# Geospatial Analysis of Erelu Reservoir using Remote Sensing and Bathymetric Techniques in Oyo, Oyo State, Nigeria.

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## Abstract

*The research was conducted to provide information about the physical characteristics of Erelu reservoir in Oyo West Local Government Area, Oyo, in Oyo State. Data acquisition featured sounding by means of an echo sounder and for depth and position determination by means of a GPS while the tidal data used were based on existing data. Initial processing performed on the observed bathymetric data included; sorting with PowerNav and HYPACK 2018. Further processing was carried out using ArcGIS 10.7 and SUFFER 2016 software. The modified normalized difference water index (MNDWI) was used to extract the shoreline of the study area, while the digital shoreline analysis system (DSAS) was used for shoreline analysis. The results of the analysis showed that the maximum and minimum depths observed were 6.03m and 0.56m respectively 2023 an indication that the water is shallow. The surface area and volume values obtained were 120.94ha and 2975635.28943.13m$^3$. Based on a linear and areal analysis, the bathymetric survey revealed that the maximum length and area reached in 2022 were 7855.171m and 84.506ha respectively, while the minimum length and area in 2017 were 7460.733m and 78.303ha respectively. Based on the results from DSAS, it was deduced that the accretion rate was high, while the erosion rate was minimal. Finally, the processed depths were analysed and presented in the form of charts, which may be used in the near future for planning and decision-making for proper management of the reservoir.*

***Keywords:*** *Bathymetry, Sounding, ArcGIS 10.7, Mapping, Reservoir, Seabed, Geospatial, Modified normalized difference water index (MNDWI), SUFFER 2016.*

## 1. Introduction

Water is the basis of life and one of the most precious commodities required for survival of any forms of life (Dirican, 2015). As a resource, water is of critical importance to both ecosystem and human development. They provide habitat, sanctuary and food for many species of fish and wildlife (Kareem, 2017). Erelu Reservoir is one of the dams built by the then Western Region Government in 1961 for the purpose of supplying portable water to Oyo town and its environs. However, the human activities that subsequently followed in the area along the margins of the dam included lowland farming, irrigation farming of arable crops and fishing, the latter issuing from the migration of fishermen into the area (Kareem, 2017).

"Shoreline" is referred to as the interface between the land and the sea (WIOMSA, 2010) and the immediate position of the land–water line at one instant in time (Boak and Turner, 2005). The change in shoreline is mainly associated with the action of waves, tides and winds, periodic storms, sea-level change, and the geomorphic processes of erosion and accretion and human activities (Carter and Woodroffe, 1994).

Several studies pointed out that two main factors could be responsible for shoreline change. These are; human activities or natural processes (Richmond, 1997, Keqizhang et al., 2004, Boak and Turner, 2005, Hanslaow, D.J., 2007, Francis et al, 2018, Paterson et al, 2010,). Also relevant to this research is that of Okegbola, M. O and Okegbola, S. A. (2020), who explored the use of Unmanned Aerial Systems (UAS) for spectral image mapping and vegetation index calculations of a portion of the Erelu Dam shoreline in Oyo, Nigeria. Compared to the true colour images, the processed spectral indices show clearer distinctions between the shoreline, clear water, and the vegetated areas. The indices highlighted the different vegetational patterns and shoreline features, demonstrating the effectiveness of using a middle-class UAV such as the DJI Phantom 4 Pro for environmental monitoring and mapping tasks.

Our study addresses the need for a detailed and updated geospatial analysis of the Erelu Reservoir in Oyo State, Nigeria. While previous studies may have explored various studies in areas like water quality, the growth patterns of various fish species, and dam integrity using electrical resistivity methods, etc, there appears to be a lack of focused research on the underwater terrain of reservoirs using modern techniques such as remote sensing (RS) and geographical information system (GIS). This gap highlights the necessity for employing comprehensive bathymetric survey approaches to provide accurate and detailed insights into the underwater terrain of the Erelu Reservoir, which are critical for effective water resource management, monitoring, environmental conservation and for determining shorelines changes.

## 2. Materials and Methods

### 2.1. Study Area

The Erelu Reservoir of the Erelu Water Corporation, Oyo West Local Government Area, Oyo State is located in the southwestern part of Nigeria, between 598224.014mE to 871327.011mN. It has a savannah climate with two distinct seasons, namely, wet Season from April to October and the dry season from November to March. The average annual temperature is 27°C and the average annual precipitation is 591.6 mm.

