ASSESSMENT OF MULTI-DECADAL LAKE VICTORIA SHORELINE VARIATIONS USING DIGITAL SHORELINE ANALYSIS SYSTEM (DSAS)

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ABSTRACT

Lake shorelines are increasingly threatened by climate change and anthropogenic activities. The study aims to conduct a long-term shoreline change of the Lake Victoria shoreline in Kisumu County, Kenya. The Digital Shoreline Analysis System (DSAS) tool, with ArcGIS was used to monitor the shoreline using several statistical approaches. Lands at Satellite images (30m spatial resolution)were downloaded from the USGS website and geo referenced and used to map shoreline changes between 1994 and 2024. The shoreline was divided into three (3) zones. The Digital Shoreline Analysis System (DSAS) was used to understand shoreline changes such as erosion and accretion processes by calculating the net shift in shoreline (NSM), end point rate (EPR), and linear regression rate (LRR) for the period of 30 years. The study reveals that both accretion and erosion play a significant role in the dynamic of the shoreline, with erosion dominant around the mouth of Kibos River(LRR of -23.11m/year)and Nyando River mouth (LRR of -44.90m/year).Accretion is noted around Nyangande. From the results of the study, the shoreline needs management and protection strategies to ensure resilience, adaptation, and sustainability of the lake ecosystem and lake basin communities in the face of changing shorelines.

KEYWORDS

DSAS; GIS; Hydrology; Shoreline, Satellite, Modeling

1. INTRODUCTION

Although lakes occupy a small portion of the earth, they are critical for the local hydrological, ecological and climate processes, and also critical sources of water for human activities. Shoreline zones play a crucial role in the region's geology, geomorphology, and climate. Due to anthropogenic disturbances, shorelines are vulnerable to destruction, hence the increasing need for monitoring and protection. The increase in population, fishing activities, and infrastructural services along the Lake Victoria shorelines results in severe pressure on the lake dynamics, leading to shoreline fluctuations over time.In recent years, many lakes have experienced remarkable changes caused by natural factors (e.g., river discharge, precipitation, and evaporation) and human activities (e.g. the demands made on water bodies by, for example, agriculture) [7]. In a study conducted by Xu et al. [9] on the rising water levels of global lakes, it was concluded that based on estimations of 14,981 lake levels, 58.68% of global lake levels increased, while 41.32% decreased between 2003 and 2009. The average increase in the lake water level was found to be 0.013m/year. For six years, most of the lakes experienced an increase in their water levels, and, rather than shrinking, an expansion in their area was realized.

Assessment and monitoring of spatio-temporal changes of the shoreline can help understand the pattern of the shoreline like erosion, and deposition. Such monitoring using traditional methods is time-consuming, tedious and expensive. Satellite and remote sensing data have been widely used to monitor shorelines as it is relatively cheaper and less time-consuming. Shorelines change with time and their boundaries are positions recorded on the date of the survey. Assessment of shorelines is essential for sustainable management strategies, protection solutions, and planning.

In Kenya, the population of the Lake Victoria Basin has been exponentially increasing thus putting a lot of stress on the Lake [4]. Also, there has been an uncontrolled rise in water levels in the lake as a result of large amounts of rainfall and increased recharge from the rivers[5]. These factors combined with poor protection services have the shoreline exposed to erosion. This has further led to unpredictable shoreline bursts and flooding claiming homesteads, crops, and business structures.

Digital Shoreline Analysis System (DSAS) are among GIS the tools available for shoreline change assessment. This approach to shoreline analysis has gained popularity over traditional field techniques due to its cost-effectiveness, reduced margin for manual errors, and user-friendly interface[3]. The objective of the study is to assess the shoreline change from 1994 to 2024 employing DSAS method and Landsat satellite data, through data analysis of historical shoreline data to calculate shoreline change. According to Nassar et al. [6]the rate of shoreline changes and movement is quantitatively and qualitatively estimated through metrics such as end point rate (EPR), linear regression rate (LRR), and net shoreline movement(NSM). The methodology provided in the study may prove useful for studies related to long-term lake shoreline changes.

