# Analysis of factors determining the hydrodynamics of Agulu Lake: A multivariate linear model approach.

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## Abstract

*This study employs an approach providing interpretation and understanding of how much of the variations in the hydrologic flows of the lake are related to morphometry, climate, and human interferences. The morphometry of lakes, climatic, and anthropogenic factors regulate the amount of outflow originating from lakes. This paper analysed and discussed the key variables amongst a range of factors determining the outflow condition of Agulu Lake. The principal component analysis (PCA) has shown that, of the nine factors identified, four components surfaced which are independent of each other. Lake morphometry, hydrological input, temperature, and evaporation rate were shown to account for 96.231% of the variance in the hydrodynamic conditioning of the lake. We then evaluated the effects of the four components on the hydrodynamic processes by isolating from each of the four components, the component defining variables (CDVs) using a multivariate linear model. Using our model, we estimated lake outflow. We found a good linear correlation between the predicted and observed annual lake outflow ($r=0.99$, $P<0.05$). The assessment indices indicate that the model represented the observed data quite well with NSE=0.991, RSR= 0.097, and PBIAS=0.0396. This shows that the model is a good predictor of the lake outflow response in relation to the hydro-climatic-morphometric parameters permitting an accurate prediction of the lake outflow from the CDVs. This approach, which uses the CDVs in a multivariate linear model, enables us to quantitatively describe the lake's responses to climatic, morphometric, and anthropogenic changes within its catchment.*

## 1.0 Introduction

Lakes are widely recognised as key indicators of environmental change (Nzoiwu and Ezenwaji, 2017). They are capable of mirroring changes in climate conditions and anthropogenic activities in their catchment area through variations in their morphometry characteristics and hydrological response. For instance, the reduction in rainfall exerts a huge impact on the hydrology of Lake Ziway, Ethiopia, by causing a reduction in the runoff. (Abraham, Woldemicheala, Muluneha, and Abateb, 2018) The consequence of such an outcome is the inability of the lake to meet the future water demands of the increasing population. Thus, the rational use of lakes requires comprehensive

knowledge of the processes that occur in the water bodies and natural trends in the development of their ecosystem (Ilyin and Ilyina, 2022). This has been achieved in previous studies through various modelling approaches. Modelling allows for quantified assessment of the impacts of climatic and anthropogenic changes on water availability and functioning of lake ecosystems (Mbanguka, Lyon, Holmgren, Lopez and Jarsjo, 2016). Modeling of lake systems further enhances our understanding of important processes controlling lake dynamics (Mbanguka, et al., 2016) such as determining the water balance of lakes (Ayenew and Gebreegziabher, 2006; Ufoegbune, Yusuf, Eruola and Awomeso, 2011), examining the sensitivity of lakes to fluctuations in climate variables (Kebede, Travi, Alemayehu and Mac, 2006; Kumambala and Ervine, 2010; Mbanguka et al., 2016), lake hydrological responses to climate change (Abraham, et al., 2018), calibration and simulation of discharge within Lake basins (Adeyeri, Laux, Arnault, Lawin and Kunstmann, 2020) and planning for water resources management (Bellin, Majone, Cainelli, Alberici and Villa, 2016). The hydrology of Agulu Lake is poorly documented. The implication of this is that, we cannot ascertain in clear terms the amount of water abstraction occurring in the lake, the volume of outflow leaving the lake at varying scales (outflow-lake level relationship), and the potential water supply capacity of the lake. How then can the vested interests and concerned communities depending greatly on this lake be assured of the sustenance of the lake for the range of its benefits? In previous work, Nzoiwu, Ezenwaji and Okoye (2017) conducted a preliminary assessment of the correlation between lake area and meteorological variables and concluded that precipitation, temperature and open water evaporation some of the factors impacting on the observed variability in the lake surface area. In this paper, multivariate linear model was used to examine and identify the underlying climate, morphometric and anthropogenic variables determining the hydrologic behaviour of Agulu Lake.

## 2.0 Materials and Methods

### 2.1 Study area

Agulu Lake is a natural inland water lake characterized by the sacred and cultural landmark of attraction and it is the largest lentic water body in Anambra state (Nzoiwu, Ezenwaji and Ezeonyejiaku, 2023). Agulu Lake is located within latitudes 6°07' and 6°09'N and longitudes 7°01' and 7°03'E in Anambra State, Nigeria (Fig 1). The lake has an area of about 440361m$^2$ or 0.44km$^2$ and a depth that varies from 1.5m to 9.5m, with an average depth of 5.7m. Bathymetric sounding

revealed the deepest part of the lake to be 9.5m (Nzoiwu, 2023). The lake's surface area has varied over time (Nzoiwu, Ezenwaji and Okoye, 2017).