The main reason for establishing the reservoir was and still is the source of water for households in Oyo and its environs. However, human activities reliant on the dam subsequently emerged in the region. They include primary activities such as lowland agriculture along the coast, the irrigarable crops, and animal grazing (Kareem 2017). (See Figure 1)

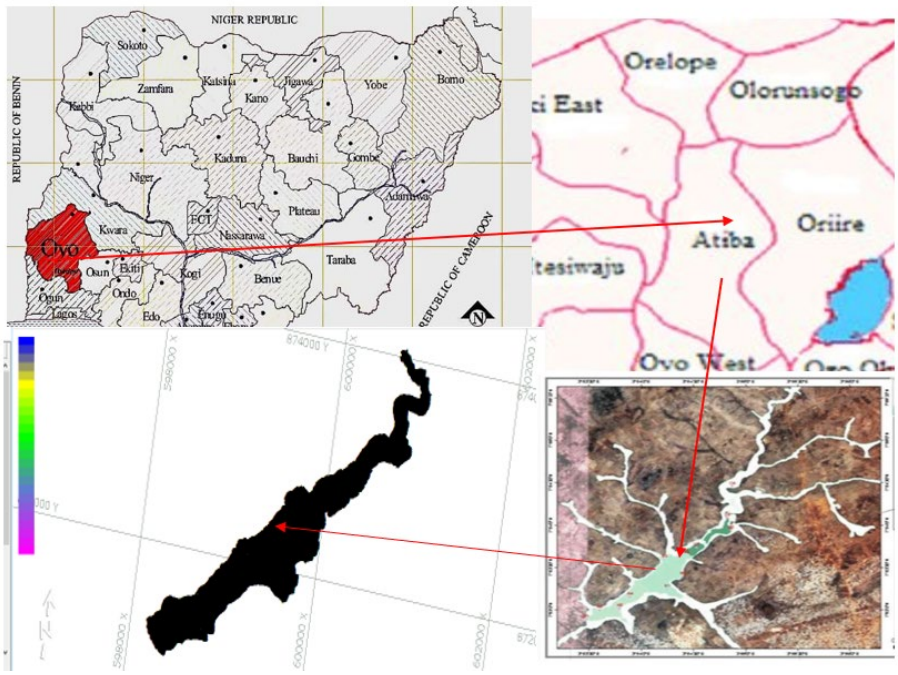


Figure 1: The Location of the study area

## 2.2. Data Acquisition

The data used in this research include Landsat Satellite imagery data series (Landsat 7,8 and 9 for the years 2007, 2012, 2017 and 2022 respectively) with the sun's elevation at 59.33162732°, 62.85384356°, 63.10947652° and 63.75595389° respectively. These images were downloaded from the USGS Earth Explorer website to determine and delineate the shoreline changes in the study area, The MNDWI equation applied in this research is expressed as follows:

$$\text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}}$$

The band combination is shown in Table 1 below.

Table 1 Band specifications used with the MNDWI

| Platform | Green | MIR |
|---|---|---|
| Landsat 7 | 2 (520nm- 600nm) | 5 (1550nm- 1750nm) |
| Landsat 8 | 3 (525nm - 600nm) | 6 (1560nm – 1660nm) |
| Landsat 9 | 4 (640nm-670nm) | 6 (1570nm – 1650nm) |

The coordinates (X, Y, Z) of each sounding points were determined using the SDE-28 single-beam echo sounder and the handheld Garmin HGPS GPS receiver. The data obtained were used to produce the final bathymetric chart of the Erelu Reservoir. (See Table 4 for the extract of the raw data sorted).

## 2.3. Methods

The downloaded satellite imagery was pre-processed for correction (radiometric, atmospheric and cloud removal) and classified into two different classes, namely water and land. Using the classification tool (set to a maximum likelihood) the process was achieved using a training sample manager, polygons were drawn for the land and water portions on the imagery. The modified normalized water index (MNDWI) was used to extract the shoreline of the Erelu Reservoir, while the digital shoreline analysis (DSAS) made the geospatial analysis of the study area possible. The digital shoreline analysis system (DSAS) was used to generate orthogonal transects, spaced 200m apart, along the reservoir and accordingly, to calculate the change statistics, using six distinct approaches. These include the end point rate (EPR), the linear regression rate (LRR), and the weighted linear regression (WLR) statistical methods. The EPR short time period method was conducted to monitor changes between the successive shoreline pairs, namely, 2007–2012, 2012–2017, 2017–2022 and 2022. The LRR and WLR statistics (which exploits all shorelines) were used to calculate shoreline changes for the entire period of 15years from 2007 to 2022.

