Assessing the Spatio-Temporal dynamics of the Shoreline Change Process in Parts of the Lake Chad Environs using Digital Shoreline Analysis System (DSAS)

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Abstract

Lake Chad, classified as one of the world's most important agricultural heritage sites, has over the past years been reported to have seriously shrunken due to several anthropogenic activities and natural factors. This results in serious modifications of its hydrological conditions especially its shorelines and spatial extents. Shoreline change refers to the loss or gain of land area or changes to the landscape at the intersection region of the land and water bodies. Lamentably for Lake Chad there is little or absence of clear identification of areas of greatest shoreline change for prioritizing resource allocation for management and protection solutions. Consequently past regulatory frameworks initiated by respective governments of the countries of Lake Chad have failed to sustainably address the underlying factors and mitigate the effects of these changes. To identify areas of great shoreline changes, this study examined the 1991 - 2021 dynamics of the Lake's Shoreline along the Nigeria boundary using Landsat imageries obtained from the USGS Website and Digital Shoreline Analysis System (DSAS) tools. The findings revealed a total decrease of 13.619 km, and an average annual decrease of 3.405 km in distances, with accretion rates dominating approximately 88.53%, while erosion accounted for 11.47%. Areas of Baga, and Wulgo Mamaduro, are experiencing accretion while Wulgo Mamaduro to Balangua region witnessed the highest erosion rates. These results will help in the identification of vulnerable areas, guide the selection of suitable sites for the establishment of monitoring programs, and for the development of sustainable strategic plans for the lake's shorelines management.

Keywords: Shoreline, Lake Chad, Landsat, Digital Shoreline Analysis System (DSAS)

1.0 Introduction

Lake Chad, classified as one of the world's most important agricultural heritage sites, in the central part of the Sahel region of Africa has been a trading hub offering economic opportunities and resources on which people living around it depend. It serves as a source of water for more than 30 million people living in the four countries (Chad, Cameroon, Niger, and Nigeria) surrounding it (Abdulkadir, et al 2022).

Sadly Lake Chad has, over the past years, been reported to have seriously shrunken (GAO et al. (2011) Yunana et al. (2017), Willibroad Lee, (2019). and FAO, (2021)). The rate of the shrinking of Lake Chad is particularly frightening. FAO (2021) predicted that it may likely disappear this century and considered the situation an "ecological catastrophe. The shrinkage was attributed principally to low inflows, the increased water supply demands due to increased population, agricultural activities, climate change phenomena, and persistent drought, among other factors. According to Gao et al.(2011), it was several anthropogenic activities and natural factors, such as Sediment supply, climate variability, and geomorphological attributes, that exposed the lake to a series .of spatial processes and changes resulting in serious modifications of its hydrological conditions especially its shorelines and spatial extents (Abdulkadir, et-al, 2022).

A shoreline is a spatial entity representing a region where water bodies such as lakes, seas, and oceans meet the land; the boundary between the land surface and water bodies (Armenio, et al. 2019). Shoreline change refers to the loss or gain of land area or changes to the landscape at the intersection of the land and water bodies' boundaries. It is caused by a combination of multiple processes of, erosion, accretion, and sedimentation, patterns of winds, waves, and changes in sea level. The change can be in shape and position over multiple spatial and temporal scales. Boguslav et al (1996) posited that exploration of the spatial process of change and modeling of spatial dynamics are essential for the understanding of geographical systems. It is therefore important to understand the spatial process and dynamics of shorelines.

Reasoning about the spatio-temporal changes of a spatial entity requires the explicit representation of the topological, metrical, and orientation properties and relations of spatial entities and the ways these change over time. Space (separation), is taken to mean a comprehensive set of inter-point separations (distances), defined by travel times between two points for a spatial system but not conforming to a continuous metric in a small number of dimensions. Similarly, Spatio-Temporal is taken to mean a conceptualization of space and time as part of a 3-D or 4-D continuum (Pip Forer, 1998).

Shoreline change analysis is about the study and evaluation of the overtime changes that occur at the shoreline. This entails analysis of the dynamics of the shoreline particularly the process of accretion and erosion and other metrological factors. The importance of proper knowledge of shoreline dynamics, especially along administrative boundaries, is clearly recognized worldwide. Assessment of shoreline change help identifies, the places that are exposed to the consequences resulting from the shoreline dynamics. In order to get meaningful results to mitigate the impact of shoreline changes, its assessment is important to predict the possible damages due to the change earlier and to help provide basis for proper precautions to minimize the impacts. However, relatively very little effort, if any, has been made to bring to fore the shorelines 'state' of Lake Chad along the defined international boundaries of the countries surrounding it.

Past regulatory framework initiated by the respective governments of the countries of Lake Chad has failed to sustainably addressed the underlying factors and mitigate the effects of the spatial changes of the Lake. There is an absence of clear identification and recognition of areas of greatest change for prioritizing resource allocation to provide optimal management and protection solutions, especially as affects the changes in the lake's shoreline areas (Abdulkadir, et-al 2022).

Shorelines are ambulatory in nature, they move with time. Their boundaries position are only the boundaries position on the date of the survey. These migration and mobility behaviors of shoreline are defined by occupation of a set of locations in some temporal sequence which can be recognized by keeping track of the locations of the shoreline overtime. Therefore understanding the shoreline changes is essential for optimal shoreline management and protection solutions, and for planning sustainable management strategies in any specifically desired area. It is important to monitor and analyze the shoreline "state" which is its trend at a location regularly, so that the overtime shoreline positions could be track and for useful decision-making purposes (Abdulkadir, et-al 2022). A spatial and temporal framework is therefore a prerequisite for analyzing shoreline migration and mobility behaviors as well as its sustainable management

For confident decision-making on sustainable mitigation measures, it is crucial to provide updated and accessible information on the extent and trends of shoreline dynamics. Hence, studying the Lake Chad shoreline dynamics, particularly along the Nigerian border, where there is a near absence of such data, is of utmost importance. Studies of the trends and extents of Lake Chad, shoreline changes particularly on parts of the Nigerian border side of the lake are rare or limited as few literature exists about it.

Overtime many methods and approaches have been developed and applied for change detection, monitoring, and estimating of shoreline change. The labor-intensive conventional terrestrial surveys methods are now giving way to Remote Sensing and GIS technology approaches. These approaches have low-cost, real-time, macroscopic, fast and relatively efficient characteristics that enables monitoring surface changes. They are now being used to extract, and monitor water body and its dynamics with reasonable accuracy and with little manpower involvements (Tamassoki et al, 2014; Shenbagaraj et al, 2018; Salghuna and Bharathvaj, 2015).

Shoreline change analysis can be carried out using Multi-spectral Landsat imageries and Digital Shoreline Analysis System (DSAS). DSAS isan extension tool for Esri ArcGIS desktop software, developed by USGS. It is one of the current software application being used for examining past or present shoreline positions. It is simple and have user-friendly interface with GIS software. The DSAS tools enables the computation of the rate-of-change statistics for a time series of shoreline position and the shoreline retreat changes in given area of stud. It is used to quantify erosion and accretion rates, and in identifying vulnerable areas.