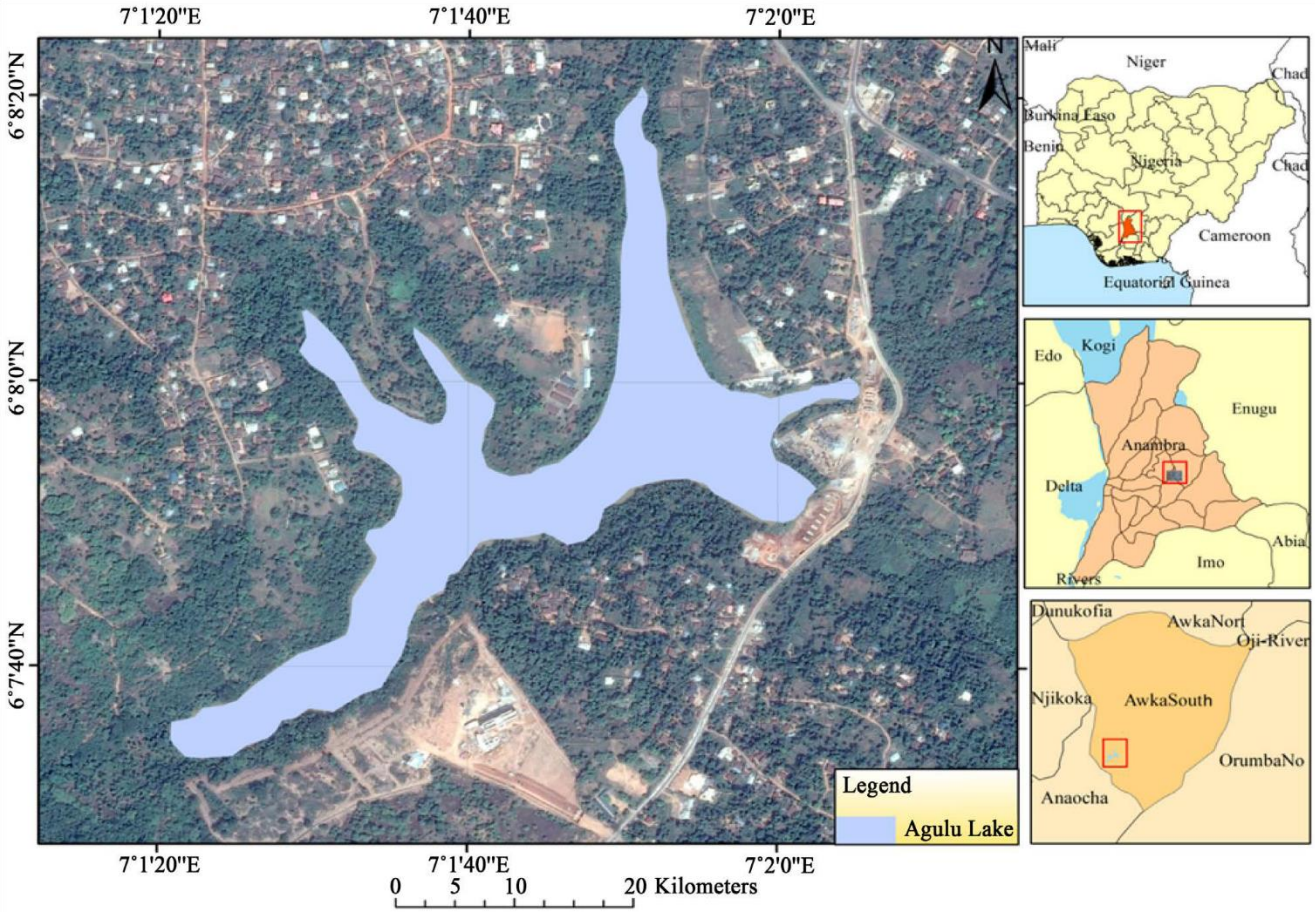



Fig 1: Map of Agulu Lake in Anambra State, Nigeria (source:

The geology of Agulu lake dominated by sediments of poorly consolidated sand units with a lithostratigraphic thickness of up to 2500m made up of Nkporo shale, Mamu formations, Ajalli sandstone, Nsukka formation, Imo shale, Nanka sands, Ameki formation, Nsugbe formation and Ogwashi-Asaba formation (Egboka, Nfor and Balanjo, 2006). The study area is situated on the Awka-Orlu uplands and the elevation of the terrain surrounding the lake varies from 300m to 600m. The area is characterized by a tropical wet and dry climate. The climate pattern that dominates Agulu Lake and its environs are controlled by the movement of the ITD and is characterized by a dry season (November to March) with dry continental North-East winds dominating during this period and a long-wet season which occurs normally from April to October and dominated by the moist maritime south-west winds. The annual rainfall of the study area ranges from 1383mm to 2090mm (Nzoiwu and Ezenwaji, 2017) while the mean annual rainfall

has varied from 1824mm to 1991.9mm with relative humidity close to 80%. The rainfall regime is of double maxima with the first peak occurring in July followed by another peak in September. The lake is one of the headwaters of the Idemili River which drains different communities in Anambra State before emptying into River Niger.

Table 1: Morphometric characteristics of Agulu Lake (Nzoiwu, 2023)

| **Morphometric characteristics** | **Values** |
|---|---|
| Surface area | 440,360m$^2$ (this varies seasonally) |
| Maximum depth | 9.5m |
| Maximum length | 1.3km |
| Mean depth | 5.7m |
| Shoreline length | 6.43km |
| Lake volume | 4,701,081m$^3$ |
| Elevation | 99.9m – 102.1m |

## 2.2 Data collection

Lake outflow, depth measurements, lake volume, lake catchment runoff. and surface area data for Agulu Lake were from previous research (Nzoiwu, 2023). The data on outflows from Agulu Lake simply depicts variations that reflect or amplify changes in monthly rainfall variations. We employed linear interpolation to interpolate these data to annual resolution and we used the annual values in the modelling approach. Rainfall and temperature data were collected from the Nigeria Meteorological station at Enugu-Agidi and the automated meteorological station at the Department of Geography and Meteorology, Nnamdi Azikiwe University Awka ($6^{O}14^{1}50.20^{11}$N, $7^{o}7^{1}17.60^{11}$E). Open water evaporation from Agulu Lake was estimated using the Penman approach formulated as follows:

$$Eo = \frac{\Delta R + \gamma Ea}{\Delta + \gamma} \quad (1)$$

where, $E_o$ is open water evaporation, $\Delta$ is slope of the saturation vapour pressure curve for water at the mean air temperature, R is from net radiation equation, $\gamma$ is psychometric constant, Ea is an aerodynamic term.