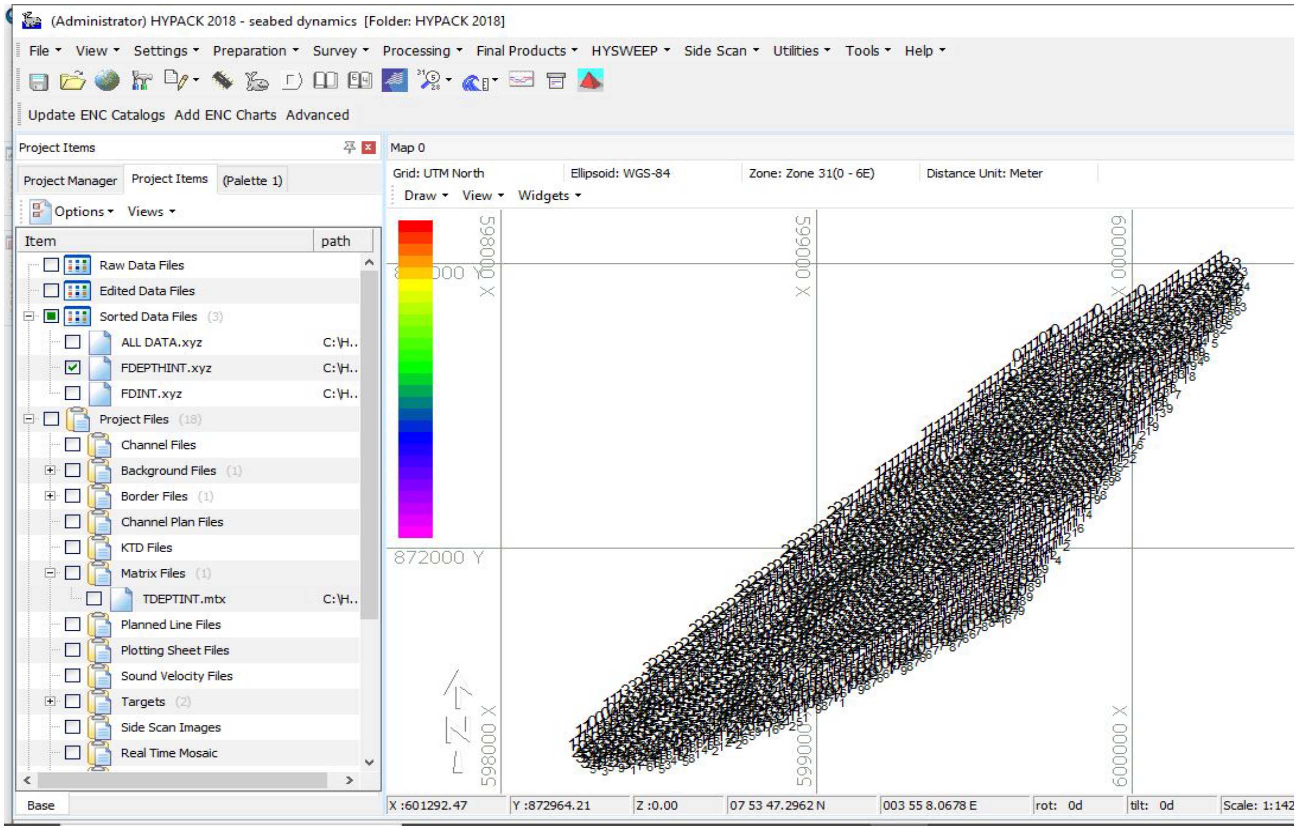

Figure 2. Diagram illustrating the interpolated depth values on Hypack workspace after interpolation

For the bathymetric survey to determine the Seabed, the coordinates (X, Y, and Z) of each sounding points at different cross-sections of the water body were obtained using a single beam echo sounder and a handheld Garmin GPS receiver. The data obtained using this sounding procedure were not reduced because the Erelu reservoir is not a tidal river, hence, the measurements in this case applied to the reduced depth. The PowerNav facility allowed for the sorting of the data, the object being to remove any false echoes. The sorted data were then processed for interpolation using Hypack 2018 software as in Figure 2 and exported as a shape file into ArcGIS for annotations (identifying each node/point with its depth value), while calculations were made on the basis of the shapefile data for TIN, volume and area.

Finally, the longitudinal and cross-sectional profiles of the reservoir bed were compiled. SUFFER software was used to produce the contours of the reservoir floor, its 3-D wireframe and the direction of flow in the study area. The methodology flowchart of the research is shown in Figure 3 below.