1.1. Study Area

The study area is located in Kisumu County (western Kenya) and concerns a shoreline of approximately43,426m. Its geographical coordinates range from longitude 34^{0}45’23” to longitude 34^{0}51’56” and from latitude -0^{0}5’28” to -0^{0}17’54”. Lake Victoria is a freshwater lake served by several rivers in Kenya as well as rivers of Uganda and Tanzania. The study area has an elevation of about 1131m, with meantemperaturesof 23.1 degrees Celsius [2]. Lake Victoria is ephemeral, and at various intervals during the Pleistocene it dried up and, in the process, was replaced by more open, grassy habitats similar to those found in the Serengeti today. These contrasting conditions in the past serve to underscore archaeological and biogeographic evidence for the social and environmental dynamism of the Lake[8]. The choice of the area was determined based on frequent floods which impact the rate of erosion and deposition, as well as the human activities such as fishing in the study area. The portion of the shoreline is mostly deeply indented

2. MATERIALS AND METHODS

The study utilizes the framework presented in Figure 1 to assess the shoreline change rate from 1994 to 2024. The study employed Landsat imagery from four specific time periods to delineate the coastal features.

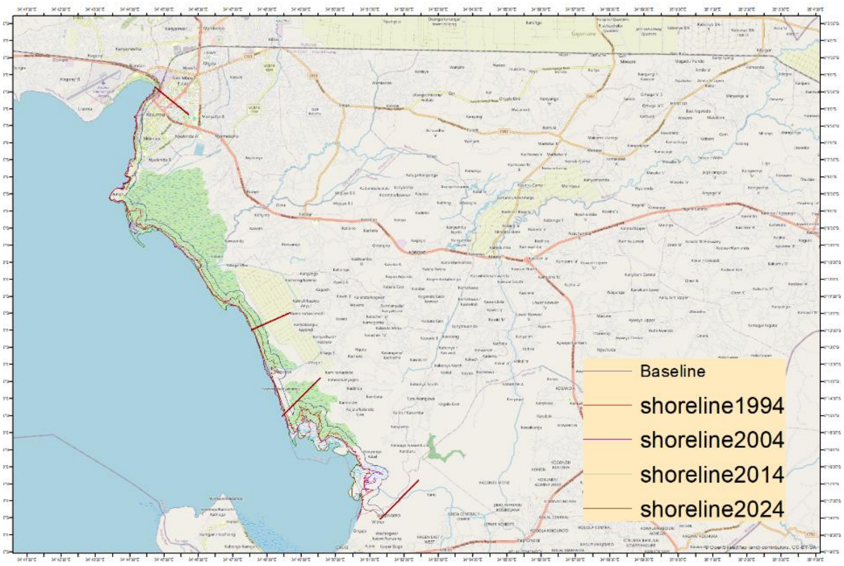

Figure 1 Demarcation of Shorelines and Baseline in the Study Area

The Landsat data was obtained from the USGS website (https://earthexplorer.usgs.gov/). The multi-temporal Landsat images were taken between 1994 and 2024, with a spatial resolution of 30 x 30 meters, as shown in Table 1.The downloaded images were rectified and projected to the World Geodetic System (WGS 84), and the Universal Transverse Mercator (UTM) zone 37N.

Table 1 Spatio-temporal satellite data

Image Type	Date Acquired	Spatial Resolution (m)
Landsat-8 OLI	2024/09/08	30
Landsat-8 OLI	2014/09/13	30
Landsat-7 ETM+	2004/11/12	30
Landsat-5 TM	1994/10/08	30

Shoreline extraction from the images included calculating the Modified Normalized Difference Water Index (MNDWI), this was done as a support to define the line representing the wet-dry boundary. The MNDWI was expressed using the shortwave infrared and visible green regions of the electro magnetic spectrum as shown in the equation:

$$MNDWI = \frac{SWIR - Green}{SWIR + Green}$$

DSAS is an open-source plugin software in ArcGIS platform. After automatically digitizing the shorelinesin ArcGIS 10.8 the extracted shoreline features were combined into a single shapefile. The baseline isthe starting point that can be offshore or onshore. Transects are cast perpendicular to the baseline at a spacing of about 100m and intersect the shorelines to establish the measurement points with respect to the baseline.A total of 480 transects were created along the shoreline. The shoreline statistical data analysis included Linear Regression Rate (LRR), Net Shoreline Movement (NSM), and End Point Rate (EPR). EPR was calculated by dividing Net Shoreline Movement by the time interval between the old and recent shoreline as shown in the equation.

$$EPR = \frac{NSM}{Time\ between\ oldest\ and\ recent\ shoreline}$$

3. RESULTS AND DISCUSSION

DSAS tool helped in measuring, and quantifying, and monitoring historic shoreline changes. DSAS created a series of perpendicular lines to the baseline called transects. Transects are created by DSAS baseline and shoreline configurations. The software evaluated a time series statistical rate of change from 1994 to 2024. The shoreline change rate was obtained from 480 transects, with an interval of 100m,and covered the entire length of the study area. The assessment portioned the study area into three zones. The zones are as follows: Zone 1, spanning from transect 1 to transect245.Zone 2 covers transect 246 to transect 317, and Zone 3 includes the shoreline from transect 318 to transect 480.