## 2.3 Data Analysis

We used the principal component analysis (PCA) in exploring and providing further explanation to the core variables determining the variations observed in the hydrologic behaviour of Agulu lake. PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (or sometimes, principal modes of variation). We used the PCA to reduce the dimensionality of the dataset and to extract the latent variables for multivariate regression (Ma, Wu, Liu, and Abuduwaili, 2014). This transformation is defined in such a way that the first principal component has the largest possible variance, and each succeeding component in turn has the highest variance possible and is orthogonal. The resulting vectors are uncorrelated and orthogonal. PCA was done by eigen-value decomposition of the data covariance (or correlation) matrix or singular value decomposition of a data matrix, usually after mean centering (and normalizing or using Z-scores) the data matrix for each attribute. The results of the PCA were discussed in terms of the loadings. The principal component loadings were run from the four orthogonal components. The multiple linear regression (MLR) analysis was done on the selected defining loadings known as component defining loadings (CDV). Lake outflow was the dependent variable while other morphometric and climate variables are independent variables. With this, a principal component regression (PCR) equation was produced and used to interpret the result.

## 2.4 Assessment of the Multivariate Linear Model

We evaluated the accuracy measure of the multivariate linear model using Nash-Sutcliffe efficiency (NSE) ratio (Nash-Sutcliffe, 1970), the root mean square error to the standard deviation of measured data (RSR) and the percentage bias (PBIAS) model assessment indices given as follows:

$$NSE = 1 - \frac{\sum\left(X_i - \hat{X}_i\right)^2}{\sum(X_i - \bar{X}_i)^2}$$

$$RSR = \frac{\sqrt{\sum\left(X_i - \hat{X}_i\right)^2}}{\sqrt{\sum\left(X_i - \hat{X}_i\right)^2}}$$

$$PBIAS = \frac{\sum(X_i - \hat{X}_i) \times 100}{\sum X_i}$$

where $X_i$, $\hat{X}_i$ and $\bar{X}_i$ are the observed annual lake outflow, the predicted annual lake outflow and mean of the observed data.

The theoretical range of NSE is from -∞ to 1, with NSE = 1 being the optimal value. The RSR varies from the optimal value of 0, which indicates zero root mean square error and perfect model simulation, to a large positive value. Lower RSR implies low root mean square error and better model simulation (Moriasi, Arnold, Van Liew, Binger, Harmel, and Veith, 2007). PBIAS is a measure of over-and-underestimation (Politi, Cutler and Rowan, 2012) or the average tendency of the simulated data to be larger or smaller than the observed counterparts (Ma et al., 2014). The optimal value of PBIAS is 0.0 with low values indicating accurate model simulation. The general performance rating of the indices is as shown in table 2.

**Table 2: Performance Rating for Recommended statistics**

| **Performance rating** | **RSR** | **NSE** | **PBIAS** |
|---|---|---|---|
| Very good | 0.0≤RSR≤0.50 | 0.75<NSE≤1.00 | PBIAS<±10 |
| Good | 0.50<RSR≤0.60 | 0.65<NSE≤0.75 | ±10≤PBIAS<±15 |
| Satisfactory | 0.60<RSR≤0.70 | 0.50<NSE≤0.65 | ±15≤PBIAS<±25 |
| Unsatisfactory | RSR>0.70 | NSE≤0.50 | PBIAS≥±25 |

## 3.0 Results

### 3.1 Variation of Agulu lake characteristics over the past 46 years

Based on the annual estimates of the morphometric characteristics of the lake, the evolution of Agulu lake was divided into five periods (table 3). During the first decade, which ended in 1984, the mean surface area lake for the decade was 0.5415km$^2$. In the second decade (1985-1994), the lake shrank and the mean surface area was 0.4687km$^2$. Between the second decade (1985-1994) and the third decade (1995-2004) the lake area was relatively stable despite the decline. The lake continued its subsequent decline in area to 0.3643km$^2$ in the last period (2015-2020). Similar trend was observed for other morphometric variables of the lake. As shown in table 3, mean lake volume, mean lake depth and mean outflow from the lake for the five periods were estimated and continued

decline has been evident. Contrarily, while the catchment runoff to the lake has been relatively stable between the first four decades, this rose sharply to a historically large amount of 1325.3mm in the last period (2015-2020).

Table 3: Changes in Morphometric characteristics of Agulu Lake over the past 46years

| Periods | Mean Lake Volume ($m^3$) | Mean Catchment runoff into the Lake (mm) | Mean Outflow from the Lake (mm) | Mean Lake depth (m) | Mean Lake Surface Area ($km^2$) |
|---|---|---|---|---|---|
| 1975-1984 | 9268445.7 | 713.8 | 2456.5 | 16.0 | 0.5414686 |
| 1985-1994 | 5306623.8 | 791.9 | 1276.2 | 11.2 | 0.468700 |
| 1995-2004 | 3816487.5 | 785.2 | 865.4 | 9.1 | 0.418800 |
| 2005-2014 | 2924169.0 | 772.2 | 640.4 | 7.7 | 0.3781124 |
| 2015-2020 | 2727263.6 | 1325.3 | 596.9 | 7.3 | 0.3643018 |

### 3.2 Extraction of components from the climate, anthropogenic, and morphometric data

To explain the major contributory factors to the observed variance in the flow process of Agulu lake, the climatic, anthropogenic and morphometric variables were subjected to principal component analysis (PCA) to explore the originality of the variance while the partial least square regression was employed to eliminate potential collinearity among the independent variables and for structural modeling. The explanation was sought to determine the dominant variables affecting the rate of outflow from the lake. In analysing the whole data, they were first transformed into a matrix of standard scores (table 4) after which the correlation analysis was performed on the transformed data. Table 5 shows the labeling and coding of the variables.

