

Figure. 1. Lagos Coastal areas (source: Mapcarta, 2021)

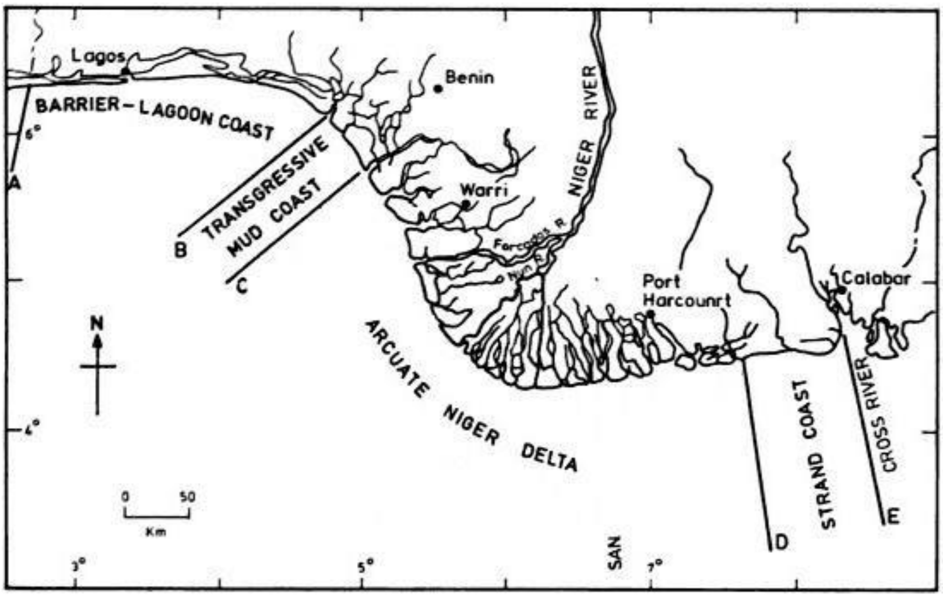

Figure. 2. The four main zones of the Nigerian coast [Ibe (1988b)]

TABLE 1.
LAGOS WEST MOLE NEARBY FEATURES (SOURCE: MINDAT, 2021)

Date of Acquisition	Satellite Data	Sensor	Path/Row	Resolution (m)
Dec. 18, 1984	Landsat – 5	TM	191/055 191/056	30
Nov 18, 1999 Dec. 01/17, 2004 Nov. 29, 2009	Landsat – 7	ETM+	191/055 191/056	30
Dec. 29, 2014 Dec. 16, 2018	Landsat – 8	OLI	191/055 191/056	30

TABLE 2.
CHARACTERISTICS OF THE DATASET USED

Feature	**Type**	**Latitude (N)**	**Longitude (E)**	**Distance (km)**	**Bearing**
Beecroft Point	Point	6° 23' 37"	3° 23' 49"	0.1(0.06 miles)	304.5° (NW)
Tarkwa Bay	Bay	6° 23' 55"	3° 23' 45"	0.7 (0.4 miles)	337.2° (NNW)
Eastern Spit	Shoal(s)	6° 24' 0"	3° 23' 59"	0.8 (0.5 miles)	13.8° (NNE)
Commodore Channel	Navigation channel	6° 24' 0"	3° 23' 59"	0.8 (0.5 miles)	13.8° (NNE)
Lagos Fairway Buoy (historical)	Beacon	6° 23' 13"	3° 24' 21"	1.1 (0.7 miles)	128.2° (SE)
Lagos Roads	Roadstead	6° 22' 54"	3° 24' 36"	1.8 (1.1 miles)	133.8° (SE)
Beecroft Point Lighthouse	Lighthouse	6° 24' 11"	3° 23' 1"	2.0 (1.2 miles)	305.4° (NW)
East Mole (historical)	Breakwater	6° 24' 40"	3° 24' 15"	2.1 (1.3 miles)	17.9° (NNE)
Greslie Point (historical)	Point	6° 24' 43"	3° 24' 17"	2.2 (1.4 miles)	18.8° (NNE)
Bruce Shoals	Shoal(s)	6° 24' 48"	3° 23' 47"	2.3 (1.4 miles)	355.2° (N)

TABLE 3A.
ACCRETIONAL SHORELINE CHANGE IN WEST MOLE OF THE LAGOS COAST

Period	Total No. of Transects	No. of Unstable Transects	No. of Accretional transects:	% of All transects that are accretional	% of All transects that have statistically significant accretion	Max. Value of Accretion (m/yr.)	Avg. of all Accretional rates (m/yr.)
1984 - 1999	15516	15461	15461	100	100	14.02	6.57
1999 - 2004	15542	9542	5543	58.09	58.09	12.11	4.93
2004 - 2009	15542	9769	6203	63.5	63.5	18.37	6.33
2009 -2014	15537	10628	2263	21.29	21.29	24.47	5.22
2014 - 2018	15529	15529	2396	15.43	15.43	11.85	2.42
1984 - 2018	15516	15516	15454	99.6	99.6	5.21	2.3

TABLE 3B.
EROSIONAL SHORELINE CHANGE IN WEST MOLE OF THE LAGOS COAST

Period	Total No. of Transects	No. of Unstable Transects	No. of Erosional Transects	% of All transects that are erosional.	% of All transects that have statistically significant erosion	Max. Value of Erosion (m/yr.)	Avg. of all Erosional rates (m/yr.)
1984 - 1999	15516	15461	0	0.0000	0	----	----
1999 - 2004	15542	9542	3999	41.91	41.91	- 22.45	-5.6
2004 - 2009	15542	9769	3566	36.5	36.5	- 22.79	-5.29
2009 -2014	15537	10628	8365	78.71	78.71	-17.81	-5.73
2014 - 2018	15529	15529	13133	84.57	84.57	-27.42	-5.66
1984 - 2018	15516	15516	62	0.4	0.4	-0.44	-0.21

TABLE 4A.
NUMBER OF TRANSECTS FOR ACCRETION GAIN FOR 2 TIME PERIODS IN EACH ZONE

Period / Zone	1984-1999	1999-2004	2004-2009	2009-2014	2014-2018	1984-2018
Zone 1	3739	1497	1177	913	449	3739
Zone 2	4032	1621	875	839	238	3998
Zone 3	4002	1055	1437	287	317	4029
Zone 4	3688	1370	2714	224	1392	3688

TABLE 4B.
AVERAGE OF ALL ACCRETIONAL RATES (m/yr.) IN EACH ZONE

Period / Zone	1984-1999	1999-2004	2004-2009	2009-2014	2014-2018	1984-2018
Zone 1	7.04	4.15	5.05	5.11	2.34	2.14
Zone 2	6.55	3.80	3.55	5.62	2.17	1.66
Zone 3	5.81	5.82	6.62	3.99	2.18	1.91
Zone 4	6.93	6.42	7.63	5.76	2.54	3.57

C. Image Pre-processing

ENVI 5.3 was used for the pre-processing specifically for noise reduction, atmospheric and radiometric corrections on the metadata file (which encompasses all the multispectral bands for each of the sensors used) to normalize the imageries in order to allow inter-comparison between scenes and to let imageries appear as if they were acquired from the same sensor. Afterwards, all the metadata for each epoch were combined to have a complete composite image file equivalent to the date of acquisition for each of the datasets and later resized to the boundary of the study area.