Generally, the shoreline does not undergo a consistent mechanism as it changes between erosion and accretion during the 30-year period. Figure 1 shows the shoreline changes from the 3 decades while Table2 displays the descriptive statistics of change rates from 1994 to 2024, utilizing LRR, and EPR using the DSAS plugin.

Table 2: Rate of Change m/year (LRR and EPR)

ZONE	**TRANSECT ID**	**EPR**		**LRR**	
		Min	***Max***	***Min***	***Max***
1	1 to245	-24.12	19.32	-23.11	16.88
2	246 to 317	0.67	18.40	0.91	15.56
3	318 to 480	-35.97	47.18	-44.90	36.11

3.1. Linear Regression Rate (LRR)

LRR is a statistical method that expresses shoreline movement and calculates the rate change. LRR is estimated by fitting a least squares regression line to shoreline points for a specific transect[1]. It utilises shoreline locations to fit an approximate trendline of the data.Zone 1showcases the highest accretion rate at 16.88m/ year with the lowest value at -23.11m/year. Accretion is noted at 67.75% of the transects with erosion covering 31.02% of the total transects. The highest LRR value in zone 2 is 16.56 m/year while the lowest value is 0.91 m/year. This signifies substantial sedimentation in the shoreline (around Nyangande)as a result of rainfall-inducedfloods in the Nyando River basin. Zone 3 has high rates of erosion indicated by an LRR of -44.90m/year with the highest accretion value of 36.11m/year.