Table 4: Standardised data matrix of climatic and morphometric variables

| rainfall | Temp | Evaporation | Inflow to the lake | Outflow from the lake | Lake area | Lake depth | Volume | Water Abstraction |
|---|---|---|---|---|---|---|---|---|
| -1.1051 | -1.2925 | -0.9549 | -1.1289 | 0.9683 | 0.0027 | 1.0808 | 1.0161 | -1.2058 |
| 0.1325 | -1.4828 | -0.1758 | -0.0467 | 0.1846 | 0.5532 | 0.3310 | 0.2411 | -1.1039 |
| -0.5025 | -0.1821 | 0.0294 | -0.3312 | 0.1858 | 0.5545 | 0.3322 | 0.2423 | -1.0806 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -0.3711 | -2.4029 | -0.2949 | -0.5423 | 2.4222 | -0.2901 | 2.2330 | 2.3511 | -1.2340 |
| -0.3259 | -1.1339 | -1.1199 | -0.4081 | 2.3562 | 2.2653 | 2.1853 | 2.2926 | -1.2114 |
| -0.5870 | -1.4511 | -1.1050 | -0.5069 | 2.2480 | 2.2004 | 2.1063 | 2.1964 | -1.1857 |
| -0.2969 | -1.1339 | -0.8582 | -0.1448 | 2.1630 | 2.1486 | 2.0437 | 2.1205 | -1.1600 |
| -0.5272 | -1.4511 | -1.3966 | -0.5026 | 2.0384 | 2.0707 | 1.9505 | 2.0086 | -1.1310 |
| -1.2546 | -0.8166 | -3.1625 | -0.9990 | 1.8181 | 1.9280 | 1.7822 | 1.8091 | -1.0942 |
| -0.5868 | -0.4993 | -2.6208 | -0.5943 | 1.4621 | 1.6816 | 1.4994 | 1.4818 | -1.0438 |
| -0.3700 | -0.8166 | -1.3966 | -0.4088 | 1.0867 | 1.3962 | 1.1842 | 1.1291 | -0.9844 |
| -0.7105 | -1.7684 | -0.5136 | -0.5132 | 0.7193 | 1.0849 | 0.8556 | 0.7752 | -0.9154 |
| -0.9246 | 1.7215 | 0.9011 | -0.8525 | 0.3928 | 0.7736 | 0.5428 | 0.4521 | -0.8390 |
| 0.0206 | 0.1352 | 0.4953 | 0.4243 | 0.1728 | 0.5401 | 0.3186 | 0.2290 | -0.7678 |
| -0.3722 | -0.8166 | -0.1591 | -0.4318 | 0.0048 | 0.3455 | 0.1385 | 0.0553 | -0.6976 |
| 0.0236 | 1.0870 | -0.6130 | 0.1125 | -0.1500 | 0.1510 | -0.0353 | -0.1077 | -0.6216 |
| 0.1837 | 0.1352 | -0.1044 | 0.1888 | -0.2649 | -0.0047 | -0.1700 | -0.2307 | -0.5484 |
| -0.3601 | -0.1821 | -0.2767 | -0.1248 | -0.3548 | -0.1344 | -0.2792 | -0.3283 | -0.4762 |
| -0.6427 | 0.1352 | -0.4059 | -0.4969 | -0.4062 | -0.2122 | -0.3434 | -0.3848 | -0.4133 |
| 0.1587 | -0.4993 | -0.5302 | 0.1524 | -0.4396 | -0.2641 | -0.3857 | -0.4216 | -0.3544 |
| 0.9024 | -0.4993 | 0.6692 | 0.7233 | -0.4313 | -0.2511 | -0.3751 | -0.4124 | -0.3118 |
| -0.3192 | 1.0870 | 1.0254 | -0.3823 | -0.4313 | -0.2511 | -0.3751 | -0.4124 | -0.2641 |
| 0.5255 | 0.4524 | 0.5350 | 0.1311 | -0.4230 | -0.2382 | -0.3646 | -0.4032 | -0.2189 |
| -1.1652 | 3.3078 | 0.6162 | -1.0908 | -0.4146 | -0.2252 | -0.3540 | -0.3940 | -0.1723 |
| 0.1953 | 0.1352 | 0.3031 | 0.1604 | -0.4313 | -0.2511 | -0.3751 | -0.4124 | -0.1121 |
| 0.1351 | 0.4524 | 0.1888 | 0.3236 | -0.4396 | -0.2641 | -0.3857 | -0.4216 | -0.0540 |
| -0.9004 | 1.0870 | 0.9078 | -1.0045 | -0.4396 | -0.2641 | -0.3857 | -0.4216 | 0.0016 |
| -0.1292 | 1.0870 | 0.5731 | -0.2539 | -0.4559 | -0.2901 | -0.4066 | -0.4397 | 0.0681 |
| -0.6108 | 2.0387 | 0.8017 | -0.4539 | -0.4881 | -0.3419 | -0.4482 | -0.4755 | 0.1467 |
| -0.2540 | 1.0870 | 0.6294 | -0.3846 | -0.5349 | -0.4198 | -0.5098 | -0.5279 | 0.2390 |
| -0.1543 | 1.0870 | -0.3214 | -0.2023 | -0.5947 | -0.5235 | -0.5903 | -0.5955 | 0.3469 |
| -0.1625 | 0.7697 | -0.2982 | -0.3252 | -0.6654 | -0.6533 | -0.6885 | -0.6764 | 0.4697 |
| 0.0558 | 1.0870 | -0.2071 | 0.0474 | -0.7318 | -0.7830 | -0.7840 | -0.7533 | 0.6047 |
| 0.1109 | -0.4993 | -0.7223 | -0.0749 | -0.7634 | -0.8478 | -0.8307 | -0.7904 | 0.7145 |
| 0.3010 | 0.7697 | 0.0629 | 0.2228 | -0.7941 | -0.9127 | -0.8768 | -0.8265 | 0.8295 |
| -0.7705 | 1.4042 | 0.8150 | -0.8495 | -0.8179 | -0.9646 | -0.9131 | -0.8547 | 0.9425 |
| -0.0740 | -0.4993 | -0.6743 | 0.0534 | -0.8353 | -1.0035 | -0.9400 | -0.8755 | 1.0525 |
| -0.0204 | -0.4993 | -0.1160 | -0.2894 | -0.8524 | -1.0424 | -0.9667 | -0.8960 | 1.1670 |
| -0.7377 | 0.1352 | 1.7262 | -0.8341 | -0.8636 | -1.0683 | -0.9844 | -0.9094 | 1.2774 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -0.5985 | 0.7697 | 0.9375 | -0.5229 | -0.4468 | -0.2755 | -0.3948 | -0.4295 | 0.9008 |
| 1.0246 | -0.4993 | 0.5524 | 1.2861 | -0.4631 | -0.3016 | -0.4159 | -0.4477 | 0.9993 |
| 0.0710 | -0.1821 | 0.9731 | -0.1572 | -0.4142 | -0.2245 | -0.3534 | -0.3935 | 1.0455 |
| 3.0346 | -0.8166 | 1.7025 | 2.8914 | -1.0018 | -1.4218 | -1.2142 | -1.0789 | 1.9733 |
| 3.0728 | -1.4511 | 1.2818 | 3.2983 | -0.8649 | -1.0715 | -0.9866 | -0.9111 | 1.7919 |
| 3.4981 | 0.1352 | 0.9841 | 3.5063 | -1.1007 | -1.7250 | -1.3951 | -1.2049 | 2.5226 |
| 1.3879 | 0.7697 | 1.3165 | 1.3365 | -0.9081 | -1.1752 | -1.0560 | -0.9633 | 2.1082 |