D. Coastline Delineation and Extraction

Modified Normalised Difference Water Index (MNDWI) was used to segregate the waterbody areas and enhance the differences between them and other non-water features (e.g., Vegetation, Bare Soil and Built-up area); raster-to-vector conversion processes were carried out with the aid of ArcGIS Software to track the generated coastlines from the MNDWI spectral index waterbody binary maps in form of vector files. Additionally, a thorough on-screen visualization, inspection, and correction were applied in order to ascertain the integrity of the extracted coastline results.

This index uses Mid-Infrared and the Green bands (Equation 1) as inputs to the process through which water could be separated from non-water features and efficiently suppresses the noise coming from non-water features such as built-up land, vegetation, and soil from the water information. The calculation of MNDWI results in the positive ratio value of water as a result of being a great absorber of Mid Infrared (MIR) light and negative values to other features.

$$M.N.D.W.I = \frac{\rho GREEN - \rho MIR}{\rho GREEN + \rho MIR} \quad (1)$$

E. Analysis of Coastline with Digital Shoreline Analysis System (DSAS) Software

In this study, time series change statistics for the extracted coastline vector data was deduced using Esri Digital Shoreline Analysis System (D.S.A.S) software in order to assess the coastline change dynamics, and trends, but the calculation was limited to the significant coastline change statistics such as Net Shoreline Movement (NSM) and the End Point Rate (EPR). Meanwhile, through Equation 2, NSM (U_{nm}) in meters is the distance between the oldest (t_o) and the youngest (t_y) coastlines at the points of intersection for each transect of epoch (2 time period) and the overall change within the period of 34-year.

$$U_{nm} = t_o - t_y \quad (2)$$

The E.P.R (U_r), calculated in m/yr according to Equation 3 was computed by dividing NSM (in meter) values by the period (n) elapsed between the oldest and the youngest coastline.

$$U_r = \frac{U_{nm}}{n} \quad (3)$$

The achievable level of accuracy with the Digital shoreline analysis system (D.S.A.S) has proved its potential usefulness in computing long-term coastline change (N.S.M and E.P.R) which ensures assessment of coastline changes due to accretion and/or erosion to be practically viable. The coastline changes at an interval of 5 meters for the west mole were deduced from the DSAS *End Point Rate (E.P.R)* and the followings were derived from Table 3A and Table 3B: Number of transects, Number of erosional transects, Percentage of all erosional transects, Percentage of transects with statistically significant erosion, Maximum value of erosion (m/yr.), Average of all erosional rates (m/yr.), Number of accretional transects, Percentage of all transects that are accretional, Percentage of all transects with statistically significant accretion, Maximum value of accretion (m/yr.), and Average of all accretional rates (m/yr.).

F. Data Preparation for Shannon Entropy Coastline Analysis

The tasks undertaken in this process were carried out in a G.I.S environment and encompass the measurement of rates of accretion and erosion based on the intersection of lines per age of the coastlines involved.

A rectangular polygon (Figure 3) that covers the entire Lagos West Mole coastline was drawn to act as a perimeter in every layer and in form of frames around the bounded area of the coastlines where other successive processes will be carried out.

The rectangular perimeter was then divided into four equal zones/sections, each of the historical coastlines sequentially falls within the zonal border. The number of transects responsible for accretional and/or erosional rates in each zone of the coastline was calculated until all the numbers, and the rates are known for all zones and the result(s) were later used as inputs to the Shannon Entropy model.

During the process, necessary adjustments were made with the enclosing rectangular polygon to have almost equal division of the coastlines, and the number of transects for the accretions and/or erosions in each zone were thereafter used because of their fitness as inputs to measure disorder in the dataset.