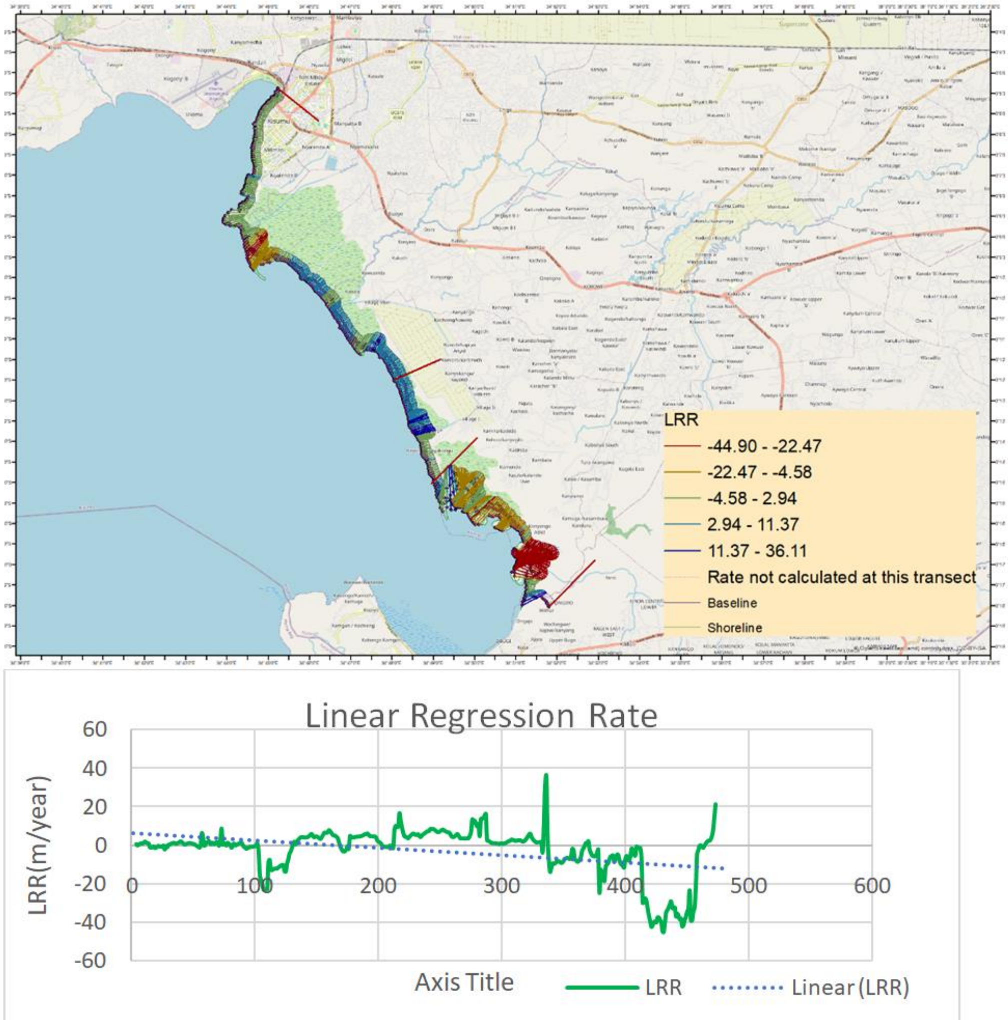

Figure 2: LRR Map from 1994 to 2024

3.2. End Point Rate (EPR)

End point rate is the net shoreline movement divided by the time interval, and measured in meters per year. Positive values indicate the shoreline is moving seaward while negative values indicate shoreline is moving landward. The EPR rate of change, in meters per year with the highest negative values of -24.12m/year indicating erosion while positive values of 16.88m/year indicate accretion in zone 1. The highest accretion rate was along zone 3 with an EPR of 47.18m/year with an erosion rate of -35.97. The accelerated accretion and erosion were attributed to increased sedimentation as a result of flooding in the Nyando River Basin. In Zone2high accretion rate is denoted by an EPR of 18.40m/year with the lowest accretion rate of 0.67m/year which indicates a stable zone.

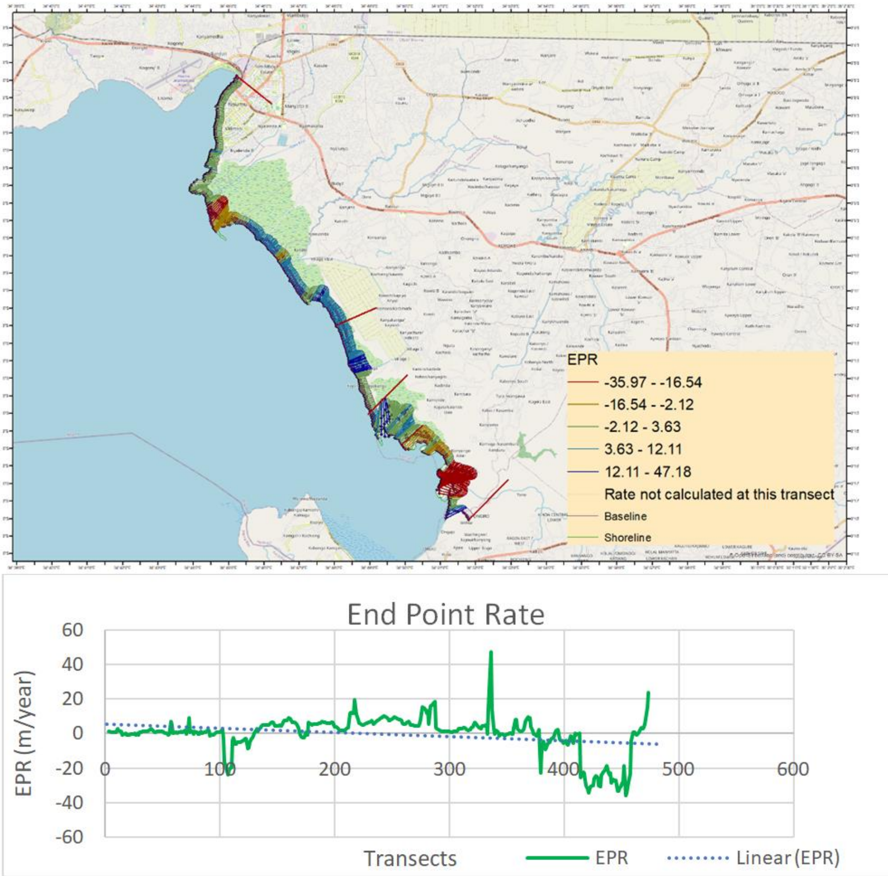

Figure 3: LRR map from 1994 to 2024

3.3. Net Shoreline Movement (NSM)

Net Shoreline Movement indicates how much has the shoreline moved. NSM shows the distance between the oldest (1994) and the youngest shoreline (2024). The negative values indicate inundation while positive values indicate accretion. The highest in undation is denoted in zone 3 (-1076.2m), while the highest value in zone 1 is -721.77m. Zone 2 generally indicates accretion which ranges from 20.17m to 552.37m. Accretion is high in zone 3 with a value of 1411.77m, this is due to the high rate of deposition by Nyando River which draws sediments from Nandi hills.