**Table 5: Labelling and Coding of the Morphometric Properties of the Basin**

| S/N | Variable Code | Variable Label | Variable Description |
|---|---|---|---|
| 1. | $X_1$ | RAIN | Rainfall |
| 2. | $X_2$ | EVAPO | Evaporation |
| 3. | $X_3$ | INFLOW | Catchment Inflow to the Lake |
| 4. | $X_4$ | AREA | Lake area |
| 5. | $X_5$ | DEPTH | Lake depth |
| 6. | $X_6$ | WATAB | Water Abstraction |
| 7. | $X_7$ | TEMP | Temperature |
| 8. | $X_8$ | VOLUME | Volume |
| 9. | $X_9$ | OUTFLOW | Outflow from the Lake |

The extent of association among the variables were shown in a 9 X 9 matrix of intercorrelations (table 6). The result of the correlation analysis revealed a multicollinearity problem as some of the variables correlated significantly with each other such as $X_4$ correlated highly with $X_5$, $X_6$, $X_8$ and $X_9$. Consequently, these were subjected to PCA with varimax rotation. Four components were extracted and accounted for 96.23% of the hydrodynamics of the lake.

Table 6: Matrix of intercorrelations among 9 climatic and morphometric variables

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 |
|---|---|---|---|---|---|---|---|---|---|
| **X1** | 1.000 | | | | | | | | |
| **X2** | .435 | 1.000 | | | | | | | |
| **X3** | .987 | .406 | 1.000 | | | | | | |
| **X4** | -.495 | -.692 | -.450 | 1.000 | | | | | |
| **X5** | -.467 | -.689 | -.437 | .908 | 1.000 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **X6** | .662 | .631 | .633 | -.816 | -.818 | 1.000 | | | |
| **X7** | -.165 | .428 | -.168 | -.380 | -.528 | .279 | 1.000 | | |
| **X8** | -.435 | -.685 | -.406 | .894 | .998 | -.784 | -.545 | 1.000 | |
| **X9** | -.415 | -.681 | -.388 | .883 | .994 | -.762 | -.553 | .999 | 1.000 |

Table 7: Varimax Related Component of climate and morphometric variables

| Variable Codes | Variable Label | Comp. I | Comp. II | Comp III | Comp IV | $h^2$ |
|---|---|---|---|---|---|---|
| $X_1$ | RAIN | -0.263 | 0.944 | -0.103 | 0.135 | 0.989 |
| $X_2$ | EVAPO | -0.452 | 0.239 | 0.209 | 0.832** | 0.997 |
| $X_3$ | INFLOW | -0.222 | 0.960** | -0.079 | 0.109 | 0.989 |
| $X_4$ | AREA | 0.884 | -0.234 | -0.050 | -0.289 | 0.922 |
| $X_5$ | DEPTH | 0.909** | -0.240 | -0.262 | -0.194 | 0.990 |
| $X_6$ | WATAB | -0.723 | 0.508 | 0.085 | 0.209 | 0.831 |
| $X_7$ | TEMP | -0.351 | -0.198 | 0.896** | 0.162 | 0.991 |
| $X_8$ | VOLUME | 0.907 | -0.206 | -0.277 | -0.194 | 0.980 |
| $X_9$ | OUTFLOW | 0.904 | -0.186 | -0.286 | -0.193 | 0.971 |
| **Eigen values** | | **4.216** | **2.356** | **1.087** | **1.002** | |
| **% of variance explained** | | **46.846** | **26.180** | **12.215** | **10.990** | |
| **Cumulative % of variance explained** | | **46.846** | **73.026** | **85.241** | **96.231** | |

*Significant loadings ± 0.80 and above* ***component defining variable*

Based on the outcome of the rotated component matrix, component I explained 46.846% of the variation in the data having an eigen value of 4.216. Variables $X_4$, $X_5$, $X_8$, and $X_9$ loaded highly on component I with component loadings of 0.884, 0.909, 0.907 and 0.904 respectively and which describes **the morphometry characteristics of the lake** in determining the hydrodynamics of the lake. This confirms the role of the lake depth-area-volume relationships established in determining the outflow conditions of the lake. Comp II has an eigen value of 2.356 and explains 26.180% of the total variance. For component II, $X_1$ and $X_3$ loaded highly with loadings of 0.944 and 0.960 respectively which explains the contribution of **hydrological input variables** of rainfall and catchment runoff into the lake in determining the hydrodynamics of the lake. In component III, $X_7$

loaded highly with a loading value of 0.896 while component III has an eigen value of 1.087 explaining 12.215% of the total variance. Thus, component III explains the **contribution of temperature** in determining hydrodynamics of Agulu lake. Lastly, component IV has an eigen value of 1.002 explaining 10.99 percent of the variance with variable $X_2$ having high loadings of 0.832. This index explains the **contribution of evaporation** in determining the hydrodynamics and morphological conditions of the lake.