In the use of satellite imageries for shoreline change detection over a period of time, change is represented not by the process but by images of the result of the process overtime. The overtime satellite images of a location represent a series of images which gives the illusion of temporal movement or state changes in the location. In effect one is dealing with entity or phenomena's state changes. To investigate a time between two known or estimated states, one has to start the interpretation process again with the aim of defining a new state. The time intervals between the images studied play an important role in detecting and quantifying the nature and timing of changes associated with anthropogenic impacts by better identifying the timing of major changes and by reconstituting baselines (Abdulkadir, et al, 2022).

This paper aim at assessing the spatio-temporal dynamics of Lake Chad shorelines using DSAS tools. A short term data (1991-2021) was used to examine the physical indicators of the natural dynamics of Lake Chad's shorelines along the Nigeria side of the Lake. The objective is to demarcate and analyze the lake's shorelines dynamics of ten year interval study epochs (1991, 2001, 2011, and 2021) using selected freely available Landsat satellite Imageries obtained from USGS website. The digitized 1991 shoreline served as the baseline year of the study. The shoreline movement or the silting of the lake are not modelled as process but rather as estimates of how far it has got at the particular epoch.

It is hoped that the study will help in identifying the vulnerable areas along the lake's shorelines and contribute to the development of sustainable strategic plans for effective measures against undesirable effects of the identified changes. It is also hoped that the study will provide a guide for the selection of suitable sites for the establishment of monitoring programs to track changes as well as serve as an addition to the existing literature on Lake Chad.

2.0 Study Area

Lake Chad lies between Latitude 12^0 30' N and 14^o 30' N of the equator and Longitude 13^0 00'E and 16^o 00'E of the Greenwich Meridian. The Lake is bounded to the North by Chad Republic, East by Cameroon, South by Nigeria and West by Niger. The Basin of the Lake, spreads over seven countries namely; Nigeria, Niger, Chad, Cameroon, Libya, Sudan, Algeria and Central Africa Republic. About 20% of the total area of the basin (427,500 km^2) is called the Conventional Basin of Lake Chad (42% in Chad, 28% in Niger, 21% in Nigeria and 9% Cameroon).

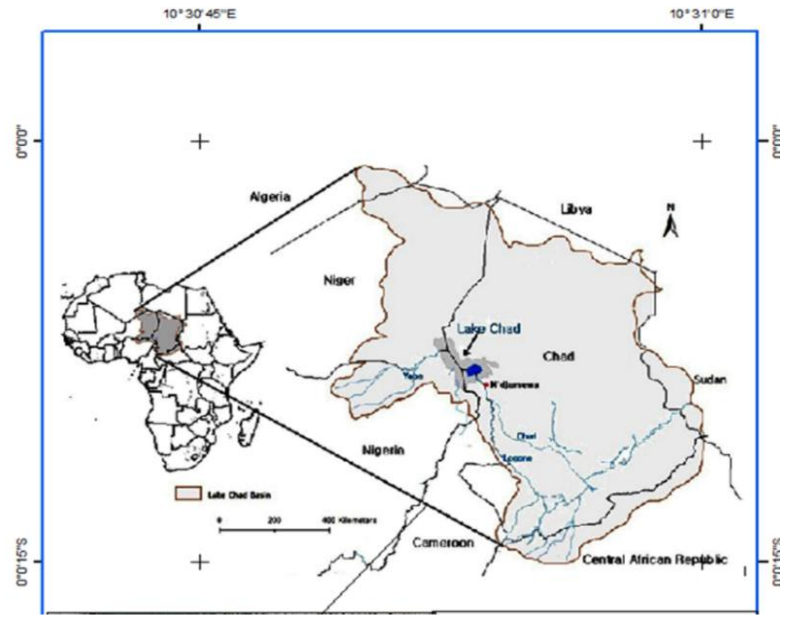


Figure 1. Study Area (Source: Abdulkadir et al, 2022)

2.1 Hydrology

Lake Chad is a closed drainage system located in the Central Sahel region of Africa. It is characterized by a south-to-north climatic gradient consequence of latitudinal decreasing rainfall (UNEP, 2008). The lake was categorized as one of the largest lakes in Africa. It is part of the interior basin which used to be occupied by a much larger ancient body of water called Mega Chad. The lake's surface area varies by season as well as from year to year. The major rivers are Chari River, fed by its tributary, the Logon. The northern half of the basin is now part of the Sahara desert, containing the Ténéré Desert, Erg of Bilma, and Djurab Desert. South of that is the Sahel zone, dry savanna, and thorny shrub savanna. The main rivers include riparian forests, flooding savannas, and wetland areas. The Lake is very shallow. It is only about 10.5 Meters at its deepest area. The shorelines are largely composed of marshes (Drake and Bristow, 2006).

According to LCDAP, (2015), despite high levels of evaporation rate standing at 220 to 230 cm/year, the lake is fresh water. Over half of the lake's area is taken up by its many small islands (including the Bogomerom Archipelago), reed beds, and mud banks, and a belt of swampland across the middle divides the northern and southern halves.

2.2 Vegetation

The dominant vegetation type around the lake is Sahelian savannah. This ecosystem is characterized by drought-resistant grasses and scattered acacia trees. These species have adapted to the region's hot, dry climate with limited rainfall. In areas with slightly better drainage and some water retention, seasonal wetlands thrived. These wetlands, teeming with reeds (Phragmites spp.) and papyrus (Cyperus papyrus), provided crucial habitat for birds and fish (FAO, 2021).

However, the receding of the lake has led to the ruin and loss of the once-extensive vegetation types. The exposed lakebed is vulnerable to desertification, with sand dunes encroaching, Seasonal wetlands have shrunk considerably, disrupting the delicate ecological equilibrium of the region. The reduction in flooded forests, dominated by species like Mitracarpus scaber and Vossia cuspidata, has not only impacted biodiversity but also diminished the vital role these forests played in filtering water and mitigating floods (LCBC, 2015).

2.3 Climate

The Lake Chad climate is dry most of the year, with moderate rainfall from June through September (LCBC, 2015). Climate in the Lake Chad drainage basin is semiarid in the south and arid in the north (Global Water Partnership (GWP). 2011). The Rainfall varies widely from year to year. The amount of annual rainfall is very low in the north of the basin, rising to 1,200 millimeters (47 in) in the south (LCBC, 2013). The annual average rainfall over the entire basin is 320 mm. It varies between 1.00 mm and 500 mm in the southern parts of the region and less than 100 mm in the northern parts of Chad.

The annual maximum temperatures are as high as 35-40°C, particularly in the northern parts of the region. The average temperature of the Lake is 21.4° C annually. Lake Chad is under the influence of the Inter-Tropical Convergence Zone (ITCZ) oscillates, seasonally between about 15°N and 15°S. In the north of the ITCZ, high-pressure air from the Sahara Desert suppresses rainfall. Low rainfall is followed by excessively high temperatures in all arid lands (LCBC, 2015). The relative humidity of the Lake is 700mm to 900mm approximately, and it influences rainfall patterns have a significant effect on the erosion and accretion process of shoreline dynamics.

2.4 Population

The population density around Lake Chad is unevenly distributed, with higher concentrations of people living in urban centers and along the shores of the lake where access to water and livelihood opportunities are available (UNEP, 2016). The major countries bordering Lake Chad, including Nigeria, Niger, Chad, and Cameroon, all have significant populations residing in the basin area. According to recent estimates, the population of the Lake Chad Basin region is approximately 50 million people (UNFPA, 2017). The average population growth rate was pegged at 2.4%-2.6% the population projection in 2023 was 57 million. However, it's important to note that this Figure can vary depending on the source and the specific area being considered within the basin.