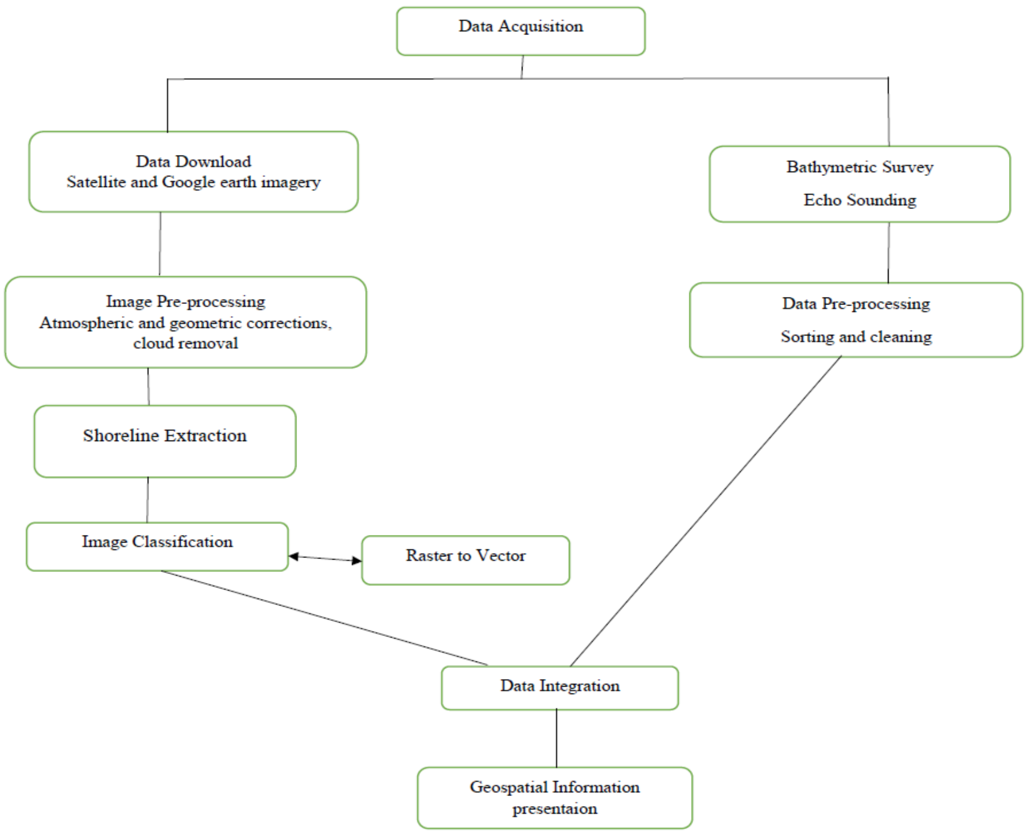


Figure 3. Flowchart of Methodology

## 3. Results

From Table 2, the total length of the shoreline over the period, 2007-2012 increased by 103.658m, decreased by 218.705m over the period, 2017-2022 and increased by 394.438m for the period 2022, the associated areas determined for each period were also calculated. Observations showed that the entire shoreline has changed over these periods and that the rate of accretion on the reservoir shores is greater than the rate of erosion. (See Figure 4 below.).

Table 2. Linear Shoreline-change Analysis for Erelu Reservoir between 2007 and 2022

| Shoreline Period | Date | Length(m) | Area(ha) | Linear shoreline change | | |
|---|---|---|---|---|---|---|
| 2007-2012 | 2007 | 7575.780 | 82.361 | 2007-2012 | 2012-2017 | 2017-2022 |
| 2012-2017 | 2012 | 7679.438 | 83.427 | -103.658 | 218.705 | -394.438 |
| 2017-2022 | 2017 | 7460.733 | 78.303 | | | |
| 2022 | 2022 | 7855.171 | 84.506 | | | |

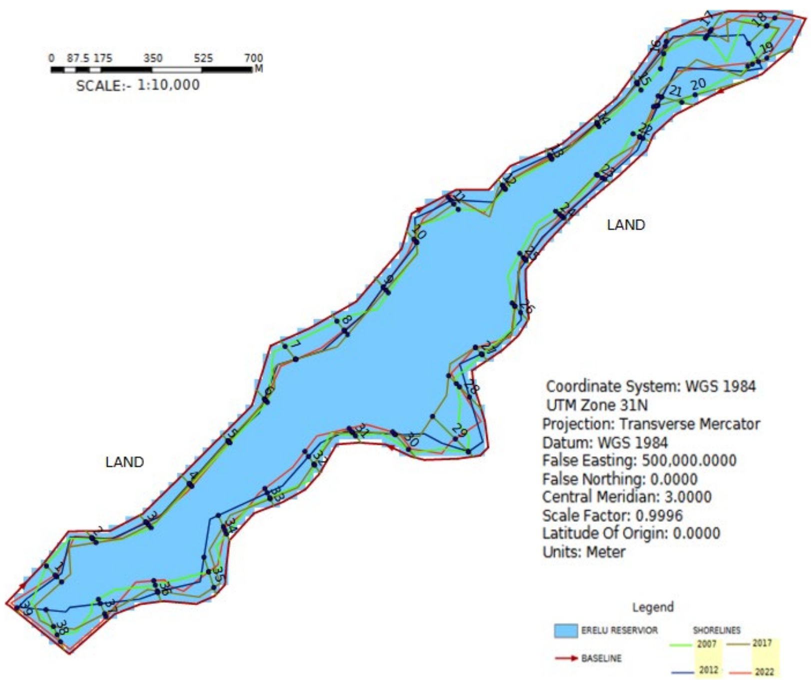


Figure 4. Shoreline change map for Erelu Reservoir between 2007 and 2022

The bar and pie charts in figures 5.1 and 5.2 below show that the year 2022 (as on 30 May 2022) was marked by the largest changes in terms of the length of the shorelines and that 2017 recorded the shortest linear shoreline. The areas covered by the shoreline for the three (3) successive periods are similar in the scene that, only the period, 2007-2012, recorded the lowest value, namely, 78.303 with 24%, as against 26%, 25% and 25% respectively 84,506, 82,361 and 83,427.

