# Assessment of Recent Changes in the Morphometric Characteristics of Fluviatile Lakes in the Benue Valley Area of Adamawa State, Northeastern Nigeria

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**Abstract:**
The assessment of temporal changes of the morphometric characteristics of lakes for the purposes of conservation, management and sustainable uses is paramount. In this study, recent (2013 to 2022) changes in the morphometric characteristics of Fluviatile Lakes in the Benue Valley Area of Adamawa State, Northeastern Nigeria were examined. An integrated approach of Bathymetric Survey, the Application of Geographic Information System (GIS) and Mathematical Computations was adopted for determination of the morphometric parameters. A total of eleven (11) morphometric parameters were examined. Percentage change and Paired T-test computations were used in analyzing changes in the lakes' morphometric parameters over nine (9) years period. Results showed that significant changes ($p<0.05$) in morphometric characteristics have occurred over Lakes Gwakra, Parya and Ribadu over the last nine years. Decrease in Surface Area, Volume and Maximum Depth of all studied lake indicated degradation of lake basin morphology and decrease in water contents possibly connected to climate change and excessive anthropogenic activities. The very low range of Index of Basin Permanence – IBP (0.03 to 0.15) of the lakes is an indication that they are excessively shallow and most likely dominated by large littoral areas of rooted aquatic plants. Dredging and conservation measures are recommended for sustainability of the lakes.

**Keywords:** Fluviatile Lakes, Morphometric Characteristics, Benue Valley, Gwakra, Geriyo, Ribadu, Parya

## Introduction

Lakes play a crucial role in the ecology of the world as surface freshwater resources. They are, in fact, the planet's most abounding, diverse, socially involved, and productive ecosystems (Sharma et al., 2015). They provide water for a variety of activities, including fishing, leisure, housework, and, to a lesser extent, the production of hydropower. The quantity and quality of the water that a lake contains, which is a measure of its morphometric attributes, have a considerable impact on the type and degree of use that lake receives.

Because lakes are essential to human life, people build them in both water-scarce and water-abundant places. When there is a water shortage, man-made lakes (reservoirs) store water during periods of abundance for use when there is a shortage, while when there is an abundance of water, reservoirs give humanity a way to temporarily store excessive amounts of water in order to prevent downstream property damage or human deaths (United Nations World Water Assessment Programme, 2010).

The morphometry of lakes and the hydrologic parameters of their catchments influence their sizes. According to Wetzel (2001) and Yonnana (2015), lake basins are created by a range of earth processes, including tectonic, volcanic, landslide, aeolian, fluvial, glacial, and coastal movements. In addition, humans have recently taken a leading role in the construction of lake basins (reservoirs) for the storage of water for various reasons.

Lake Morphometry is simply the study of shape and structure of lake basins (Florida LAKEWATCH, 2001). It is a science that examines the dimensions and shapes of lakes and reservoirs, as well as the physical factors that affect a lake's depth, size, shape, and surface area. It offers a numerical description of a lake's shape as well as information on its length, surface area, volume, and average depth. To acquire a sense of the physical state of lake waters both vertically (subsurface dimensions) and horizontally (surface dimensions) morphometric information is required (Sulastriningsih et al., 2021; Ridoan et al., 2016). In addition, lake morphometry is crucial for identifying the causes of modifications in a lake's physical, chemical, and process characteristics (Muhtadi et al., 2020; Wetzel 2001; Hakanson 2005a,b; Barroso et al., 2014; Cole & Weihe 2016). Moreover, it can be used to describe the potential for lakes biological production (Azzella et al. 2014; Seekell et al. 2018) and assess the degree of sensitivity to the influence of material loads from the lakes vicinities (Hakanson 2005a; Ptak et al. 2018). As a result, gathering and analyses of morphometric data are very essential for the management and sustainable use of lakes' aquatic resources (Wetzel 2001; Cole & Weihe 2016; Siddiq et al 2019). Base on numerous studies, the effects of lake morphometric parameters on such processes as water retention time, stability of the water column, and stratification, which in turn affect the limnologic characteristics of lakes, have been thoroughly examined and acknowledged. (Sobek et al., 2011; Jeppensen et al., 2005; Hakanson 2005a; Algesten et al., 2004; Hakanson 2004; Hellstrom 1991; Hamilton and Lewis 1990; Solomons and Förstner 1984).