The population around Lake Chad is predominantly engaged in agriculture, fishing, and pastoralism, with many communities relying on the lake for their livelihoods (UNEP, 2016). However, the region faces numerous challenges, including water scarcity, desertification, and conflicts over dwindling resources, which have led to population displacement and migration to urban areas.The ongoing humanitarian crisis in the Lake Chad Basin, fueled by the activities of insurgent groups such as Boko Haram, has further exacerbated the challenges faced by the population in the region (UNFPA, 2017). Displacement, food insecurity, and limited access to basic services have had a profound impact on the lives of millions of people living around Lake Chad.

3.0 Materials and Method

3.1 Materials

The materials used include: the freely available satellite images dataset (Landsat 4, 5, 7 ETM+ and Landsat 8 OLI) imageries respectively of the study area downloaded from the United States Geological Survey (USGS) via its website (http://earthexplorer.usgs.gov/). Table 1 is the descriptions of attributes of these satellite imagery. It comprises of Data type, Date, Data Sources, Resolution, and Path Row.

The images have a temporal (December /January) coverage of three decades, from 1991-2021 and are of the same seasons (Dry season).

The Nigeria Topographical Sheets Monguno 46 N.E, Chad-Baga S.E 25, Chad Wulgo S.W 49 and Ngala NE 69 Respectively at scale 1:10000 and administrative map covering Nigeria border collected from Yobe State Geographic Information Service (YOGIS) were used for reference

Table 1: Type and Sources of Data.

S/N	Data Type	Date	Data Sources	Resolution	Path/Row
1	Landsat 4	Dec/1991	USGS	30 M	185 / 51
2	Landsat 7 ETM	Dec/2001	USGS	30 M	185 / 51
3	Landsat 7 ETM	Dec/2011	USGS	30 M	185 / 51
4	Landsat 8 OLI	Jan/2021	USGS	30 M	185 / 51

Source: USGS (20083.3.2

Software used

The software used in the research include, ArcGIS 10.6.1 with DSAS ad-in, QGIS 3.14., ENVI 5.1.And Microsoft office.

3.2 Method

The workflow diagram is shown in Figure 2

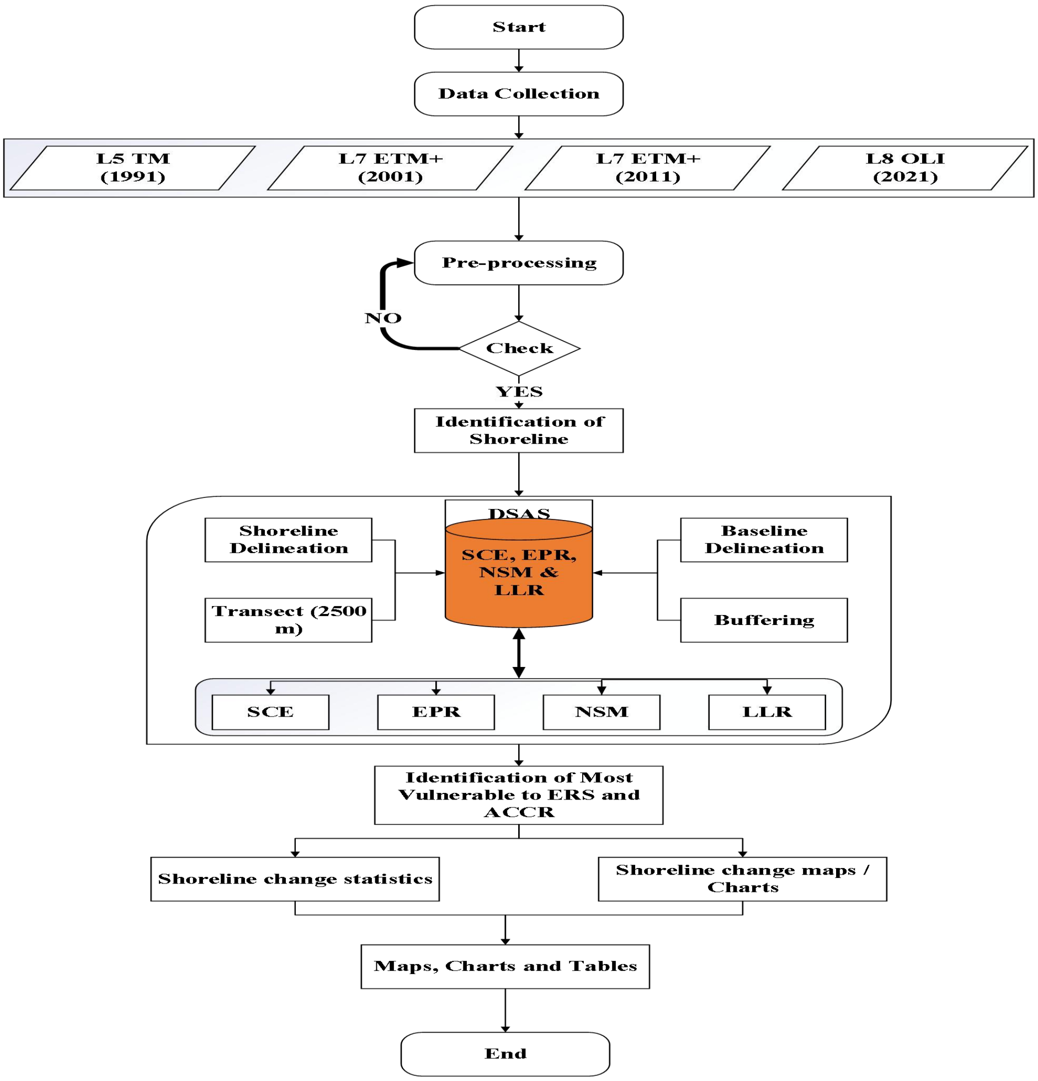


Figure 2: Workflow diagram

The location of the shoreline of 1991, 2001, 2011 and 2021 were determined through the following process Data collection, Image Processing, Layer stacking, shoreline digitization, baseline extraction respectively.

The Satellite datasets were downloaded from USGS website using earth explorer. Path 185 and row 51 were specifically used. The images with cloud cover of less than 10% were selected Landsat 7 ETM images of 2011 covering the study area were found to have scan line error. QGIS was used to fix the error by Gap mask which was extracted from the metadata files of the satellite imagery. The fill-no-data tool was selected for scan line correction.

ENVI 5.1 was used to perform a radiometric correction, atmospheric correction conversion of Digital Number (DN) to Top of Atmosphere (TOA) reflectance. The calibrations and corrections were automatically carried out by the software. The Dark Subtraction atmospheric correction method was applied to all the datasets to retrieve surface reflectance data. This atmospheric correction method is preferred for satellite images containing large water surfaces because it corrects atmospheric errors due to water vapor and dust particles suspended in the atmosphere that badly affect data.

The QGIS 3.14.15 layers stacking module was used to form false color composites Table 2 depicts the band combination used. The band was imported to the QGIS environment and select the combination for processing the output.

Table 2: Landsat Band Combination Used

S/N	Landsat	Band Combination
1	Landsat 4	3 ,2, 1
2	Landsat 7	3, 2, 1
3	Landsat 8 OLI	6, 5, 4

Source: USGS (2008)

The shorelines of the lake on in the selected satellite imageries were digitized. The digitized shoreline data were placed in a single feature class within a personalized geo-database. Each shoreline vector represents a specific position in time and was assigned a date in the shoreline feature-class attribute table.