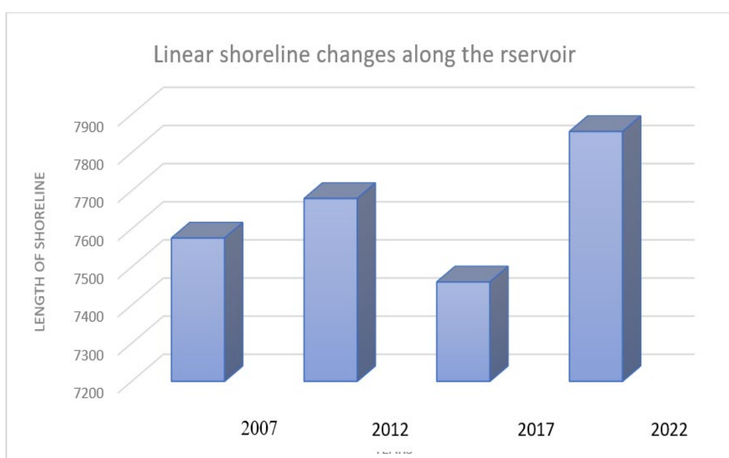


Figure 5.1 Bar chart of the reservoir showing the linear shoreline change

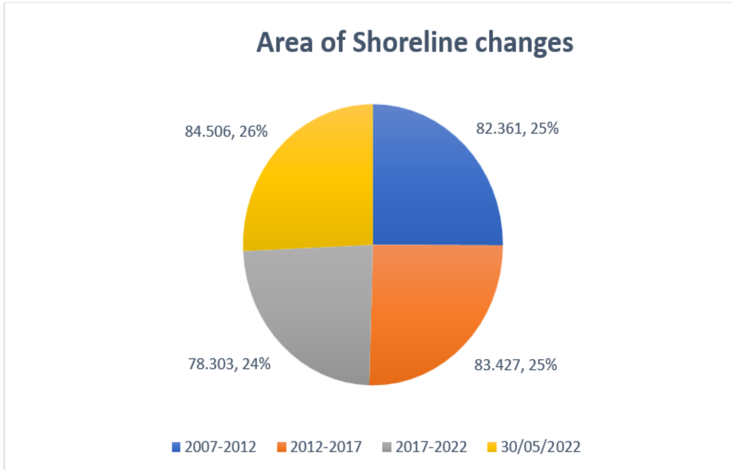


Figure 5.2. Pie chart of the reservoir showing the areas of shoreline change

Five parameters namely, end point rate (EPR); linear regression rate (LRR); R-squared of linear regression (LR2); standard error of linear regression (LSE) and confidence interval of linear regression (for 90%) (LCI90), were used in the DSAS analysis to assess the dynamics of the shorelines over the period, 2007– 2022 (15years). A total of 39 transects were obtained from DSAS, with erosion indicated in 15 transects, accretion in 23 transects and no change in one transact. It is therefore revealed that accretion rather than erosion is rampant in the area covered by the changing shoreline. Table 3 shows the overall shoreline change rates. The positive values indicate accretion of the shorelines while the negative values indicate erosion of the shoreline.

Figure 6 shows the following: (A) the shoreline position plotting for transect_ID = 29; (B) the linear regression equation for transect_ID 29 is (y = 0.2227x - 365.29). These values were determined by plotting the shoreline positions with respect to time (in the number of years) a, while the slope of the equation describing the line shows a rate of 0.2227m/year; (C) the shoreline position plotting for transect_ID = 36; (D) the linear regression equation for transect_ID is 36 (y = -0.864x + 1688.8) showing a rate of -0.864 m/year.