Due to anthropogenic influences as well as natural phenomena that can cause rapid environmental changes to their ecosystems, lakes are among the most fragile environments in the world (Abebe et. al., 2018). Owing to the effects of these factors lakes and reservoirs are subjected to gradual changes in their basin morphologies and losses in their hydrological potentials over time (Yonnana, 2015). Through the combined effects of climatic change, catchment erosion and deposition rates linked to changing land uses, and accumulation of mineral and organic materials, they can either Shrink and subsequently dry up or collect materials that will fill up their basins. Several studies have consistently pointed out the vulnerability of these important water bodies to influences of climate change and land uses (Duluth, 2007; Gasiorowski, 2008; Kunz et al., 2010; Dong and Song, 2011).

Abebe et al., (2018) observed that changes in lakes can be manifested in surface area, volume or capacity changes and variation in the water quality depending on the dynamics in the contributing area, the size and shape of the water body, and the geologic formation. As such, the study of lake of changes in lake morphometry is important not only to understand the spatial or temporal dynamics in the shape and size of the lake, but also to grasp changes in its hydrologic and limnologic characteristics (Sandwell, et al., 2000; Schäfer et al., 2014). In general, historical morphometric investigations offer details on bathymetric features, changes in erosion and sediment deposition over time, and space, which in turn can be used to study and remedy the implications on both physical and biological systems (Abebe et al., 2018).

In the past, mapping of lakes and determination of their morphometric characteristics were very tedious tasks that required laborious surveying methods and procedures (Climate Policy watcher, 2023 February). Today, with advent of various forms of water depth sounders and satellites as well as the applications of Remote Sensing and Geographic Information Systems (GIS), such lake studies are simplified. The possibilities of assessing temporal morphometric changes in lakes using bathymetric map and Remote Sensing and GIS technologies have been acknowledged (Abebe et al., 2018; Menberu et al., 2021)

In the Benue valley area of Adamawa Sate is situated over 12 fluviatile lakes that are of ecological, sociocultural, and economic relevance. Serving as habitats to numerous species of aquatic biodiversity, source of water, and nutrients to many riparian plants and animals as supplying means of livelihood to many human communities in the area, the lakes are considered with high levels of relevance and regards. However, being components of the natural environment, they are subjected to changes in their morphometric characteristics over time. This informed the need for the baseline study conducted between 2013 and 2015 as reported by Yonnana (2015) and Yonnana et al., (2015).

Braced by the baseline studies of the morphometric characteristics of Lakes Gwakra, Geriyo, Parya and Ribadu carried out by Yonnana et al., (2015), the current study focuses on ascertaining morphometric changes that have occurred over the lakes in the last nine (9) years (2013 to 2022). The study aims at ascertaining the nature and magnitudes the changes in order to proffer meaningful suggestions towards qualitative management of the lakes' ecosystems for sustainability.

## Materials and Methods

### *Study Area*

The four lakes on which studies were conducted are situated within the Benue river Valley area of Adamawa State. This study portion of the Benue valley lies between latitudes 09°09'00"N and 09°33"00″N of the Prime Meridian and between Longitudes 12°21'00"E and 12°5400E of the Prime Meridian (figure 1). Locations of the studied lakes are presented on Table 1.

The study region falls within the southern Sudan Savanna belt of Nigeria, which has a semi-arid environment with five months of rainy season and seven months of dry season. Peak rainfall is recorded in the months of August and September, with annual precipitation values ranging from 656.70mm to 1113.30mm. The driest months are January, February, and March, with annual evaporation values ranging from 1675.91mm to 3272.62mm (Upper Benue River Basin Development Authority-UBRDA, 2013).