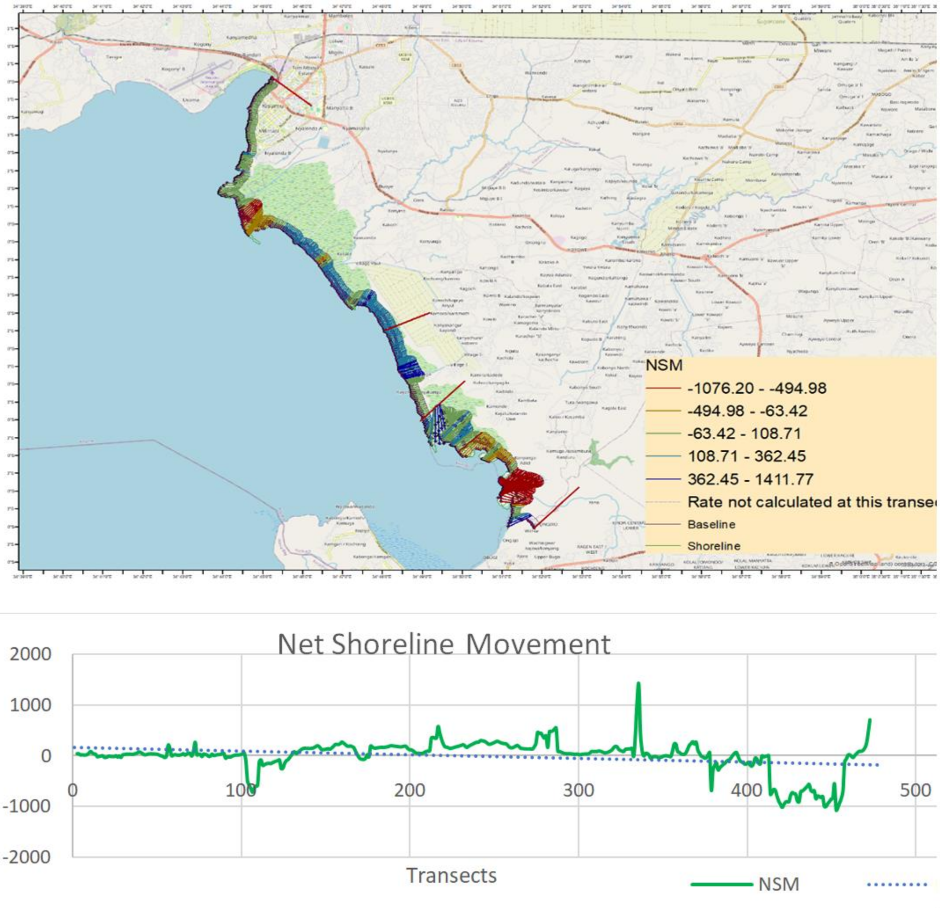

Figure 4: NSM map from 1994 to 2024

4. CONCLUSIONS

The study's findings show the complex dynamic of the Lake Victoria shoreline in Kisumu County from 1994 to 2024. Dividing the shoreline into three (3) zones unveiled distinct erosion and accretion trends. Zone 2 demonstrated accretion, unlike Zone 3, which had high levels of erosion around River Nyando. Zone 1 has the highest accretion rate of 19.32m/year (EPR) and 16.88 m/year (LRR). The highest accretion in Zone 2 is 18.40m/year (EPR) and 15.56m/year (LRR). Zone 3 has the highest accretion rate of 47.18m/year (EPR) and 36.11m/year (LRR). Vulnerable areas close to River mouths like River Nyando in Zone 3 and Kibos River in Zone 1 had high erosion values thus prone to erosion. In contrast, high accretion is witnessed in zone 3, part of Nyando River basin. This is a result of high sedimentation due to rainfall-induced floods. Additional parameters such as suspended sediment transport rates, tidal patterns, and bathymetric patterns can be added in future studies to give more data-driven results.

As the shoreline undergoes accretion and erosion, potential economic impacts and destruction of properties as a result of shoreline flooding warrant for action. The results of the study show the significance of informed shoreline management and protection strategies through historical data to ensure resilience, adaptation and sustainability of the lake ecosystem and lake basin communities in the face of changing shorelines.

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