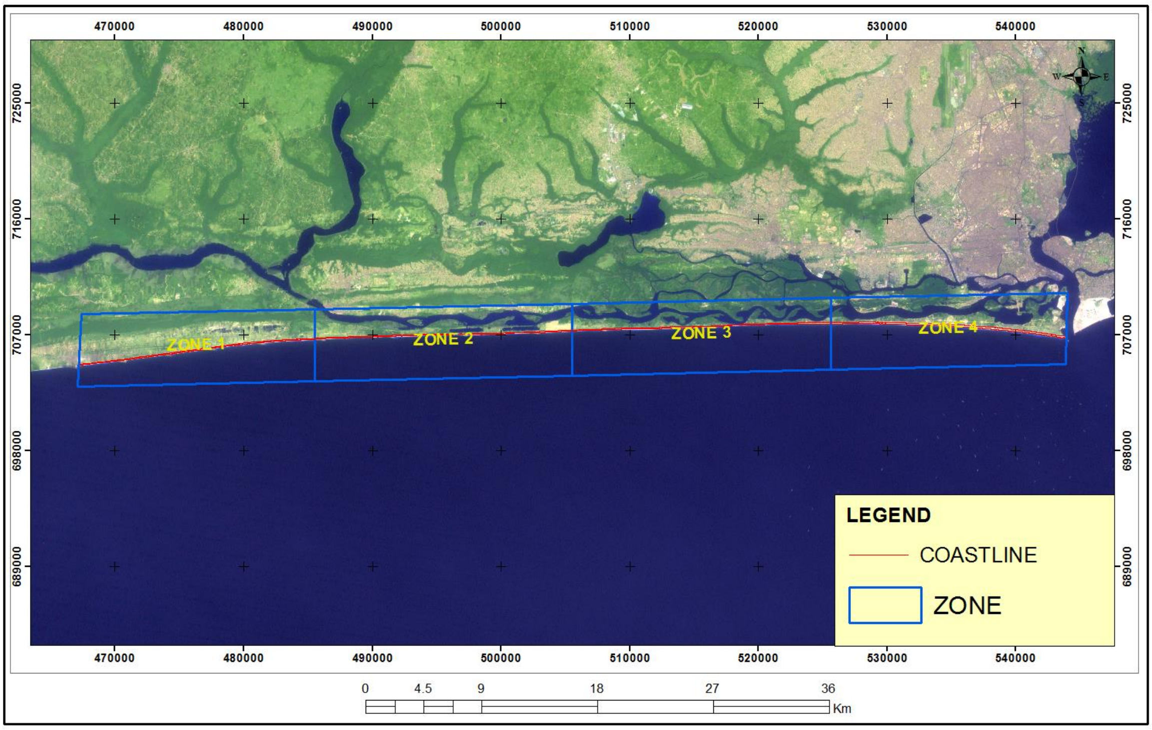

Figure. 3. Rectangular Polygon showing the four zones along West Mole

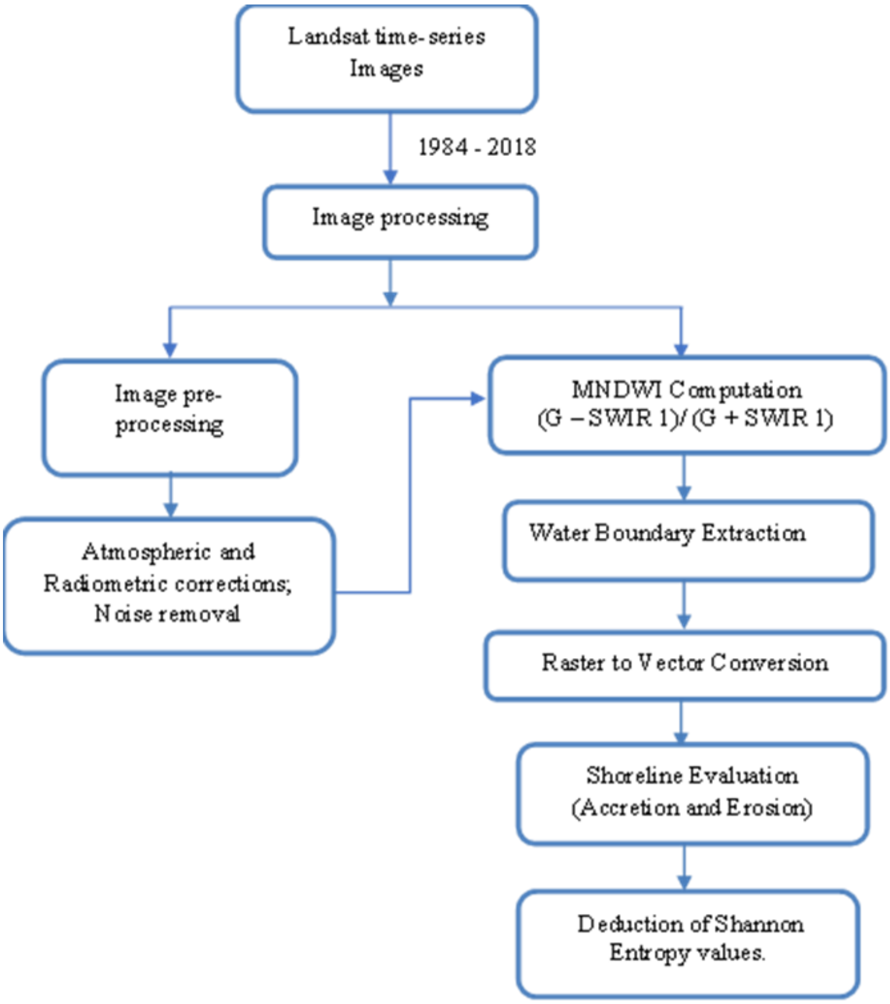

Figure. 4. Flowchart of the methodology

G. *Shannon Entropy Model for 2 time period*

This was used to study the compactness and dispersion of accretions and/or erosions along the Lagos West mole coastline. Shannon entropy was calculated for the study area for each of the two time periods. The Entropy calculations (both the absolute and relative) for these periods [29] are as follow:

$$E_i = -\sum_{j=1}^{n} P_j \ ln\ (P_j) \tag{4}$$

$$E_r = \frac{E_i}{\ln(n)} \tag{5}$$

where $P_j = u_j / \Sigma\, u_j$ is the probability of occurrence of the event (i.e., variable) in the *jth* zone, u_j is the value of the observed variables (transects) in the *jth* zone, and *n* is the total number of zones along the coast = 4. The absolute entropy value ranges from 0 to log (*n*). A zero-entropy value depicts a vast compactness of either the accretion or erosion along the coast while the value near ln (n) denotes enormous dispersion. Relative Entropy (Equation 5) always fluctuates between the values of 0 and 1 and if the transects is centralized in one region, then Equation (5) would give the lowest value of zero. Otherwise, it would return a maximum value of 1 if the distribution was evenly dispersed. Figure 4 shows the flow chart of the methods used in this study.

H. *Shannon Entropy Model for Zones*

Now, to determine the entropy for each zone, Equation (4) has to be reviewed and rewritten as (Equation 6):

$$E_j = -\sum_{i=1}^{m} P_i \ \log_e(P_i) \tag{6}$$

where $P_i = u_i / \Sigma\, u_i$ is the probability of occurrence of the variable in the *ith* row for 2 time periods, u_i is value of the observed variable in the *ith* for 2 time periods, and m = Overall number of 2 time periods = 6.

III. RESULTS AND DISCUSSION

The coastline dynamics were investigated through the respective analyses of individual transects earlier drawn perpendicularly to the baseline. This has been the most extensively used technique in researching and studying the coastline changes and is based on the assumptions [30] that: at every point, the coastline advances or recedes along a major course, which is perpendicular to the coastline's main orientation.

The popularity of the transect approach can be attributed to its computational ease of use. The manual approach was originally conceptualized by [31] and the computation was later automated through measurements along a baseline and the punch cards onto the computer. Consequently, there is gradual automation of most operations and a significant reduction in processing time. Moreover, [32] established a novel approach for defining baselines and transects that significantly enhanced automated components, taking full use of advances in computing.

Table 4A and Table 4B indicate an average of all accretional rates (m/yr.) in each zone for the West Mole as well as many transects for accretion gained at 2 time periods (epochs) while Table 4a and Table 5b also indicate the average of all erosional rates and the number of transects for each zone in the mole. Number of transects in Table 4A and Table 5A was used for the calculation of Shannon Entropy (or information Entropy) as it is the major factor responsible for boundary change over time. Areas or pixel counts (which serve as a major factor when dealing with L.U.L.C image) were not used because (a) the coastlines are not closed, (b) If at all the coastlines are being closed, the area cannot be calculated as a result of stable regions between the two coastlines, (c) Even if the coastlines are managed with stable regions and the calculation carried out, their validation cannot be guaranteed.

It should be noted that, on the one hand, the Shannon Entropy works not only on the number of accretional and/or erosional transects but also on how each number of transects balances with one another in each zone irrespective of the percentage of accretion or erosion. On the other hand, the number of transects for stable regions also have impacts on Shannon results, thus, a region with more stable transects will reduce the number of accretional and/or erosional transects.

In addition, Table 6a and Table 6B show results for the percentage of accretions (see Table 3A for details) and erosions (see Table 3B for details) for each epoch (2 time periods) and the entropies for the two-time period with their ranks in the accretional and erosional areas for the mole. Table 7 shows the Shannon entropy result for different zones for both the accretion and erosional areas.

A. *Coastline Change within the study area, 1984-2018*

The goal of historical coastal displacement analysis is to get a better knowledge of the past so that it can be connected to the present and, if need be, future coastline locations could be predicted. To observe the impact of coastline change, a long and continuous set of data was gathered to derive the coastline from satellite data using M.N.D.W.I spectral index, and the vectorized coastlines were saved as a single shapefile in a Personal Geodatabase, along with the appropriate date i.e., MM/DD/YY. By buffering the nearest coastline (1984) to the onshore, a baseline from which the changes are to be computed was created in another shapefile in the same database. Transects perpendicular to the coast were laid every 5 meters using D.S.A.S along the entire coastline from the baseline. The endpoint rate (EPR) statistical technique was utilized to calculate the coastal change rates. Endpoint rate calculations were estimated using the differences in location between the oldest and most recent coastlines in a dataset.