ArcGIS 10.6.1 was used to digitize and create Shape files for the year 1991, 2001, 2011 and 2021 respectively. The shape files were saved in singe geo-database with its attribute as designed by DSAS Add-in.

The 1991 shoreline was selected as the baseline year for the determination of the shoreline changes over the study period. Baseline is a horizontal line that is manually drawn and edited using the standard ArcGIS editing tool. It is used in casting transects and change rate calculation. The distances from the baseline to each intersection point along transect were used for statistical computation.

Shoreline Delineation were done in ArcGIS environment to determine the location of all epoch from 1991 to 2021 at intervals of ten years. Transects were generated by the digital shoreline analysis system (DSAS) using the baseline and shoreline position. The transects intersect each shoreline to create a measurement point, these measurement points were used to calculate shoreline change rates in this study, transect was set at 5 Km from baseline and spacing of 250m to compute rate of shoreline dynamics.,

The requirement needed for shoreline dynamic statistics computations was selected based on the criteria of the DSAS add-in extension. The extent and trends of the shoreline dynamic were analyzed in stages. The rate of shoreline dynamics was calculated from the transect feature created and all updates, edits, and modifications have been made, the transect data was used to compute change statistics. For the purpose of this study, over 250 transects spacing are laid at baseline of 5km interval along the shoreline position.

The change statistics considered were Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR) The Shoreline

Change Envelope (SCE) the units are in meters. The graphical representation of shoreline dynamic was done in MATLAB

To identify the areas that are vulnerable to accretion and erosion, the data used for this study were visualized from computed rate of Statistics in digital shoreline analysis system (DSAS), ArcGIS desktop was used to Georeference the administrative map and Topographical Sheet of the study area to help in extracting the settlements within the shoreline proximity in order to identify the areas

4.0 RESULTS AND DISCUSSION

Image pre-processing covers scan line error correction, atmospheric correction, radiometric correction, dark object subtraction and image enhancement. The results obtained are as shown in Figure 3a, and Figure 3b, for scan line error correction. Figure 4, the respective 1991, 2001, 2011 &2021 Classified Landsat images of Lake Chad.

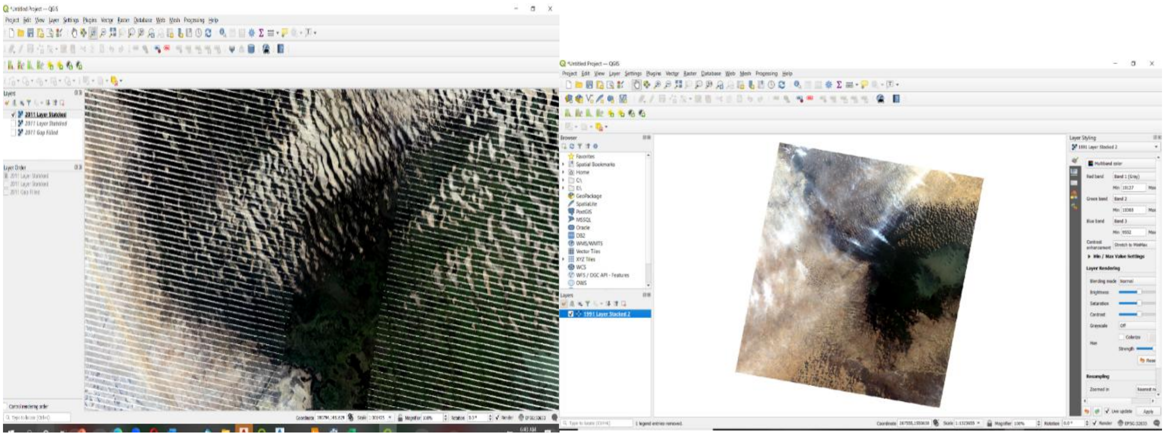


Figure 3a: Scan Line error of Landsat Image 2011. Figure3b: Scan Line error correction

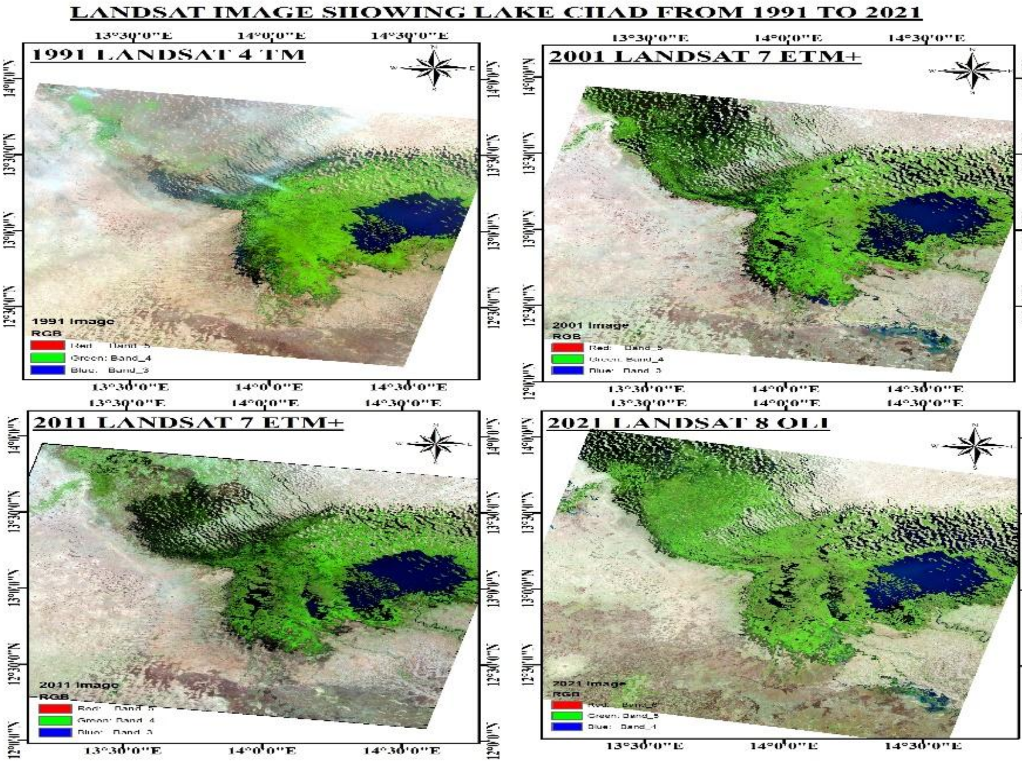
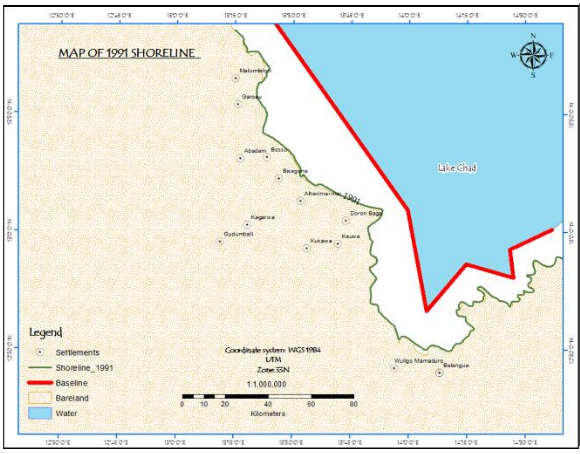


Figure 4 1991, 2001, 2011 &2021 Classified Landsat images of Lake Chad

Figures 5, 6, 7, and 8 are maps showing the shoreline location with baseline for each of the four study epoch (1991, 2001, 2011 and 2021) respectively.