Table 3. Analysis of Rate-change Statistics resulting from DSAS

| TRANSECT | RATE-CHANGE STATISTICS | | | | |
|---|---|---|---|---|---|
| ID | EPR | LRR | LR2 | LSE | LC190 |
| 1 | 2.17 | 0.9 | 0.03 | 38.27 | 10.1 |
| 2 | 1.57 | 1.48 | 0.83 | 5.2 | 1.37 |
| 3 | 1.09 | 1.48 | 0.54 | 10.75 | 2.84 |
| 4 | -0.7 | -0.47 | 0.27 | 6.05 | 1.6 |
| 5 | -0.46 | -0.21 | 0.07 | 5.89 | 1.55 |
| 6 | -0.03 | 0.29 | 0.08 | 7.61 | 2.01 |
| 7 | -0.07 | -1.23 | 0.07 | 34.09 | 9 |
| 8 | 1.3 | 0.28 | 0.01 | 30.8 | 8.13 |
| 9 | 0.89 | 1.32 | 0.46 | 11.19 | 2.95 |
| 10 | 0.87 | 0.85 | 0.6 | 5.4 | 1.42 |
| 11 | 2.07 | 2.71 | 0.53 | 20 | 5.28 |
| 12 | -0.99 | -0.64 | 0.25 | 8.67 | 2.29 |
| 13 | 0.55 | 0.82 | 0.5 | 6.37 | 1.68 |
| 14 | 0.37 | 0.62 | 0.33 | 6.99 | 1.85 |
| 15 | 0.38 | 0.93 | 0.18 | 15.54 | 4.1 |
| 16 | 2.9 | 4.23 | 0.41 | 39.71 | 10.48 |
| 17 | 0.6 | 0.77 | 0.09 | 19.45 | 5.13 |
| 18 | 2.74 | 0.7 | 0.01 | 65.53 | 17.3 |
| 19 | 3.71 | 4.17 | 0.72 | 20.43 | 5.39 |
| 20 | 0.78 | -2.04 | 0.03 | 85.54 | 22.58 |
| 21 | 0.82 | -0.72 | 0.01 | 46.88 | 12.37 |
| 22 | -0.13 | 0.64 | 0.07 | 18.72 | 4.94 |
| 23 | 1.51 | 1.93 | 0.63 | 11.42 | 3.01 |
| 24 | 0.73 | 1.38 | 0.33 | 15.55 | 4.1 |
| 25 | 0.5 | 1.11 | 0.26 | 14.81 | 3.91 |
| 26 | -0.03 | 0.86 | 0.09 | 21.73 | 5.74 |
| 27 | 0.1 | -0.01 | 0 | 22.96 | 6.06 |
| 28 | 3.63 | 4.56 | 0.46 | 38.31 | 10.11 |
| 29 | 7.47 | 6.72 | 0.27 | 85.67 | 22.61 |
| 30 | -0.9 | -2.25 | 0.15 | 42.36 | 11.18 |
| 31 | -1.28 | -1.54 | 0.5 | 12.06 | 3.18 |
| 32 | -3.64 | -4.03 | 0.86 | 12.85 | 3.39 |
| 33 | -2.7 | -2.81 | 0.95 | 5.05 | 1.33 |
| 34 | 0.97 | -0.55 | 0.01 | 37.29 | 9.84 |
| 35 | -3.85 | -4.51 | 0.41 | 42.41 | 11.19 |
| 36 | -2.51 | -1.73 | 0.31 | 20.26 | 5.35 |
| 37 | 0.78 | 1.06 | 0.05 | 37.2 | 9.82 |
| 38 | 3.94 | 1.66 | 0.04 | 63.07 | 16.65 |
| 39 | 0 | 0 | 0 | 0 | 0 |

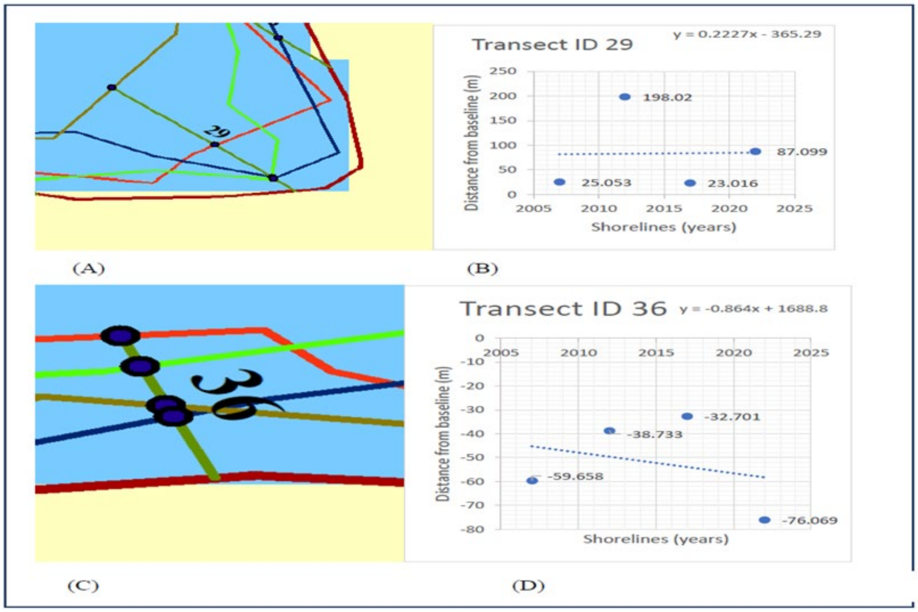


Figure 6. Extract of DSAS results of Transect_ID = 29 (accretion) and Transect_ID = 36 (erosion) for the study area.