TABLE 5A.
NUMBER OF TRANSECTS FOR EROSION FOR 2 TIME PERIODS IN EACH ZONE

Period / Zone	1984-1999	1999-2004	2004-2009	2009-2014	2014-2018	1984-2018
Zone 1	0	1134	2012	2529	3290	0
Zone 2	0	1227	1423	1877	3795	35
Zone 3	0	1303	125	2049	3738	27
Zone 4	0	335	6	1910	2310	0

TABLE 5B.
AVERAGE OF ALL EROSIONAL RATES (M/YR.) IN EACH ZONE

Period / Zone	1984-1999	1999-2004	2004-2009	2009-2014	2014-2018	1984-2018
Zone 1	0	-3.79	-5.32	-4.82	-6.01	0
Zone 2	0	-7.39	-5.17	-5.63	-7.46	-0.15
Zone 3	0	-5.41	-5.89	-6.17	-4.94	-0.28
Zone 4	0	-5.93	-5.62	-6.56	-3.34	0

TABLE 6A.
SUMMARY FOR ENTROPY OF DIFFERENT YEARS IN THE WEST MOLE FOR ACCRETIONAL AREAS

Period	% of Accretion (m/yr.)	Absolute Shannon Entropy	Relative Shannon Entropy	Threshold $(1/2\ \ln(n))$	Transect Balancing	Distribution (Disperse)
1984 - 1999	100	1.385508538	0.999433148	0.693147181	5	5
1999 - 2004	58.09	1.374312239	0.991356726	0.693147181	4	4
2004 - 2009	63.5	1.292114915	0.93206389	0.693147181	3	3
2009 -2014	21.29	1.224895274	0.883575169	0.693147181	2	2
2014 - 2018	15.43	1.126291701	0.812447726	0.693147181	1	1
1984 - 2018	99.6	1.385525281	0.999445226	0.693147181	5	5
5 = Very high, 4 = High, 3 = Moderate, 2 = Low, 1 = Very Low						

TABLE 6B.
SUMMARY FOR ENTROPY FOR THE DIFFERENT YEARS IN THE WEST MOLE FOR EROSIONAL AREAS

Period	% of Erosion (m/yr.)	Absolute Shannon Entropy	Relative Shannon Entropy	Threshold	Transect Balancing	Distribution (Disperse)
1984 - 1999	0	0	0	0.693147181		
1999 - 2004	41.91	1.292993137	0.932697393	0.693147181	3	3
2004 - 2009	36.5	0.817712107	0.589854601	0.693147181	2	2
2009 -2014	78.71	1.378785861	0.994583762	0.693147181	5	5
2014 - 2018	84.57	1.368843462	0.987411837	0.693147181	4	4
1984 - 2018	0.4	0.684799264	0.493978251	0.693147181	1	1
5 = Very high, 4 = High, 3 = Moderate, 2 = Low, 1 = Very Low						

TABLE 7.
SHANNON'S ENTROPY FOR DIFFERENT ZONES

ZONE	ZONE 1	ZONE 2	ZONE 3	ZONE 4
Accretion	1.556357546	1.473989034	1.419037996	1.584805876
Erosion	1.321745639	1.299969734	1.098095611	0.909572437
Diff	0.234611907	0.174019301	0.320942385	0.675233439
ln(n)	1.791759469	1.791759469	1.791759469	1.791759469
1/2 ln(n)	0.895879735	0.895879735	0.895879735	0.895879735