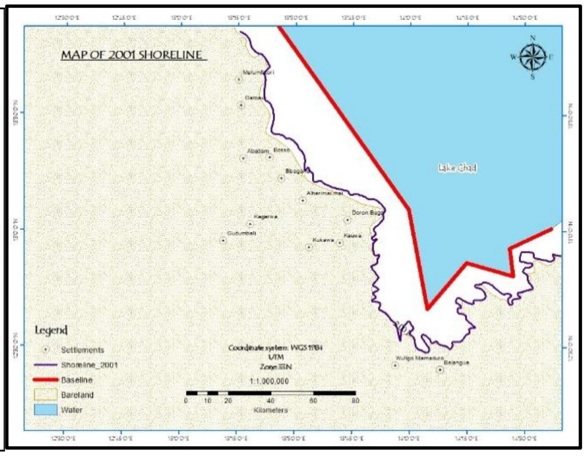


Figure 5: Location of Shoreline in 1991F figure6: Location of Shoreline in *2001*

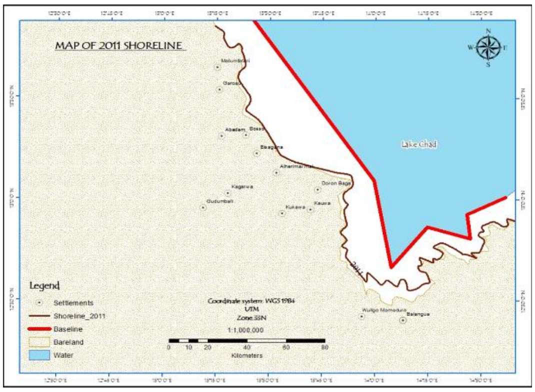


Figure 7: Location of Shoreline in 2011 **Figure 18: Location of Shoreline in 2021**

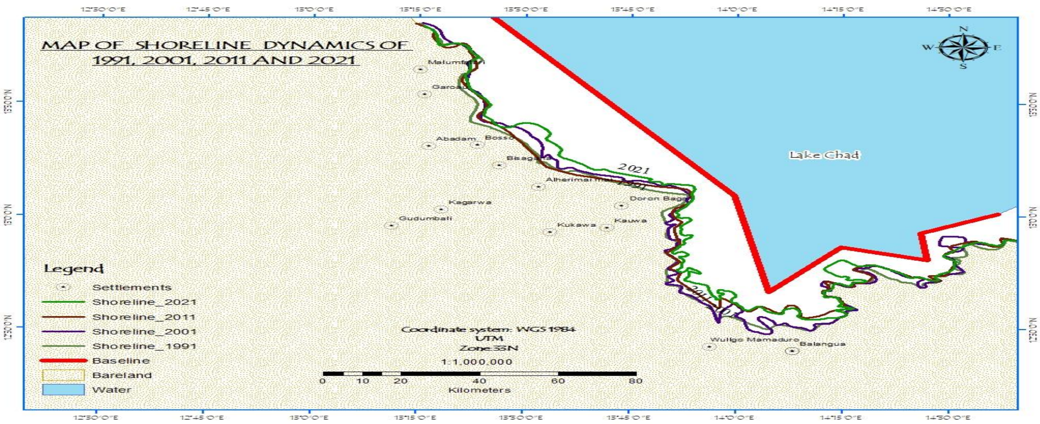


Figure 9: Shoreline Dynamic Map of 1991, 2001, 2011 and 2021:

5.0 Analysis of the extents and trends of the shoreline dynamic

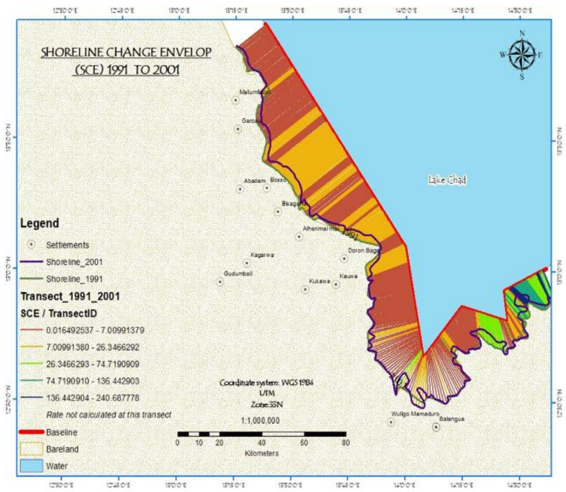
The analysis of a variation in accretion and erosion as means to identify relative change in shoreline over a certain period has been a subject considered by many researchers (Baral, Pradhan, Samal and Mishra (2018),Kuleli , Guneroglu , Karsli , Dihkan (2011),Dereli and Tercan (2020) etc.) using different approaches. In this study the Analysis of the extents and trends of the shoreline dynamic of the Lake Chad was carried out using DSAS. These covered, Shoreline Change Envelop (SCE,) Net Shoreline Movement (NSM), End Point Rate (EPR) from 1991-2001, 1991-2011 and 1991-2021

5.1 Shoreline Change Envelop SCE

Shoreline Change Envelop (SCE) denotes the range of shoreline changes observed during the study period. It measures the total change of shoreline movement in terms of eroded or accreted distances.Table is the summary of the numerical values of the SCE Report (1991-2001, 1991-2011, and 1991-2021). Figure10 and Figure 11 are maps showing the graphical representation the shoreline change envelope for 1991 to 2001 and 1991-2021 respectively.

Table 3 Shoreline Change Envelop (SCE)Report (1991-2001, 1991-2011, and 1991-2021)

Year	Av. Dist. (m)	Max. Dist. (m)	Min. Dist.(m)	No. Transect	Acr (%)	Ers (%)
1991-2001	1838.99	8144.48	*2.21*	*994*	*86.02*	*13.98*
1991-2011	2021.91	12713.19	*1.15*	*998*	*79.16*	*20.84*
1991-2021	3511.16	11482.04	*1.98*	*990*	*91.72*	*8.28*



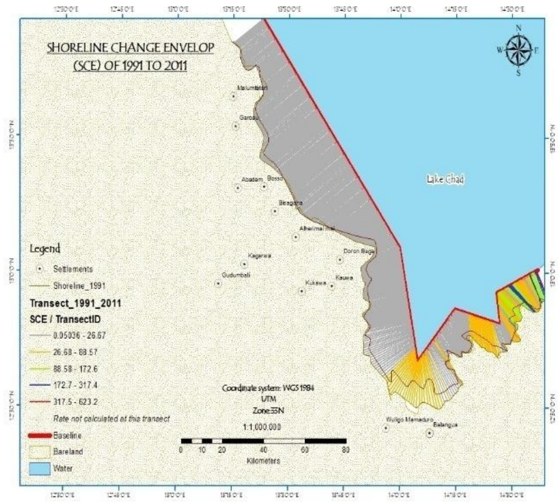


Figure 10: SCE Map 1991 to 2001 Figure 11: SCE Map of 1991 to 2011.