Having determined the underlying variables determining Agulu Lake's hydrological and morphological condition, these four dimensions together explained 96.231% of the variance in hydrodynamic conditioning of the lake. Further, the sum of the squared loadings ($h^2$) of all components were determined. This is known as communality, and it explains the proportion of the variance of each variance which is accounted for by all the extracted components. Thus, the uniformly high values of the communalities (table 7) are explained by the fact that the four components accounted for almost all the variance (96.231%) in the lake.

We employed multivariate regression analysis on the component defining variables (CDVs) from each of the components. The standard linear regression model assumes the value of Y has a linear form with the set of predictor variables ($X_1$. $X_2$, $X_3$…., Xn) as follows:

$$Y = f(X_1, X_2, X_3 \ldots, X_n) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots + \beta_n X_n$$

Principal Component Regression (PCR) was employed to extract the underlying effects of the explanatory variable and to use these to predict the dependent values. The dependent variable (Y) is the lake outflow with a loading of 0.904 in component I. Using the PCR ensures that only independent effects were used with the certainty of excluding local variance noise to improve the quality of the least regression model. From table 7, the highest loading from each component known as the component defining variable (CDV) were isolated. The CDVs were used as explanatory variables which have now replaced the original variables. The original variables of these isolated variables cannot be used because of their multicollinearity that will expectedly distort the result. The PCR equation expressing the closest possible relationship between the basin area and the 4 specified variables is:

$$Y(X_9) = -646.59 + 223.75(X_5) + 0.17(X_3) - 21.235(X_7) - 0.033(X_2)$$

The contributions of individual variables to the explanation of the variation are given by the $R^2$ change and the level of variation is the total runoff being discharged that can be explained by the

linear dependence upon the independent variables operating together as seen in equation 1. The summary of the result is shown in Table 8

**Table 8: Result of PCR Analysis**

| **Statistics** | **Result** |
|---|---|
| Multiple Correlation (R) | 0.995 |
| Co-efficient of Multiple Determination | 0.991 |
| Standard Error of Estimates (mm) | 80.389 |

The combined strength of the relationship between these 4 variables and the annual lake outflow was assessed by the Multiple Regression Coefficient (R) and coefficient of multiple determination which gave 99.1%. This shows that PCR model is a better predictor of the lake outflow response in relation to the hydro-morphometric parameters permitting an accurate prediction of the annual lake outflow from the CDVs. From the base constant of -646.59 in the equation, it means that this lake outflow value must be obtained as fixed before the influence of predictor parameters will begin to have effect on the lake. $X_5$ and $X_3$ in the equation which are depth and inflow indicate that increase in the variables will result to increase in lake outflow. More so, based on the outcome of coefficients of $X_7$ and $X_2$, any increase in temperature and evaporation respectively will result in decreasing outflow from the lake. In addition, the standard error of 80.38 achieved in our calculation means that any value of estimated outflow of the lake from the regression equation will have 95% chance of falling within +/- 80.38mm of the actual value.

### 3.3 Assessment of the Multivariate Linear Model

In the model, parameters $X_4$, $X_5$, $X_8$, and $X_9$ extracted from the PCA were assigned to the independent variables, and the lake annual outflow was assigned to the dependent variable (Y). The match between the observed lake outflow and the model predicted value is shown in figures 2 and 3. The regression coefficients ($\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$) were 223.75, 0.17, -21.235 and -0.033 respectively. The standard error of estimate was calculated using the equation:

$$SE = \sqrt{\frac{\sum(Y - Y^1)^2}{N}}$$

Here Y is the observed lake annual outflow, $Y^1$ is the predicted lake annual outflow, and N is the number of pairs of values. The standard error of the estimate (SE) is 80.389. There is a good

correlation between the predicted values and the original annual lake outflow data ($r = 0.995$, $p < 0.05$). Thus, the correlation coefficients are significant at 0.05 level showing that the predicted lake outflow significantly correlated with the observed lake outflow.