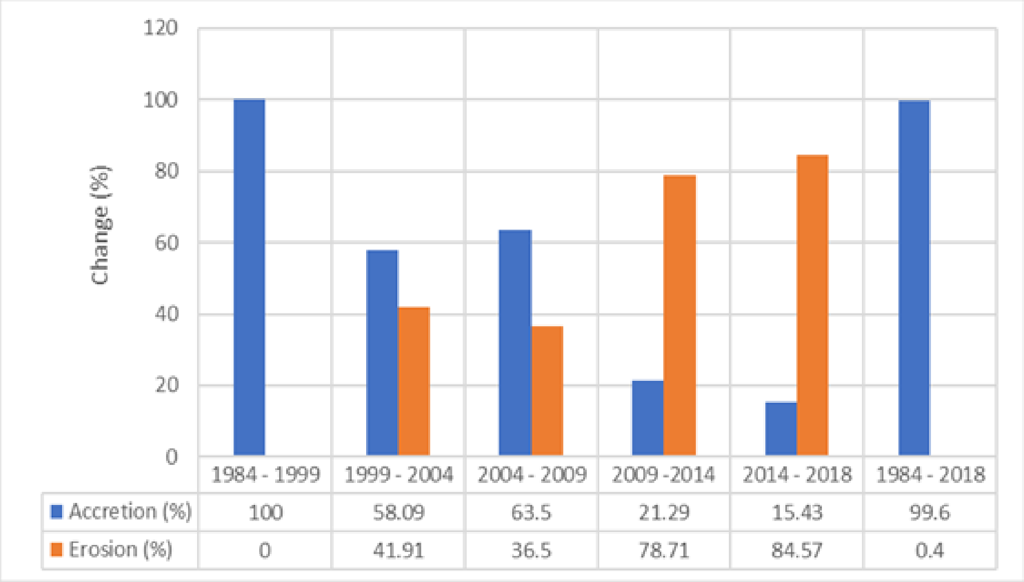

Figure. 5. Coastline changes (in %) for the six epochs

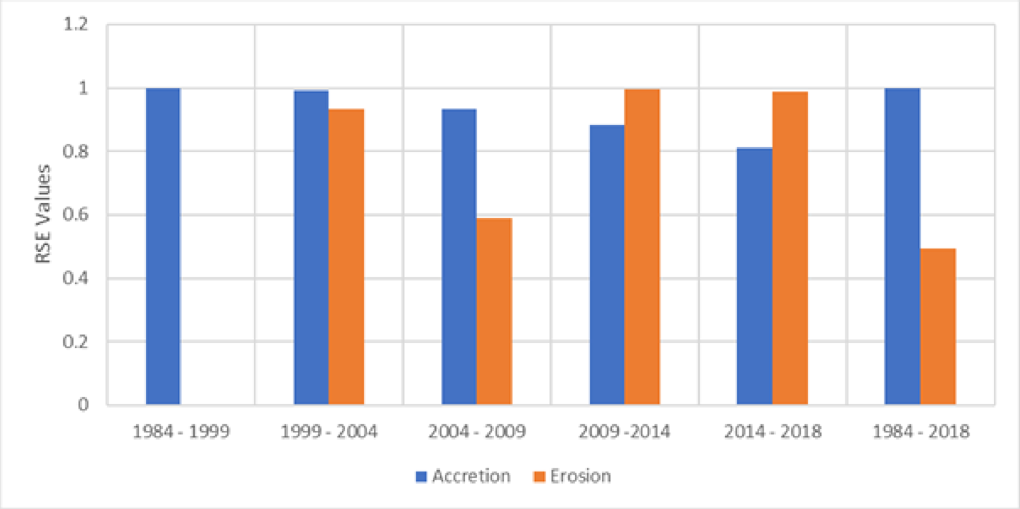

Figure. 6. Relative Shannon Entropy Values for the region

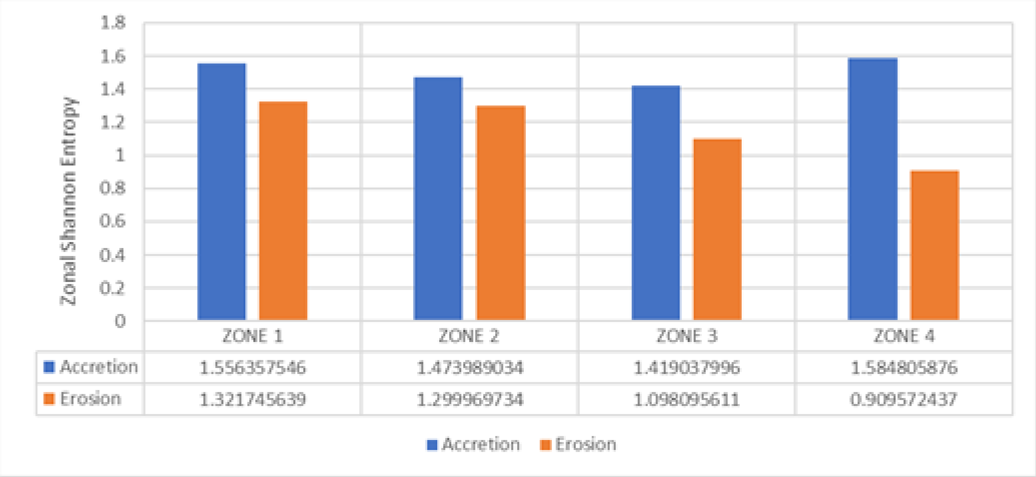

Figure. 7. Shannon's entropy for different zones

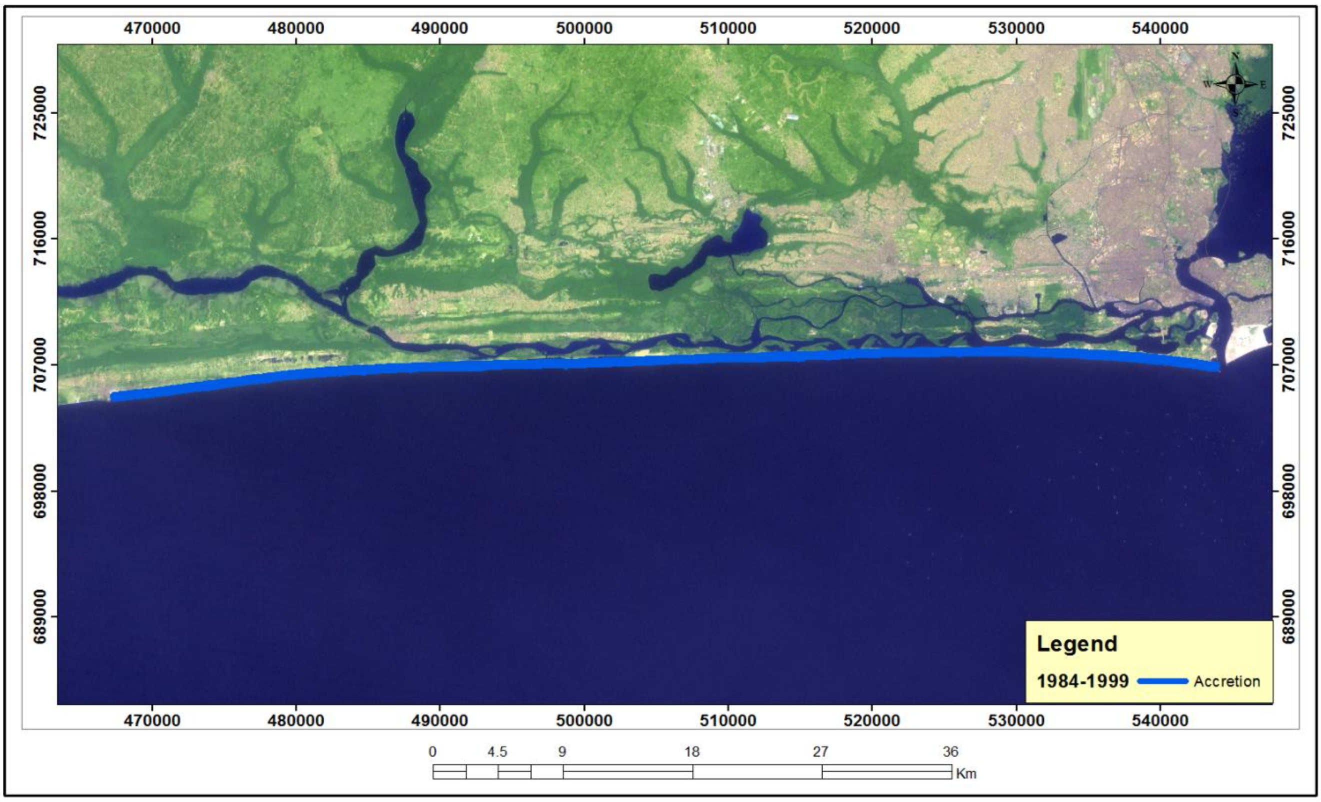

Figure. 8. Changes along the Lagos West mole from 1984-1999

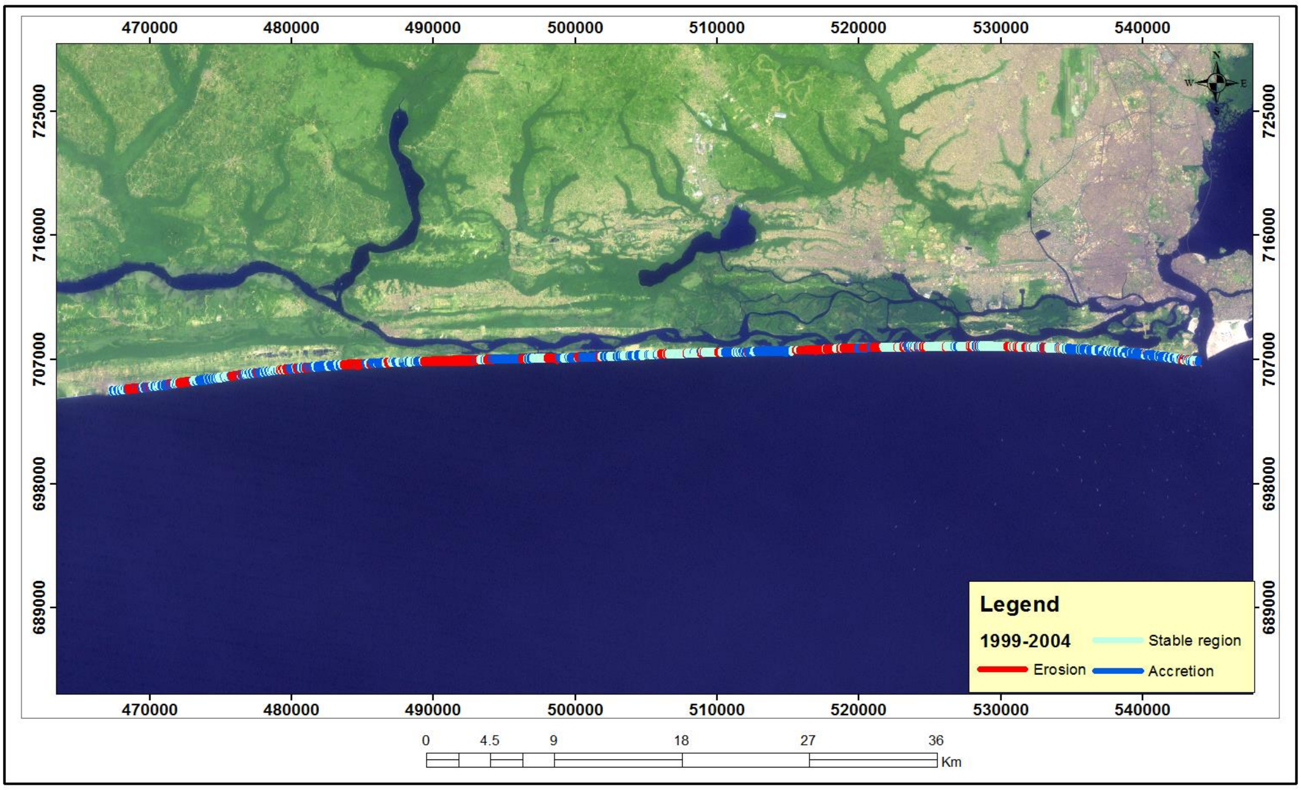

Figure. 9. Changes along the Lagos West mole from 1999-2004

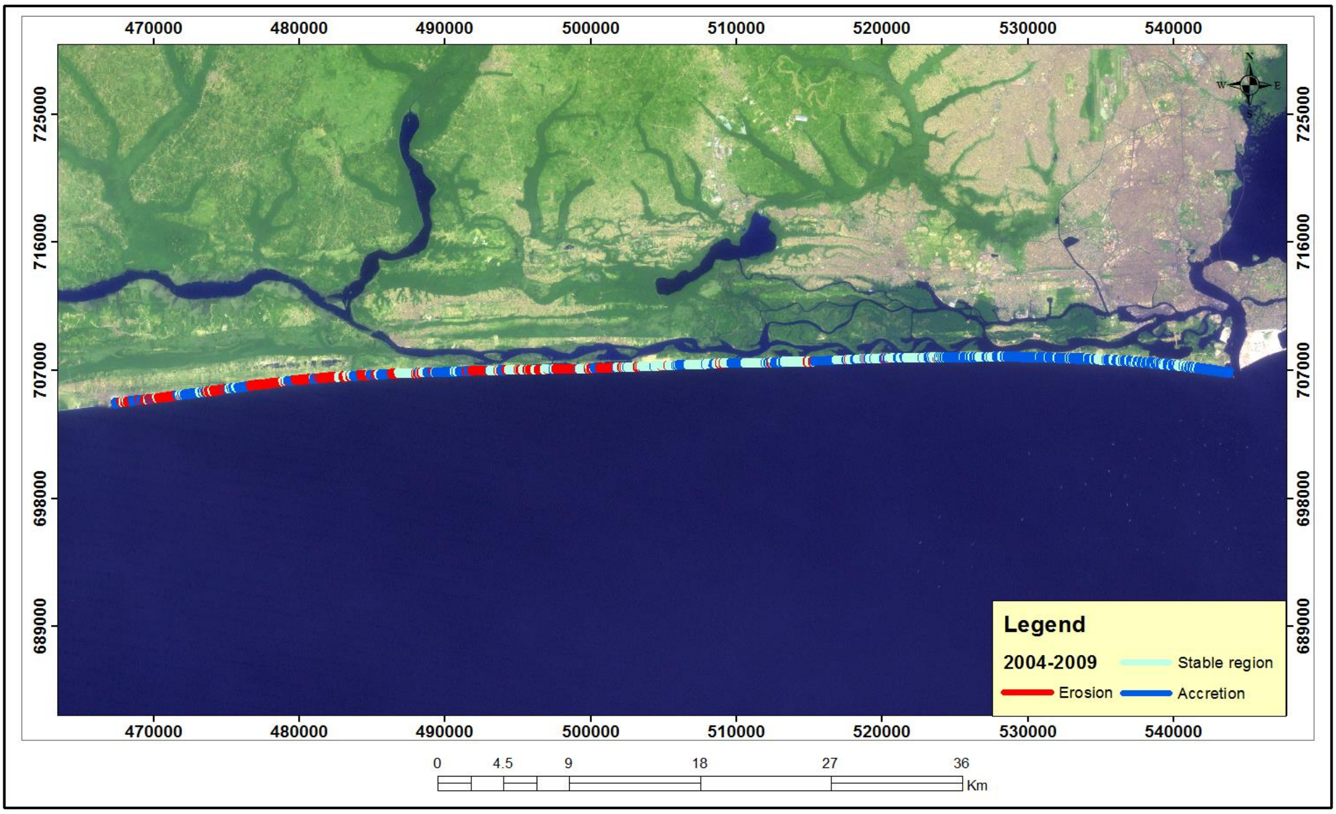

Figure. 10. Changes along the Lagos West mole from 2004-2009

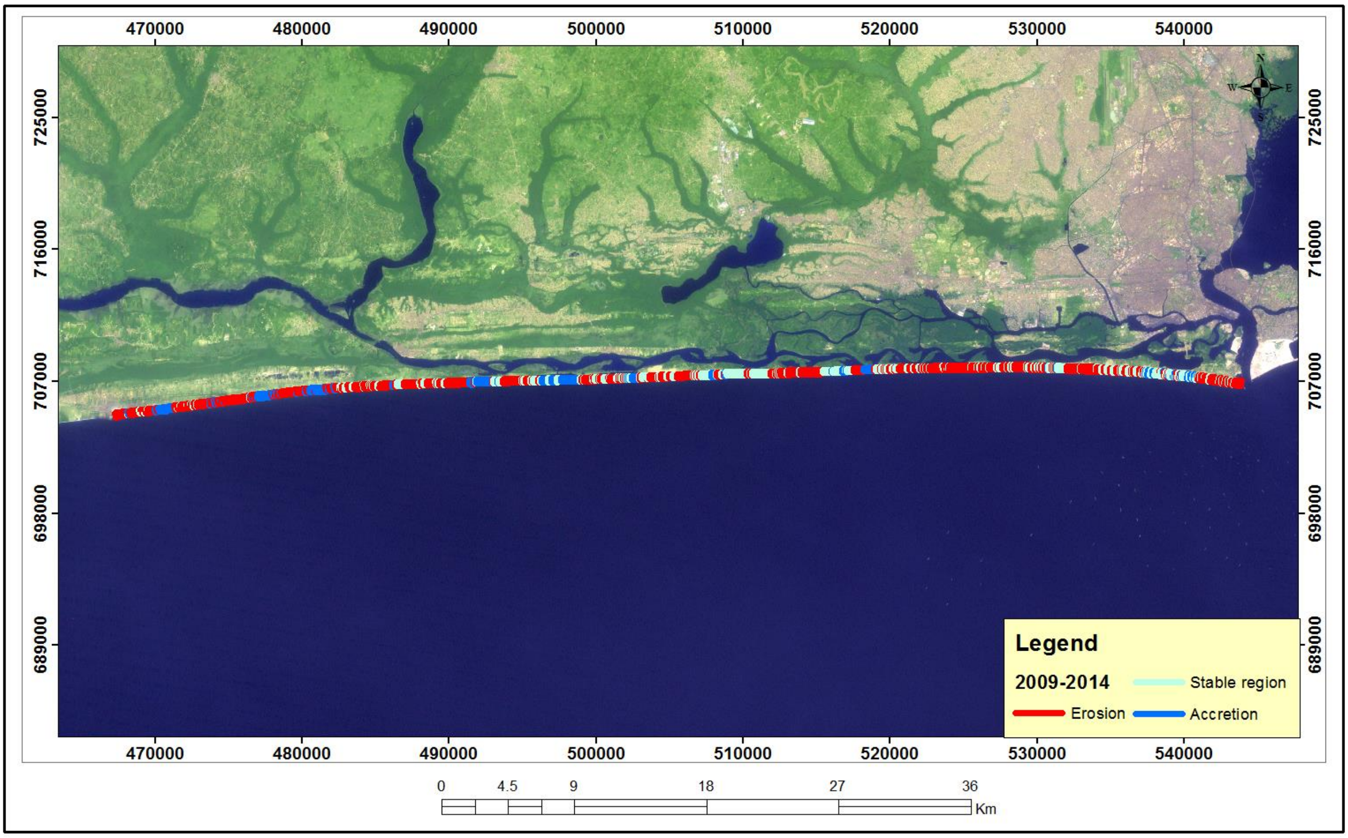

Figure. 11. Changes along the Lagos West mole from 2009-2014

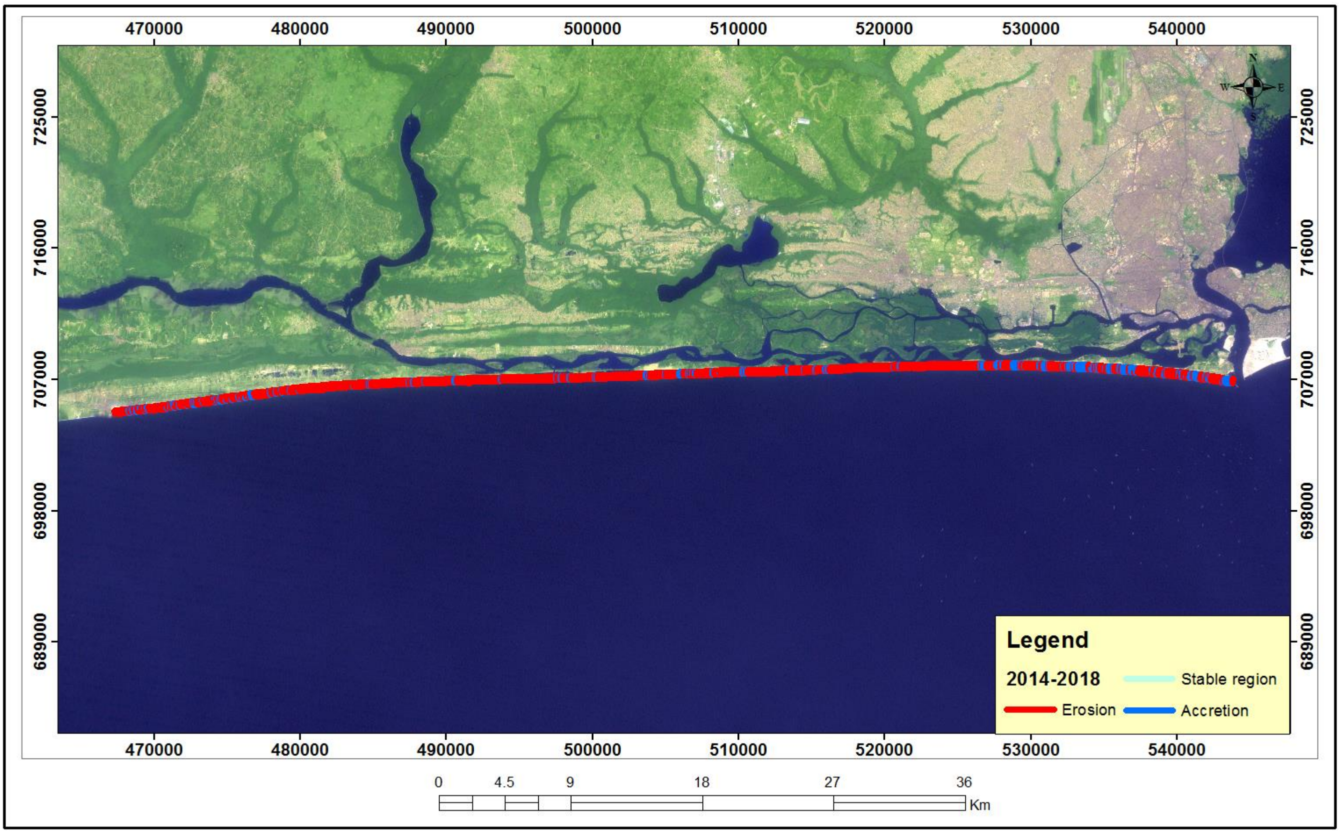

Figure. 12. Changes along the Lagos West mole from 2014-2018

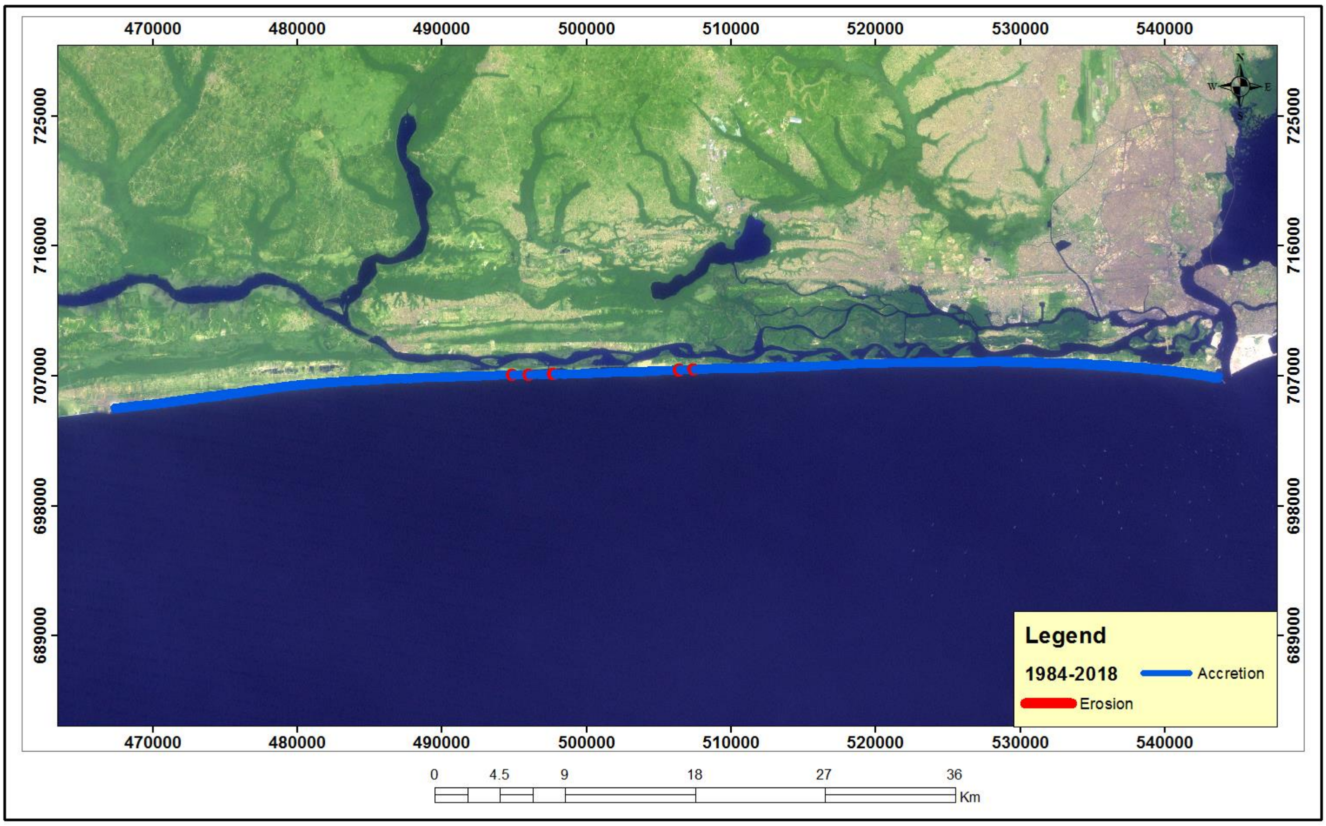

Figure. 13. Changes along the Lagos West mole from 1984-2018

The coastlines studied in this work were for 1984, 1999, 2004, 2009, 2014 and 2018. The statistical analysis with aid of D.S.A.S gave both the positive and negative values as well as zero values. The positive values denote accretions, negative values denote erosions while zero values denote the stable region. Based on the results of the coastline in its entirety, it was observed that where erosion is more significant was due to increase human activities along the coast during the study period. This is also justifiable from previous studies [12, 14, 33]. However, the main accretion tendency may be attributable to sediment deposits [2, 12, 22], while [34] presumed that lower coastal current velocity and relatively shallow near-shore bathymetry may also contributed to such tendency.