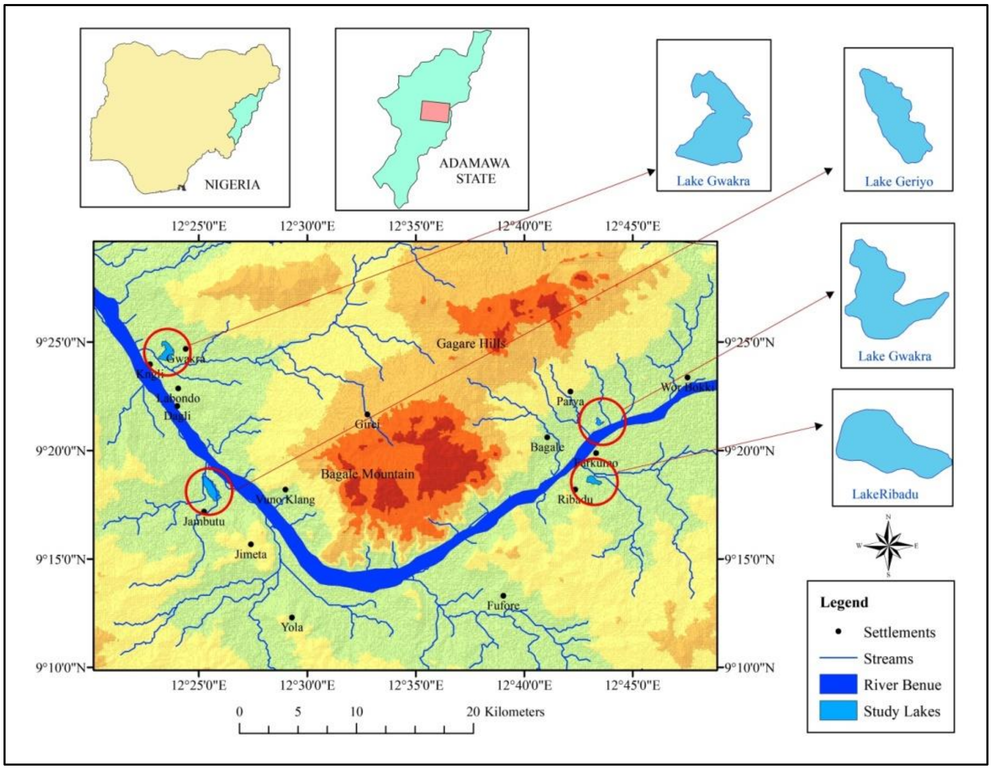


**Figure 1:** The Study Area

**Table 1:** Location and elevations of the study lakes

| S/No | Lake | Longitude | Latitude | Elevation (m.a.s.l) |
|---|---|---|---|---|
| 1 | Lake Gwakra | 09°24’26"N | 12°23’38"E | 151 |
| 2 | Lake Geriyo | 09°18’15"N | 12°25’34"E | 152 |
| 3 | Lake Parya | 09°21’17"N | 12°43’27"E | 162 |
| 4 | Lake Ribadu | 09°18’36"N, | 12°43’12"E | 158 |

Since the lakes are fluviatile in nature, they are recharged by overflow of the Benue River during the rainy seasons, direct rainfall, and surface runoffs. Ephemeral in character, the runoffs take their sources from hills and uplands in the study region and transit a variety of land use zones, primarily agriculture and built-up areas, where they obtain the majority of the physicochemical parameters drained into the lakes. The area is also characterized by a sedimentary geologic structure, largely the Bima and Yola Sandstones from which the soils were derived. Most of the area’s indigenous vegetal species have been depleted by anthropogenic activities and the original land cover replaced by largely farmlands and human settlements. All these study area characteristics and activities tend to contribute to the changing morphometric characteristics of the fluviatile lakes in the area.

**Data Collection**

Both process and historical methods of lake system studies in geomorphology as suggested by Kashiwaya (2017) were employed in this study. An integrated approach of Bathymetric Survey, the Application of Geographic Information System (GIS) and Mathematical Computations was adopted for the study.

Bathymetric survey of the lakes was conducted by a combined sounding routine which involved the use of HONDEX PS-7 Portable Handheld Depth Sounder. Garmin eTrex-20 Global Positioning System (GPS) and the Sounding Rod (staff) Method as described by Davis et al., (1981) and Basak (1994). The use of these equipment was complemented with The Handheld Depth Sounder was used for most of the depth measurements owing to its accuracy in measuring water depths within the range of 0.6m to 80m. The soundings were conducted along defined paths of about 15 m apart across each of the lakes. At each sounding point, Three dimensional coordinates (x,y,z) representing Easting, Northing and water depth were obtained. The X and Y coordinates were obtained in Universal Traverse Mercator (UTM) coordinate system. Totals of 1227, 1016, 839 and 802 sounding points were established and measured for Lakes Gwakra, Geriyo, Ribadu and Parya Ribadu, respectively. The bathymetric surveys and mapping were conducted in March 2022.