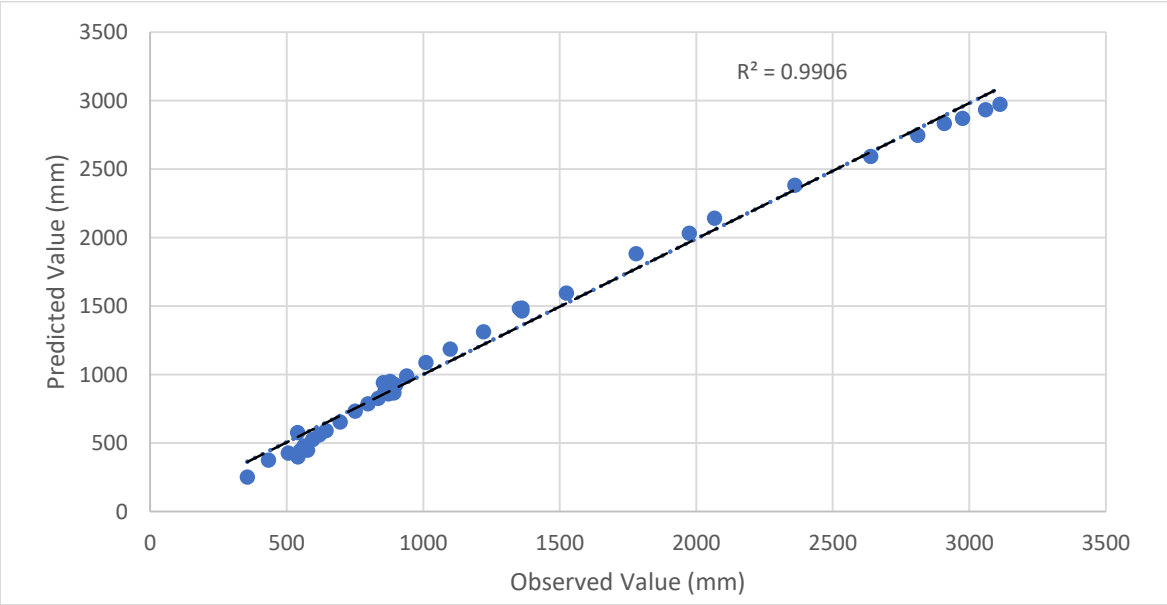



Fig 2: Comparison of the lake outflow predicted by our model and the observed lake outflow (1)

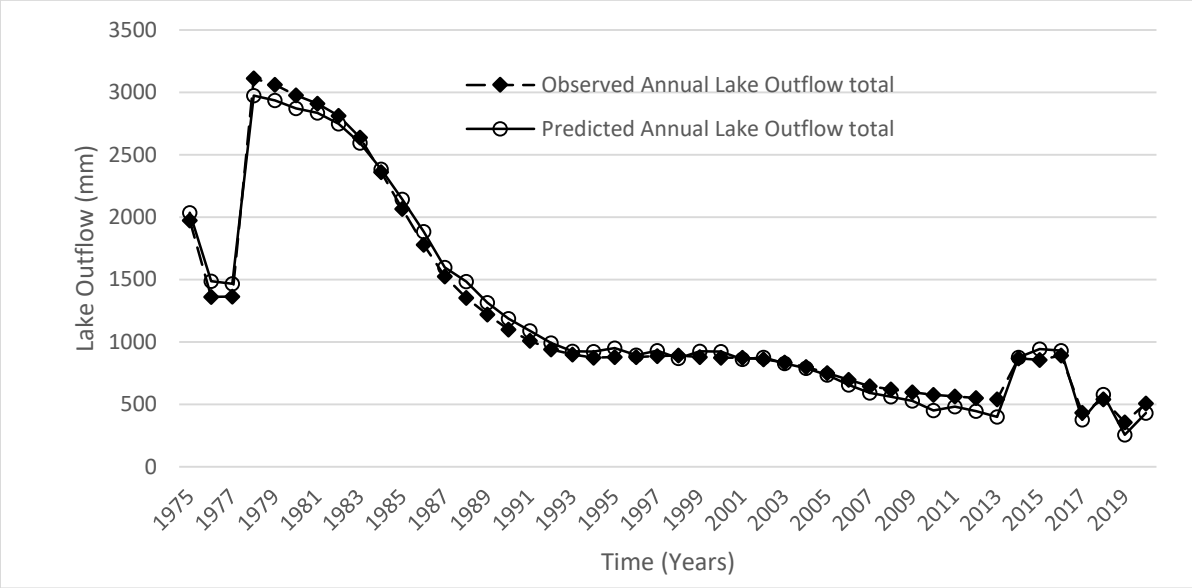



Fig 3: Comparison of the lake outflow predicted by our model and the observed lake outflow (2)

The accuracy measure of the multivariate linear model was evaluated using Nash-Sutcliffe efficiency (NSE) ratio (Nash-Sutcliffe, 1970), the root mean square error to the standard deviation of measured data (RSR) and the percentage bias (PBIAS) model. The model assessment indices

were NSE=0.991, RSR= 0.097, and PBIAS=0.0396. Given the general performance rating (table 2), the model was very good and reconstructed the annual lake outflow of Agulu lake well.

## 4.0 Discussion

This study adopted a multivariate linear model approach in x-raying the hydrodynamics of Agulu lake in relation to outflow to variations in climatic, morphometric and anthropogenic variables. PCA extracted factors that constitute the dominant variables affecting the rate of outflow from the lake. Consequently, out of 9 variables identified, four components were extracted following varimax rotation. Component I, with the highest weight due to the percentage of variance explained (46.846%), reflected the **role of morphometry parameters** in determining the hydrodynamics of the lake. Within this component, $X_4$ (lake area), $X_5$ (lake depth), $X_8$ (lake volume), and $X_9$ (lake outflow) have high loadings with lake depth and lake volume the being the main morphometric variables with loadings of 0.909 and 0.907 respectively. In determining the outflow conditions of the lake, this confirms the role of the lake depth-area-volume relationships established. The relationship between lake level and lake outflow was established by conducting monthly lake level and outflow measurement for a period of 15months (table 4.3). We measured lake level/depth at the point of outflow. At this part of the lake, the depth varies from 1.2m to 3.9m between the dry and rainy seasons. The measured data were used to derive a polynomial equation ($R = 15.485H^{1.8208}$) which defines the nature of such relationship with an $R^2$ of 0.904 depicting a good correlation (fig 4). The simulated outflows from the lake based on