From Table 6A and Table 6B, there was no record of erosion occurrence in 1984-1999 (long term) epoch but massive accretion rate. Between 1999-2004 & 2004 – 2009, there were more than average record of accretion but between 2009-2014 & 2014-2018, the rate of accretion was below the average and finally in 1984-2018 (Long term), high rate of accretion occurred. Therefore, it can be concluded from the general trend on the West Mole that accretion is more predominant and very evident, thereby causing sediments accumulation; however, it could be seen that, the erosion was dominated in the periods of 2009-2014 and 2014-2018. Fig. 5 shows the graphical chart of coastline changes in percentage for the six epochs presented in Table 6a and Table 6b. The average and maximum accretion and erosion rates for each epoch that occurred in the West Mole of the Lagos Coast are shown in Table 3A and Table 3B.

B. *Shannon's analysis of the West Mole coastline*

The relative coastal area was equally segmented into different four zones to consider and assess the accretional and/or erosional coastal expansion directions. The Shannon entropy technique was utilized to reveal the configuration and orientation of pattern occurrences and determine the degree of concentration or dispersion of variables (events) over n zones. The lowest value of zero will be attained if the dispersion is mostly concentrated in one zone. Conversely, well-distributed events throughout the zones will have the highest log value (n). The Shannon entropy values were later normalised to have the Relative Shannon entropy values between ranges of 0 and 1. As for the zonal entropy, it should be between 0 and log (m), where m (= 6) is the total number of 2 time periods.

From Table 6A, accretions are well dispersed in the West Mole of the Lagos coastline, however the rate of dispersion keep decreasing among the first five short term period but there were observed changes in the direction at the long-term period 1984-2018 (See Figures 8 to 13 for details).