### 3.1. Shoreline Dynamics:

The DSAS analysis revealed 39 transects, 15 of which indicated erosion, 23, accretion, and one, no change. This indicates that the shoreline is generally experiencing more accretion than erosion. The positive values in the transect-change statistics indicate areas of accretion, while the negative values denote erosion. The most significant accretion was observed in Transect 29, with a rate of 0.2227 m/year, while the most severe erosion was seen in Transect 36, at -0.864 m/year.

### 3.2. 3-D Information

The final depth data in figure 4 were used to produce the topographic plans of the Isobath maps of the study area, in Figures7, and the 3-D wireframe model, in Figure 8.

Table 4. Fraction of Raw Depth Data

| S/N | Date | Time | Easting(m) | Northing(m) | Depth(m) |
|---|---|---|---|---|---|
| 1 | 9/1/2023 | 3:56 AM | 599165.2 | 872162.3 | 0.58 |
| 2 | 9/1/2023 | 3:57 PM | 599215.9 | 872148.2 | 1.52 |
| 3 | 9/1/2023 | 3:58 PM | 599861.4 | 872283.7 | 3.53 |
| 4 | 9/1/2023 | 3:58 PM | 598502.8 | 871380.0 | 6.23 |
| 5 | 9/1/2023 | 3:59 PM | 598833.7 | 871738.8 | 2.28 |
| 6 | 9/1/2023 | 3:59 PM | 599783.9 | 872476.7 | 4.37 |
| 7 | 9/1/2023 | 3:59 PM | 599278.4 | 872054.5 | 3.59 |
| 8 | 9/1/2023 | 3:59 PM | 598452.9 | 871365.9 | 5.34 |
| 9 | 9/1/2023 | 3:59 PM | 598514.9 | 871387.9 | 6.07 |
| 10 | 9/1/2023 | 3:59 PM | 598616.1 | 871417.8 | 5.86 |

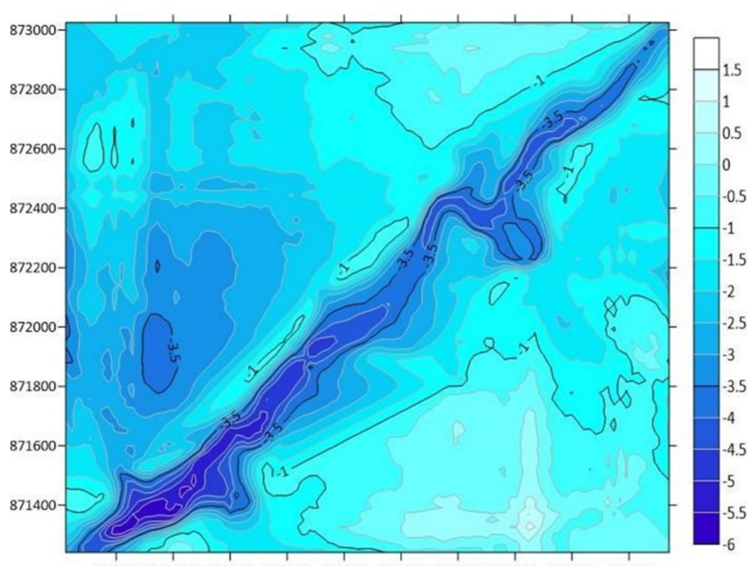

Figure 7. Isobaths map of the study area

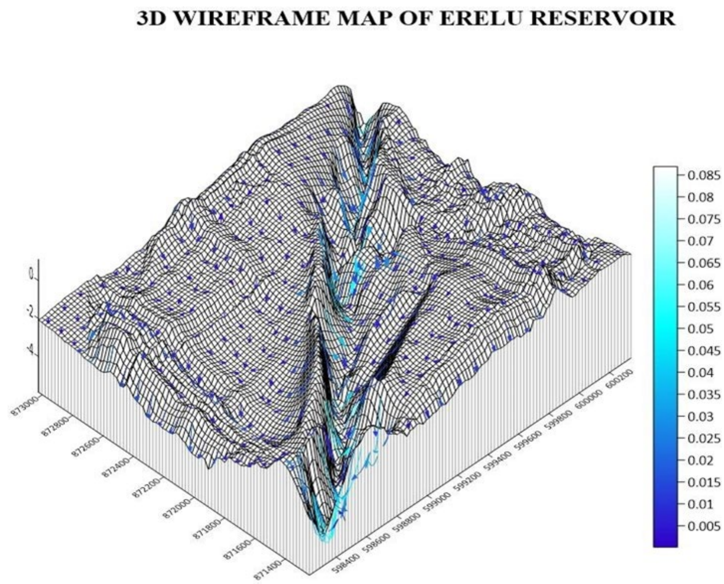


Figure 8. 3D wireframe model showing the direction of water flow

### 3.3. Surface Area and Volume results

Figure 9 shows the bathymetric chart of the study area. The volume of water carriage capacity in the reservoir area was computed from the data. The bathymetric data revealed that the maximum and minimum depths of the reservoir were 6.03meters and 0.56meters, respectively, indicating that the water body is relatively shallow. As listed in Table 3, the surface area of the reservoir was measured at approximately 120.94hectares, with a total volume of around 2,975,635m$^3$. The bathymetric chart, isobaths map (see Figure 7) and 3-D wireframe models (see Figure 8) provide insights into the reservoir's underwater topography, showing the flow direction and depth variations across the study area.