Table 4: Overall Shoreline Dynamic SCE (1991, 2001, 2011, and 2021)

Year	Average Dist. (m)	Max. Dist.(m)	Min. Dist.(m)	No. of Transects	(Acr) %	(Ers) %
1991-2001-2011-2021	4055.69	12713.19	289.28	499	88.53	11.47

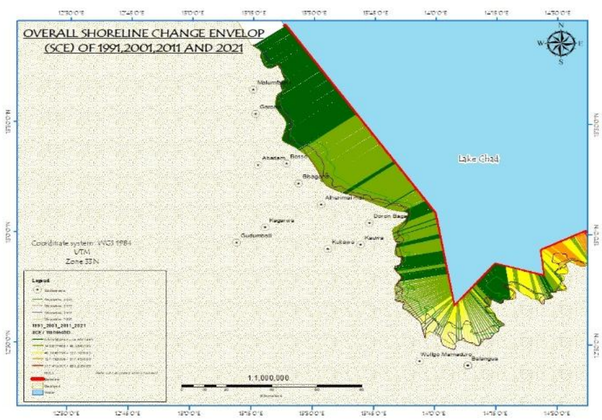


Figure 12: Overall SCE of 1991 to 2021

From 1991-2021 (Table 4) the SCE results shows average distance of 3511.16 m, maximum distance: 11482.04 m, minimum distance: 1.98 m.

5.2 Net Shoreline Movement (NSM)

Net Shoreline Movement (NSM) indicates how much has the shoreline moved duringthe study period. The calculation of NSM involves determination of the maximum, minimum and average data from all transacts. This is to show the overall characteristics of the changes in the area under study.Figure 13 is the NSM of 1991 to 2001 and Figure 14 is the NSM Map of 1991 to 2011. Table 5 is the summary of the NSM Report.

Table 5: Net Shoreline Movement (NSM) Report (1991-2001, 1991-2011, and 1991-2021)

Year	Av. Dist. (m)	Max (-) Dist. (M)	Max. (+) Dist. (m)	No. Transect	Acr (%)	Ers (%)
1991-2001	1576.28	-4428.03	8144.48	994	86.02	13.98
1991-2011	1680.48	-3170.90	12713.19	998	79.06	20.84
1991-2021	3345.06	-3802.62	11482.04	990	91.72	8.28

NSM average distance: 3345.06 m, maximum negative distance: -3802.62 m, maximum negative distance transect ID: 904, average of all negative distances: -1002.69 m, number of transects with positive distance: 908, percent of all transects that have a positive distance: 91.72%, maximum positive distance: 11482.04 m, maximum positive distance transect ID: 296, average of all positive distances: 3737.7 m.

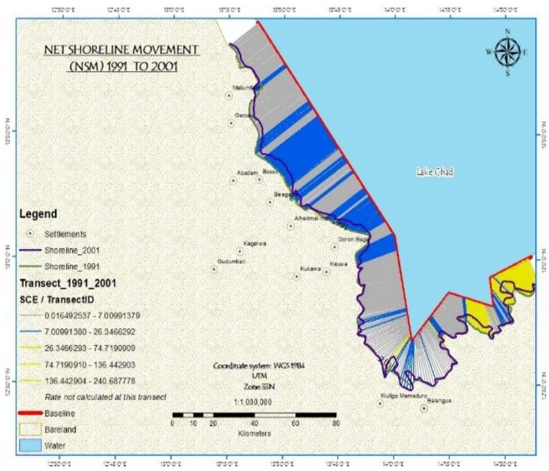


Figure 13: NSM 1991 to 2001

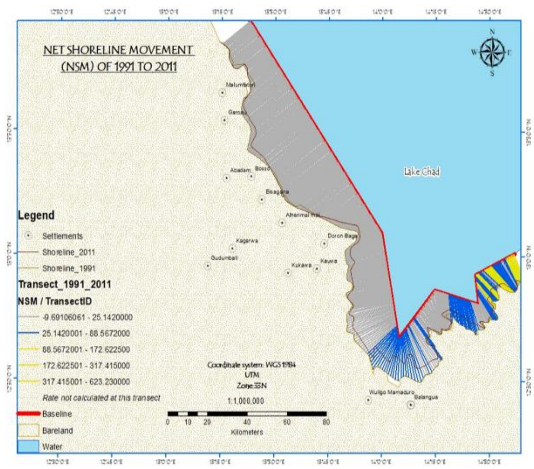


Figure 13: NSM 1991 to 2001 **Figure 14: NSM Map of 1991 to 2011**

Table 6: Overall Shoreline Dynamic NSM (1991, 2001, 2011, and 2021)

Year	Average Dist. (m)	Max (-) Dist. (m)	Max. (+) Dist. (m)	No. Transect	(Acr) %	(Ers) %
1991-2001-2011-21	3319.59	-3800.7	10421.78	499	88.53	11.47

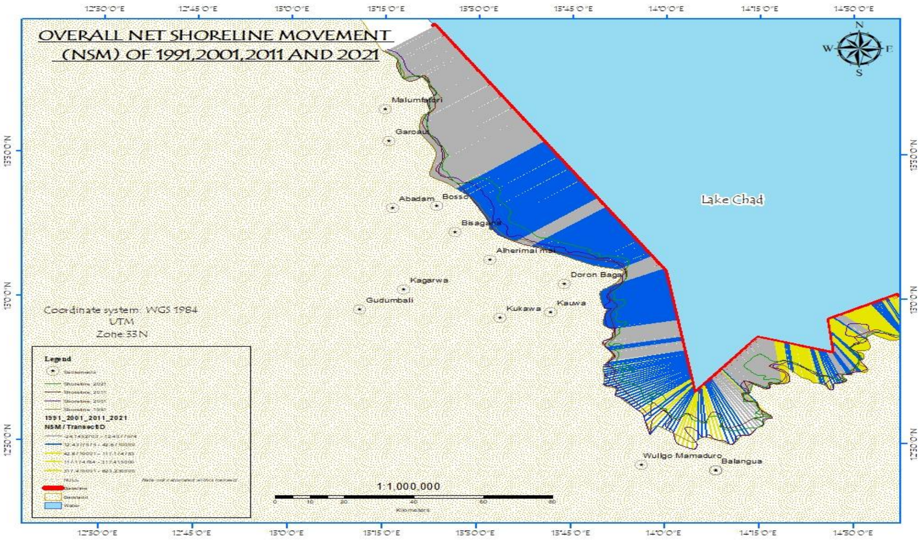


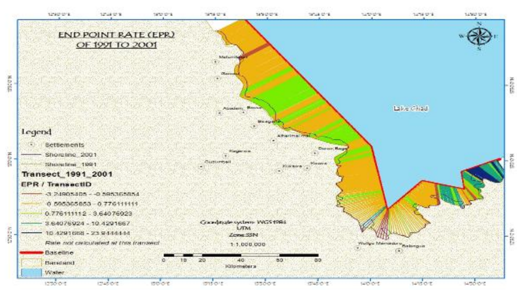
Figure 15: Overall NSM of Map 1991 to 2021

5.3 End Point Rate (EPR)

The End Point Rate is the net shoreline movement divided by the time interval. It is measured in meters per annum Positive Values of EPR indicate the rate of shoreline shifting in seaward and negative landward.Figure 16 shows EPR Map of 1991 to 2001and Figure 17shows EPR Map of 1991 to 2011period respectively.