The Bathymetric survey data were compiled processed and analyzed using Microsoft Excel and ArcGIS 10.3 Software. The data were compiled and saved as Text Tab Delimited format in Microsoft Excel and then imported as point shape file features in the ArcMap environment of ArcGIS 10.3 for preparation of the lakes' bathymetric maps as described by Ezekiel et al., (2019).

**Morphometric Analyses**

From the bathymetric maps generated, the lakes' Perimeters technically known as Shoreline Lengths ($S_L$) and their Surface Areas ($A_0$) where measured using the calculate Geometry procedures of the attribute table in ArcGIS 10.3. Other dimensional parameters as Maximum Length ($L_{Max}$) and Maximum Width ($W_{Max}$) were measured directly using the measure tool of the GIS software.

While the lakes' shoreline elevation and maximum depth values were measured directly on the field, other parameters such as the Relative Depth ($Z_r$ ), Mean Depth ($Z_{Mean}$), Development of Volume ($D_v$ ), Lake Volume (V), Shoreline Development Index (DL) and Index of Basin Permanence (IBP) were calculated mathematically using the appropriate formulae as shown in Table 1. Changes in the morphometric characteristics of the lakes were finally deduced by comparative analyses of the currents results with those of Yonnana et al., (2015). Percentage change and Paired samples t-test (at $\alpha \leq 0.05$ level of significance) computations were used in analyzing changes in the lakes' morphometric parameters over eight years period.

Table 1: Morphometric parameters and their symbols and formulae

| S/No | Morphometric Parameter | Symbol/Formula |
|---|---|---|
| 1 | Shoreline Length | $S_L$ |
| 2 | Maximum Length | $L_{max}$ |
| 3 | Maximum Width | $W_{max}$ |
| 4 | Surface Area | $A_0$ |
| 5 | Maximum Depth | $Z_{max}$ |
| 6 | Mean Depth | $Z_{mean} = V/A_0$ |
| 7 | Relative Depth | $Zr = \frac{50(z_{mean})\sqrt{\pi}}{\sqrt{A_0}}$ or $\frac{88.6 \times z_{mean}}{\sqrt{A_0}}$<br>Where; $\pi$ =3.142 |
| 8 | Shoreline Development Index | $D_{SL} = \frac{S_L}{2\sqrt{\pi A_0}}$<br>Where; $\pi$ =3.142 |
| 9 | Development of Volume | $D_V = \frac{3Z_{mean}}{Z_{max}}$ |
| 10 | Volume | $V_{z0-z1} = \frac{1}{3}\left(A_{z0} + A_{z1} + \sqrt{A_{z0} \times A_{z1}}\right)(z_0 - z_1)$<br>Where; $V_{zo-z1}$ = volume of truncated part of the lake between the shoreline on depth ($z_0$) and successive depth $z_{1;}$<br>$Az_0$ = Surface Area at $z_0$<br>$Az_1$ = Surface Area at $z_1$ |
| 11 | Index of Basin Permanence | $IBP = V/S_L$ |

Source: Wetzel (2001); SWCSMH, (2015)

**Results and Discussion**

Changes in the morphometric characteristics of the studied lakes are presented on Tables 1, 2, 3 and 4. Results showed a general decrease in shoreline (perimeter) of the lakes. Although the decrease was very slight (2.30%) over Lake Gwakra, there was sharp noticeable change in the shape of the lake (Fig.2). Changes in the shoreline lengths of the other lakes were computed at 22.8%, 22.2% and 1.3% for lakes Geriyo, Parya and Ribadu, respectively; all indicating decrease in the lakes' perimeters (Tables 1, 2, 3 and 4). These decreases had influences on changes in the Maximum Lengths, Maximum Widths and Surface Areas of the lakes, thus having the possibilities of influencing the effects of wind on the lakes in terms of exposure to free oxygen diffusion.