The outputs of Shannon entropy model depend on how the transects were balanced with each other in each zone but not necessarily on the percentage of accretion gained. However, in some other cases, the epoch (2 time periods) with much percentage of accretion can have lesser value of Shannon Entropy if the transects in each respective zone are not balanced, as exemplified between periods of 1999-2004 and 2004-2009; the latter has higher percentage of accretion yet the value of Shannon Entropy is still less compared to the former.

Summarily, accretions are all spread (disperse) because the values of Shannon entropy are all greater than the threshold. Absolute Shannon entropy (Table 6a) also follow the same pattern with the relative Shannon Entropy. The erosional areas (Table 6B) for the same West Mole took a different direction from accretional areas, erosions in most epochs are also disperse while two of them are compact and minor since they were not greater than the threshold, although, there is no uniformity in their distributions. The epochs with entropy greater than half the threshold show dispersion while the lesser ones show compactness. Figure 6 shows the graphical bar chart for the degree of dispersion and/or the compactness in the region.

From Table 7, the zonal entropy values are above the half-way mark of $\ln(m)$ in all zones for both the accretion and erosions, however Zone 4 has the highest rate of accretions, followed by Zone1, Zone 2 then Zone 3. On the hand, for erosions, Zone 1 has the highest followed by Zone 2, Zone 3 then Zone 4. The difference between the values of accretion and erosions (in Table 7) shows that accretions are more dominated in the Lagos West Mole than the erosion. Figure 7 summarises the zonal distributions and trends for both the accretion and erosion for the number of 2 time period.