Table 7: End Point Rate (EPR) Report (1991-2001, 1991-2011, and 1991-2021)

Year	Average Rate (m)	Max (V) erosion (m)	Max. (V) Acr (m)	No. Transect	(Acr)%	(Ers) %
1991-2001	156.81	-440.51	810.23	994	86.02	13.98
1991-2011	83.85	-158.22	634.36	998	79.06	20.84
1991-2021	115.01	-130.74	394.77	990	91.72	8.28



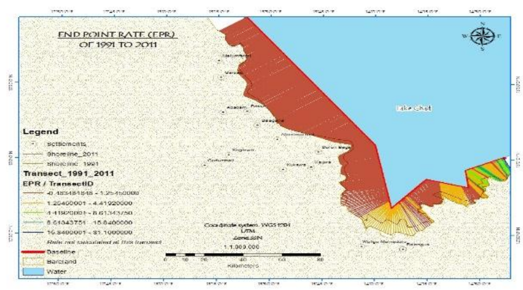


Figure 16: EPR Map of 1991 to 2001 Figure 17: EPR Map of 1991 to 2011

Table 8: Overall Shoreline Dynamic EPR (1991, 2001, 2011, and 2021)

Year	Av. Rate (m)	Max (V) Ers (m)	Max. (V) Acr (m)	No. Transect	%(Acr)	%(Ers)

1991-2001-2011-2021	114.14	-130.67	358.31	499	88.53	11.47

Table 8 shows that the End Point Rate (m/yr) has average rate of 114.14 m.Themaximum value erosion: -130.67 m, percent of all transects that have statistically significant accretion: 91.38%, The maximum value accretion: 358.31m,

5.4 Linear Regression Rate (LRR)

Linear Regression Rate (LRR) is the statistical method used to express shoreline movement and calculate rates of change. LRR iscalculated by fitting a least squares regression line to shoreline points for a specific transact. It utilizes shoreline locations to fit an approximate trend line of the data. (Figure 18) Figure 19 is the map of the Overall LRR of 1991 to 2021

Table 9: Overall Shoreline Dynamic LRR (1991, 2001, 2011, and 2021)

Year	Average Rate (m)	Max (V) Ers (m)	Max. (V) Acr (m)	No. Transect	%(Acr)	%(Ers)
1991-2001-2011-2021	103.58	-93.04	440.17	497	88.53	11.47

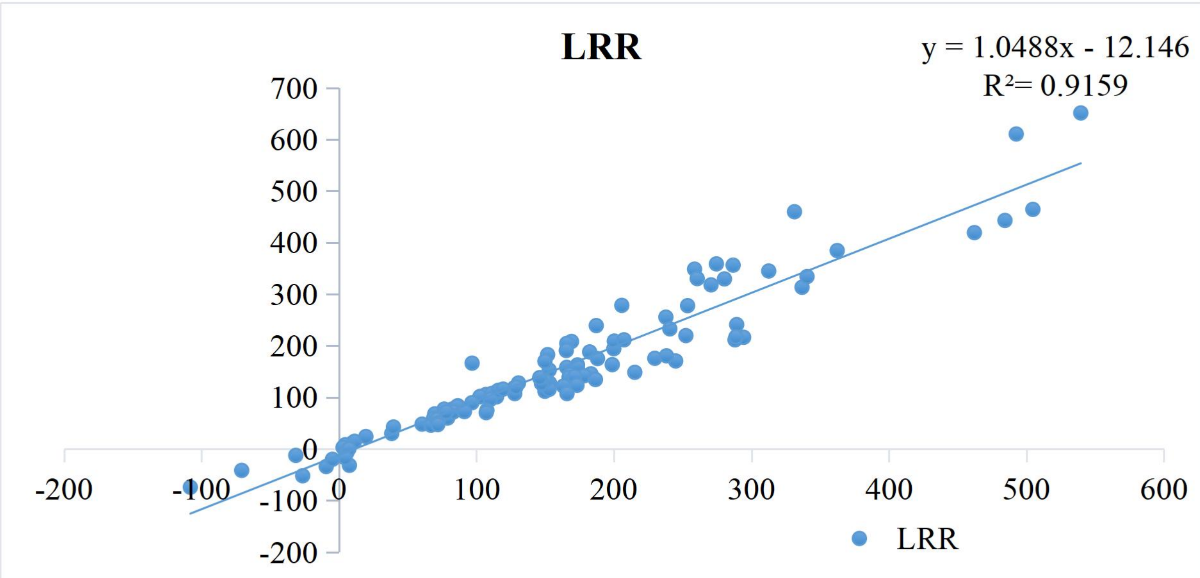


Figure 18: Linear Regression Rate (LRR) (1991-2021)

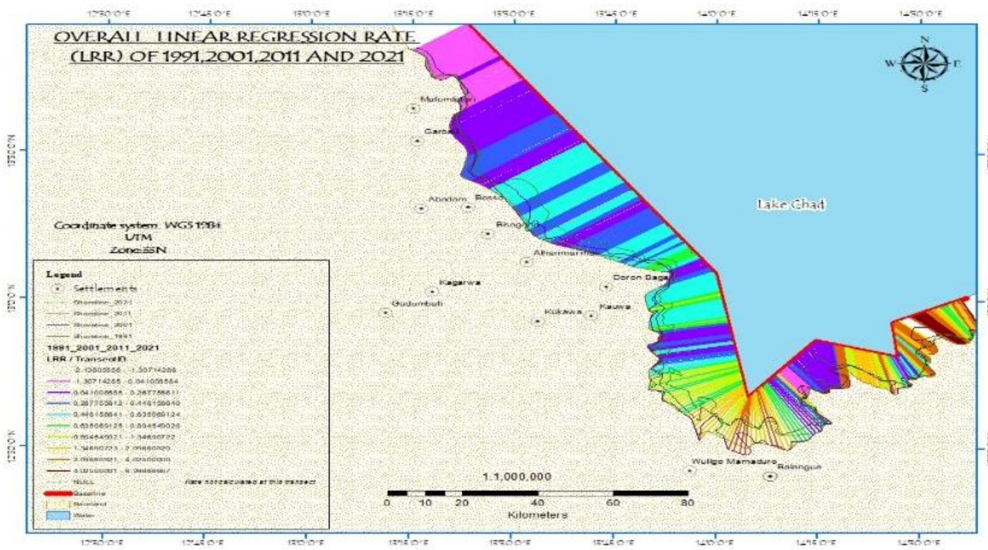


Figure 19: Overall LRR of 1991 to 2021

From Table 9 it can be seen that the overall Linear Regression Rate (m/yr) shows an average rate of 103.58 m,The percent of all transects that are erosional: 11.47%, The maximum value erosion: -93.04 m,The transect ID 453 has maximum value erosion. The percent of all transects that are accretion was 88.53%. The maximum accretion value 440.17 m. The transect ID: 164 has maximum value accretion