There was decrease in the mean depths of the lakes (33.3%, 41.5% and 34.6% for Lakes Gwakra, Parya and Ribadu, respectively) with slight increase (4.8%) over Lake Geriyo owing to skeletal dredging by humans for rice cultivation. The decrease in the lakes' mean depths in turn influenced their Relative Depths and Developments of Volume. Besides, the mean depth values (ranging from

0.38 m to 0.87 m) as shown on Tables 2 to 4 portrayed vital information on the gradual increasing shallow states of the lakes. Consequently, they could be considered as very shallow lakes (mean water depths < 3.0 m) as opined by Singh et al., (2023)

**Table 2:** Changes in the morphometric parameters of Lake Gwakra from 2013 to 2022

| S/NO | LAKE GWAKRA<br>Morphometric Parameters | 2013 | 2022 | Percentage Change | Nature of Change |
|---|---|---|---|---|---|
| 1 | Shoreline Length (Km) | 5.22 | 5.1 | 2.30 | Decrease |
| 2 | Maximum Length (Km) | 1.66 | 1.62 | 2.41 | Decrease |
| 3 | Maximum Width (Km) | 1.52 | 1.12 | 26.3 | Decrease |
| 4 | Surface Area ($Km^2$) | 1.41 | 1.13 | 19.5 | Decrease |
| 5 | Maximum Depth | 1.46 | 1.22 | 16.4 | Decrease |
| 6 | Mean Depth (m) | 0.6 | 0.4 | 33.3 | Decrease |
| 7 | Relative Depth | 0.04 | 0.03 | 25.0 | Decrease |
| 8 | Shoreline Development Index | 1.24 | 1.35 | 8.1 | Increase |
| 9 | Development of Volume (Dv) | 1.23 | 0.86 | 30.1 | Decrease |
| 10 | Volume (mcm) | 0.85 | 0.45 | 47.1 | Decrease |
| 11 | Index of Basin Permanence (IPB) | 0.16 | 0.09 | 43.8 | Decrease |

The Relative Depth of a Lake is the its maximum depth expressed as the percentage of its mean diameter. It is a measure of lake stability in relation to mixture by wind. As such lakes with low relative depths are more susceptible to mixture wind action. Results showed that all the lakes are characterized by very low relative depth values (0.03 to 0.17). Furthermore, the relative depth values were found to have decreased over lakes Gwakra, Parya and Ribadu over the nine years study period. This indicates decrease I water stability as well as increase in susceptibility to mixture by wind. However, a 33.3% increase in relative depth was observed over Lake Geriyo owing to slight increase in mean depth and development of volume despite decrease in the lake water volume. The major factor behind this scenario is anthropogenic. Lake Geriyo serves as the major source of water for the Geriyo Irrigation Project operating in the area. Thus the farmers periodically engage in local dredging activities over the lake in order to sustain water availability for irrigation. These activities include sediment influx control around the lake shores and inlets as well as weeding and removal aquatic macrophytes from the lake littoral zone to minimize organic sedimentation.

Shoreline Development Index ($D_{SL}$) is the ratio of shoreline length to the length of the circumference of a circle of area equal to that of the lake (Hutchinson 1957; SWCSMH, 2015). It is an important lake morphometric parameter that reflects lake shape regularity or irregularity (Muhtadi et al., 2020) as well as the potential for development of littoral communities, which are usually of high biological productivity (SWCSMH, 2015). According to Muthadi (2020), a $D_{SL}$ value greater than 1.0 indicates the lake shape is irregular, while a value less than 1.0 indicates a regular lake shape. Results showed high and increasing values shoreline development indices (1.35 to 1.60) over the lakes. This is an indication of irregularity in the shapes of the lakes as well as increasing possibilities for shallowness and development of littoral communities in the lakes. The indices for Lakes Gwakra, Geriyo and Ribadu were found to have increased by 8.1%, 2.9% and 8.8%, respectively over the nine years period (Tables 1, 2 and 4). The low percentage change for Lake Geriyo was due to the periodic littoral weed control carried out by irrigation farmers in the lake area. However, the shoreline development index for Lake Parya was found to have decreased by 13% (Table 3). This decrease was due to the recent transformation of a substantial part of the lake littoral zone (5.0 Hectares) to marshland (Figure 2).

Development of Volume ($D_v$) is a measure of departure of the shape of the lake basin from that of a cone (Hutchinson 1957; SWCSMH, 2015). The Development of Volume values of the studied lakes have evolved between 0.81 and 1.35 over the nine years study period. The implication is that although the lakes are shallow, they are characterized by very slight conical basin morphologies. This is clearly portrayed in the bathymetric maps presented in figure 2, where the lakes exhibited single and narrow zones of maximum depths.