Table 3. Surface Area and Volume

| Description | Values (m) |
|---|---|
| Maximum depth | 6.47m |
| Minimum Depth | 0.65m |
| Surface Area | 1209419.82m$^2$ (120.94 Ha) |
| Volume | 3664537.13m$^3$ |

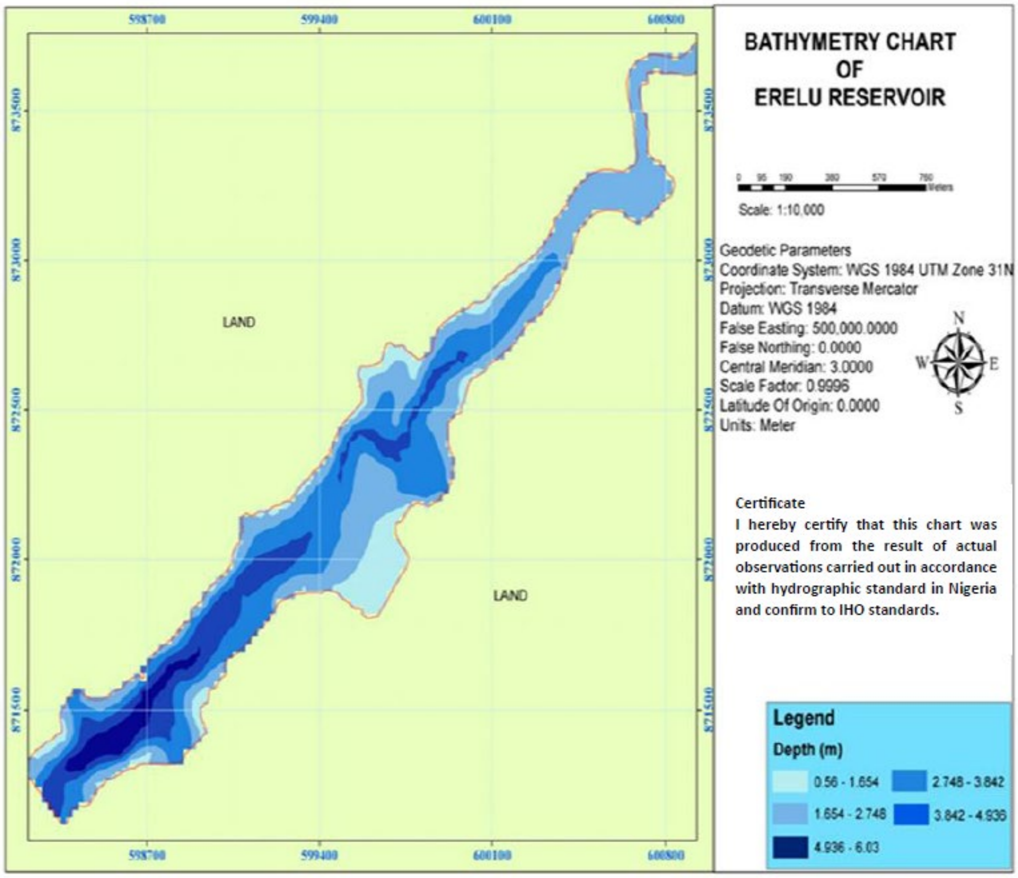


Figure 9. Bathymetric Chart

## 4. Conclusion

The study effectively demonstrates the application of remote sensing and bathymetric techniques in monitoring and analysing the physical characteristics of the Erelu Reservoir. The findings reveal significant changes in its shoreline 2007-2012 increased by 103.658m, decreased by 218.705m over the period, 2017-2022 and increased by 394.438m for the period 2022 and its water volume 3664537.13m$^3$ over the years, thus clearly indicating a dominant trend of accretion over erosion in most parts of the reservoir. The bathymetric data further underscore its shallowness, which has implications for water resource management and environmental conservation efforts.

The results underscore the need for the ongoing monitoring and management of the reservoir to mitigate the impacts of shoreline erosion and to ensure that the water resources in the area are sustainably used. Furthermore, the study provides valuable insights that can inform future policies and interventions aimed at preserving the ecological and hydrological integrity of the Erelu Reservoir.

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