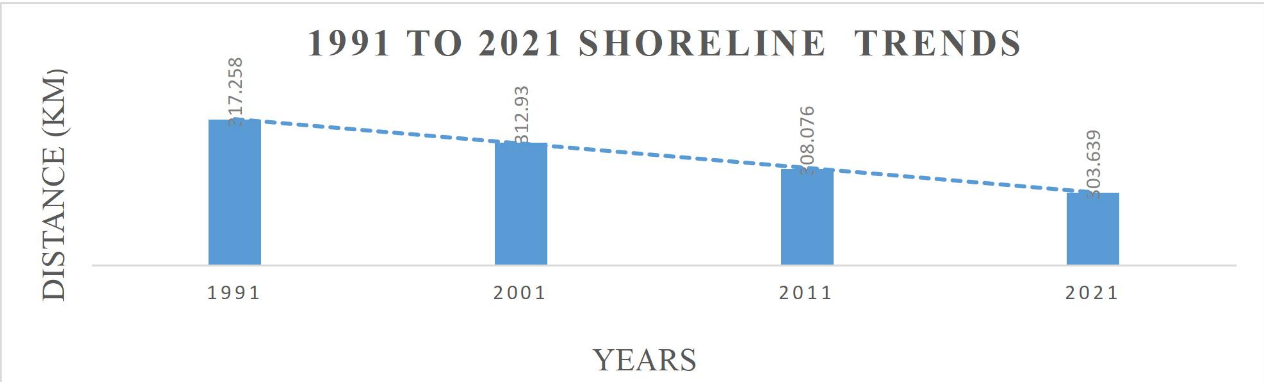
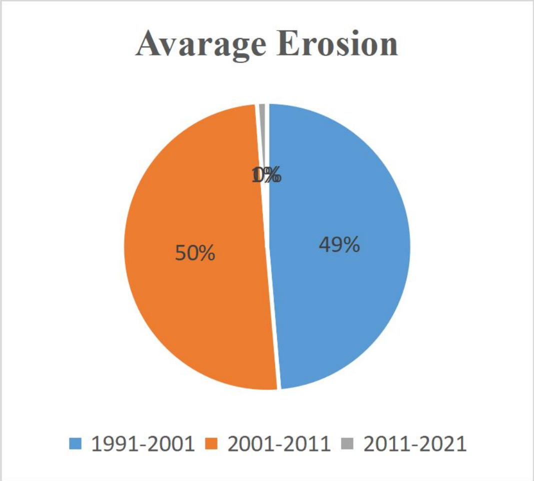


Figure 20: Shoreline Trends (1991-2021)

Figure 20 is the summary of the Shoreline Trends (1991-2021) while Figure 21 and Figure 22 1991-2021 Average Erosion and Average Accretion respectively



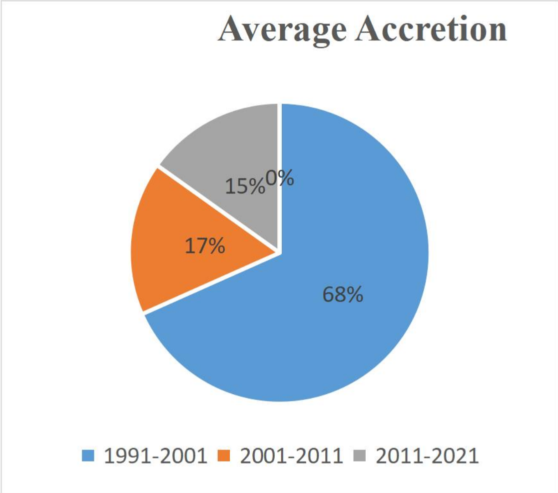


Figure 21: 1991-2021 Average Erosion **Figure 22 1991-2021 Average Accretion**

5.5 Summary

The study focused on320 Km Nigerian part of Lake Chad region, with aim of determining shoreline dynamics along the Nigeriaside of the Lake. The freely available Landsat satellite imageries dataset was obtained from USGS website and was to determine the locations of the shoreline from 1991 to 2021 at interval of ten years. The shoreline changes results from erosion or Accretion. Accretion can be classified based on the short length of transects and erosion by longest length, results revealed from DSAS end point results (EPR).

The data were pre-processed, analyzed and interpreted the result. Satellite datasets were downloaded from (USGS) pre-processed using QGIS and ENVI application software. Shorelines retreat locations were identified and delineated from the datasets and analyzed using digital shoreline analysis system (DSAS).Shoreline Change Envelop (SCE), Net Shoreline Movement (NSM), End point Rate (EPR)and linear Regression Rate (LRR) were computed. Transects were set at 250m with 20m spacing interval, buffering was done to determine the proximity between the selected baseline to the shorelines of epochs. The extent and trends of the shoreline dynamic were determined by analyzing the NSM, SCE and EPR obtained from the DSAS report of 1991-2001, 1991-2011, and 1991-2021 respectively. The overall extend were also computed from 1991-2021 to obtain comprehensive report of NSM, SCE, EPR and LRR of the epochs.

The results reveal that accretion rates dominates 88.53% approximately and erosion 11.47% over the epochs. These happens due to accumulations and transportation of sediments. The linear variations in the shorelines result to decrease in extents from 317.258 km to 312.930 km between 1991 and 2001, and 308.076 km to 303.639km between 2011 and 2021.

To identify most vulnerable areas to erosion and accretion respectively. The study area was divided into two zone. The results of the DSAS analysis identified areas vulnerable to accretion as Malamfatori, Garoua, Bosso and Bisagana located in North Eastern and South Eastern parts of the Lake while those vulnerable to erosion as Doron Baga, Wulgo Mamaduro and Balangua located in the South Eastern and South Western part of the Lake along the Nigeria’s border.

6.0 Conclusion and Recommendations

The results of spatio - temporal assessment of the Lake Chad shoreline dynamics on the Nigerian side of Lake Chadshows varying erosion and accretion processes trends during the study period. The study findings reveal that accretion occurred most frequently from 1991 to 2021, with accretion rates dominating approximately 88.53%, while erosion accounted for 11.47%. There was a total decrease of 13.619 Km, with an average annual decrease of 3.405 Km during the period of 1991 to 2021.

The results also indicated that Malamfatori region on the Northeastern side shoreline is undergoing natural accretion. Northern Bosso region was shown to be exposed to a high accretion vulnerability, in both the southeast and southwest directions. The areas of Baga, Wulgo Mamaduro, and Balangua were identified as areas experiencing accretion from both the southeast and southwest, respectively. However, the Wulgo Mamaduro to Balangua region witnessed the highest erosion rates. The accretion is likely to be due to the effects of sediment transportation and sand dune migration from the eastern part of Lake Chad and rainfall variability due to climate change phenomena.

The integration of DSAS and GIS techniques employed in this study provides an alternative, inexpensive, and rapid means for monitoring shoreline environments, which could be used for low accuracy shoreline dynamics assessment project especially when funding is a challenge as is case in most developing countries where funding for such endeavors is limited. It is hope that findings of this research contribute to the existing literaturefor a better understanding of the shoreline dynamics in the Nigerian sector of Lake Chad, supporting informed decision-making and sustainable management strategies for this vital water resource.

As part of the recommendations, the LCBC is encourage to

i) Setup a comprehensive monitoring system that combines satellite imagery, remote sensing technologies, and on-ground data collection to consistently track shoreline changes. This will provide accurate and up-to-date information to understand the patterns and extent of changes over time.
ii) Implement sustainable water management practices within the Lake Chad Basin including launching initiatives aimed at restoring and preserving the lake's ecosystems. Replanting native vegetation, protecting wetlands, and rehabilitating degraded areas could help stabilize the shoreline and mitigating erosion
iii) To demarcate the shoreline configuration more accurately, using high-resolution satellite images or by use of Drones and LIDAR technologies.

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