**Table 3:** Changes in the morphometric parameters of Lake Geriyo from 2013 to 2022

| S/NO | LAKE GERIYO | 2013 | 2022 | Percentage | Nature of |
|---|---|---|---|---|---|

| | Morphometric Parameters | | | Change | Change |
|---|---|---|---|---|---|
| 1 | Shoreline Length (Km) | 8.1 | 6.25 | 22.8 | Decrease |
| 2 | Maximum Length (Km) | 3.14 | 2.45 | 22.0 | Decrease |
| 3 | Maximum Width (Km) | 1.07 | 0.88 | 17.8 | Decrease |
| 4 | Surface Area ($Km^2$) | 2.82 | 1.59 | 43.7 | Decrease |
| 5 | Maximum Depth | 1.48 | 1.17 | 20.9 | Decrease |
| 6 | Mean Depth (m) | 0.40 | 0.42 | 4.8 | Slight Increase |
| 7 | Relative Depth | 0.02 | 0.03 | 33.3 | Increase |
| 8 | Shoreline Development Index | 1.36 | 1.4 | 2.9 | Increase |
| 9 | Development of Volume (Dv) | 0.81 | 1.07 | 24.3 | Increase |
| 10 | Volume (mcm) | 1.12 | 0.66 | 41.1 | Decrease |
| 11 | Index od Basin Permanence (IPB) | 0.14 | 0.11 | 21.4 | Decrease |

Lake Volume (V) is a measure of the lake water content in cubic meters ($m^3$) or million cubic meters (mcm). It is an important morphometric parameter that defines the functionality of the lake to greater extent such that significant decrease in the lake volume signifies depletion in water content. Sadly, results revealed substantial decrease in the volume of the lakes over the nine years study period. The decrease in volume ranged from 41.1% over Lake Geriyo to 52.9% over Lake Parya (Tables 2 to 5). This decrease in volumes could be tied to the combined effects of climate change, excessive extraction of water for irrigation and siltation of the lake basins. In a recent study conducted by Peter (2023), it was observed that the drastic degradation of Lake Gwakra was strongly tied to its siltation by sediments from the Jibiro Drainage Basin whose pour point diverted into the lakes in the last few years. The decrease in size and change in shape of Lake Parya as shown by its recent bathymetric map (Fig 2) are responsible for the lake's 52.9% change in volume. It was gathered from field observation that a substantial part of the lake (5.0 Hectares of its surface area) has been converted to marshland over the last six to seven years owing to increasing temperature/evaporation and human influences.

**Table 4:** Changes in the morphometric parameters of Lake Parya from 2013 to 2022

| S/NO | LAKE PARYA<br>Morphometric Parameters | 2013 | 2022 | Percentage Change | Nature of Change |
|---|---|---|---|---|---|
| 1 | Shoreline Length (Km) | 3.34 | 2.60 | 22.2 | Decrease |
| 2 | Maximum Length (Km) | 0.89 | 0.7 | 21.3 | Decrease |
| 3 | Maximum Width (Km) | 0.34 | 0.3 | 11.8 | Decrease |
| 4 | Surface Area ($Km^2$) | 0.26 | 0.21 | 20.5 | Decrease |
| 5 | Maximum Depth | 2.43 | 1.26 | 48.1 | Decrease |
| 6 | Mean Depth (m) | 0.65 | 0.38 | 41.5 | Decrease |
| 7 | Relative Depth | 0.23 | 0.17 | 26.1 | Decrease |
| 9 | Shoreline Development Factor | 1.84 | 1.60 | 13.0 | Decrease |
| 10 | Development of Volume (Dv) | 0.98 | 0.90 | 8.2 | Decrease |
| 11 | Volume (mcm) | 0.17 | 0.08 | 52.9 | Decrease |
| 12 | Index od Basin Permanence (IPB) | 0.04 | 0.03 | 25.0 | Decrease |

Index of Basin Permanence (IBP) is a morphometric parameter that indicates the lake's littoral effect on its basin volume. IBP values less than 0.1 indicate excessive shallowness and dominance of rooted aquatic plants within the lake, while values greater than 2.0 indicate more permanence in water status (SWCSMH, 2015). From the study, a general decrease in IBP was observed for all the lakes. The range from 0,03 (Lake Parya) to 0.15 (Lake Ribadu) portrayed the shallow status of the lakes and their dominance by rooted aquatic plants (Plates1a and b) which define the influence of the littoral zones on the lakes volume.