Meanwhile, the observed trends in dispersed accretions in the West Mole of the Lagos coastline as depicted in Table 6a, for the first five short term periods and the changes in the direction at for the long-term period between 1984-2018 are presented in Figures 8 to 13 as shown in the appendix.

IV. CONCLUSION

Coastal changes should be seen as major threat to the features along the Lagos coast and adequate survey profiling should be carried out within the region on regular basis. According to the findings of the research, the proficiency of remote sensing in extreme events monitoring by highlighting the trends of coastlines for both the short and long terms has been revealed. The coastline changes along the Lagos West Mole were assessed using Landsat TM, ETM+ and OLI images and Shannon Entropy model. Shannon entropy model is a well-known concept and has the advantage of being easy to calculate, but its originality does not consider the spatial context of distribution. Despite, the results revealed noticeable changes over the 34-year considered in this study. It was observed that accretion is more predominant and uniform than the erosion. Moreover, the integrated approach adopted in this study is unique to the coastline unlike other studies that are peculiar to urban environment.

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Author Contributions

Isa Adekunle Hamid-Mosaku: Supervision, Conceptualization, Methodology, Data analysis, Reviewing, Editing and Coordination of the research. Ibrahim Opeyemi Shittu: Data Curation, Satellite data analysis & Validation, Visualization, Methodology, Manuscript writing, reviewing and editing. Olalekan Abeeb Jimoh: Data Curation, Satellite data analysis and Methodology. Fatai Olatoye Oguntade: Data Curation, Satellite data analysis and Methodology. Rasidat Adekola: Data Curation, analysis and Methodology.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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