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(a); Lake Parya (a); Lake Gwakra

**Plate 1(a) and (b):** Evidence of rooted aquatic plants in Lakes Parya and Gwakra

**Table 5:** Changes in the morphometric parameters of Lake Ribadu from 2013 to 2022

| S/NO | LAKE RIBADU Morphometric parameters | 2013 | 2022 | Percentage Change | Nature of Change |
|---|---|---|---|---|---|
| 1 | Shoreline Length (Km) | 3.94 | 3.89 | 0.8 | Increase |
| 2 | Maximum Length (Km) | 1.53 | 1.42 | 7.2 | Decrease |
| 3 | Maximum Width (Km) | 0.8 | 0.72 | 10.0 | Decrease |
| 4 | Surface Area ($Km^2$) | 0.81 | 0.68 | 16.4 | Decrease |
| 5 | Maximum Depth | 2.95 | 2.24 | 24.1 | Decrease |
| 6 | Mean Depth (m) | 1.33 | 0.87 | 34.6 | Decrease |
| 7 | Relative Depth | 0.12 | 0.09 | 25.0 | Decrease |
| 9 | Shoreline Development Factor | 1.24 | 1.36 | 8.8 | Increase |
| 10 | Development of Volume (Dv) | 1.35 | 1.15 | 14.8 | Decrease |
| 11 | Volume (mcm) | 1.08 | 0.59 | 45.4 | Decrease |
| 12 | Index od Basin Permanence (IBP) | 0.27 | 0.15 | 44.4 | Decrease |

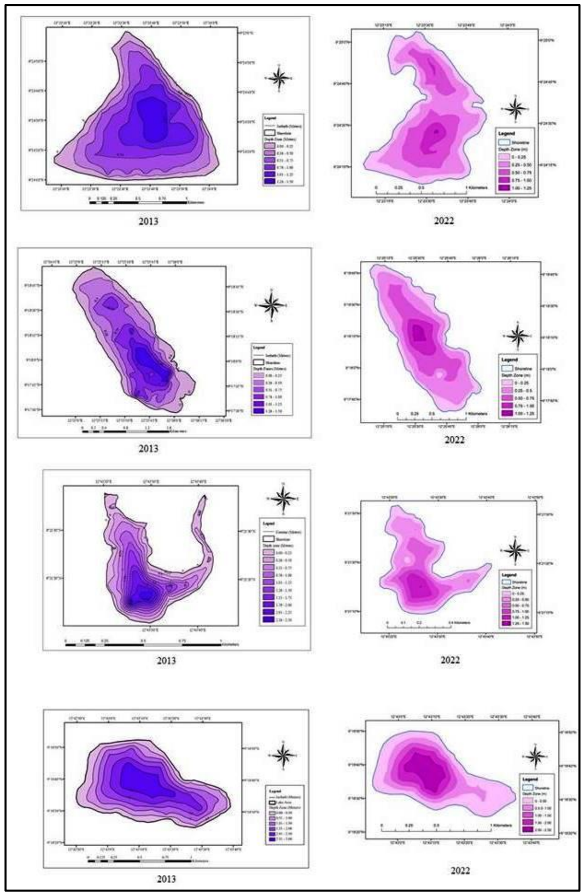


**Figure 2:** Bathymetric maps showing variations in the morphologic nature of the lakes from 2013 to 2022

## Conclusion

On a general note, it was discovered from Students T-test analyses that except for Lake Geriyo, all the other lakes exhibited significant changes ($p<0.05$) in their morphometric characteristics over the nine years period of study. The T-test result for Lake Geriyo showed a p-value of 0.062 indicating that the changes over the lake were not significant at 95% confidence interval. Besides, there was an increasing tilt away from regularity in the shapes of the lakes as well as a general decrease in their volumes. These are all clear indicators of morphometric degradation that could pose adverse effects on the lakes' physical, chemical and biological properties. Furthermore, considering the current trends of natural and anthropogenic factors acting on the lakes, the possibilities of further degradation and depletion of their resource potentials are eminent. Thus, urgent attention towards the reclamation of the lakes' morphologies and conservation for sustainable uses is required.

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