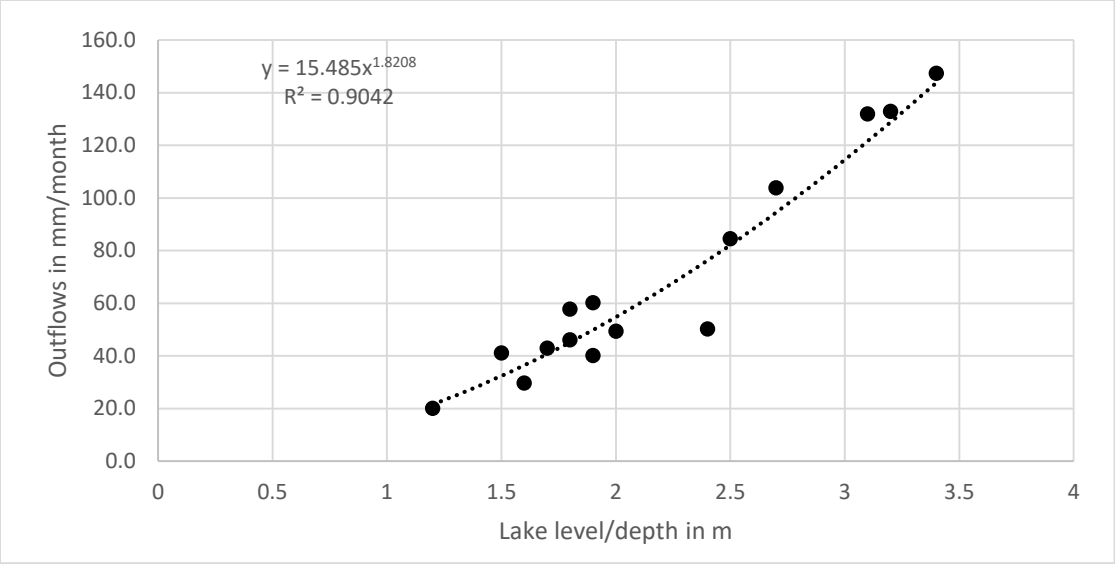



Fig 4: Relationship between lake outflow and mean monthly lake level/depth

the polynomial equation were compared with the observed flows at the outflow point. This is depicted in figure 5. The results yielded a good agreement between observed and estimated flows given a Nash-Sutcliffe, $R^2 = 0.74$. In addition, morphometric parameters of lakes such as depth and lake area were shown by Mehner and Brucet (2022) to affect all horizontal and vertical gradients of abiotic factors in lakes and the fish composition of lakes. Håkanson (2005) demonstrated that the size and form of lakes regulate many general transport processes such as sedimentation and outflow, which in turn regulate many abiotic state variables like temperature,

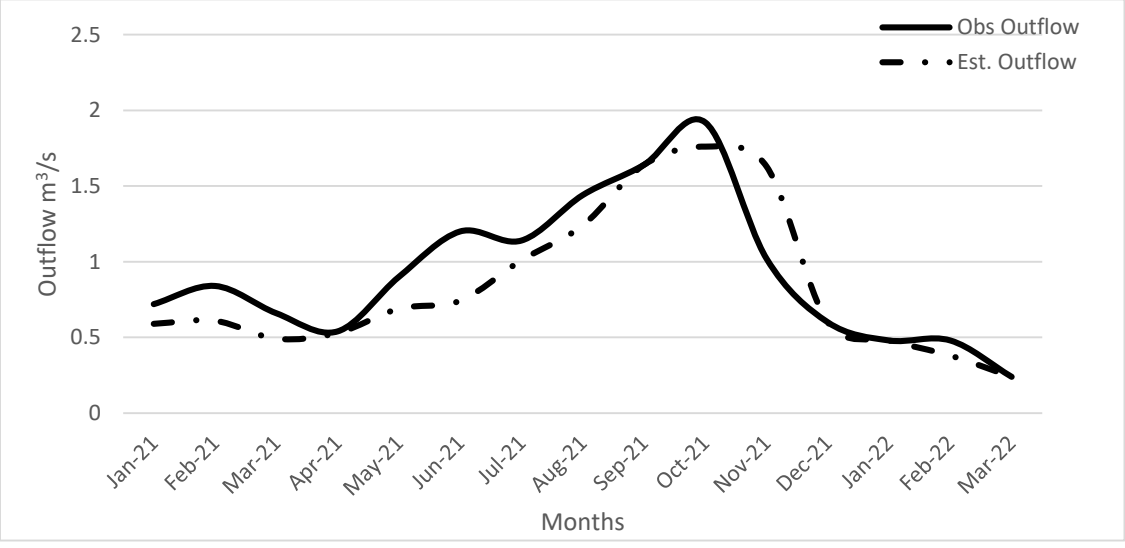



Fig 5: Simulated vs Observed outflows at Agulu Lake Outlet by lake level-outlet flow equation

oxygen concentration etc. The second component, explaining 26.180% of the total variance, provides insight on the contribution of **hydrological input variables** of rainfall and catchment runoff in defining the hydrodynamics of the lake. It has $X_1$ (rainfall) and $X_3$ (inflow) being the dominant variables within this factor with high loadings of 0.944 and 0.960 respectively. Among the extracted climatic variables, $X_7$ solely explains 12.215% of the total variance and reflects the contribution of temperature in the behaviour of Agulu Lake in relation to its outflow conditioning. With a loading of 0.896, temperature informs the third component. This is followed by component 4. The fourth component in explaining 10.99% of the variations in the lake behaviour, has $X_2$ as the main factor having high loadings of 0.832 and refers to lake evaporation as one of the determining factors of the hydrodynamics of Agulu Lake. In a study by Tan and Liu (2020), it was established that the water level of major lakes in China, Mongolia and Russia was sensitive to temperature resulting to a 2.14m reduction in water level per depth. For exoreic lakes like Agulu Lake, such a reduction of water level and depth due to temperature is capable of reducing outflow from the lake. Similarly, temperature and evaporation were reported in Kiani et al. (2017) as contributory factors towards the shrinking of the water level of Tashk and Bakhtegan Lakes, Iran. Warmer lake surfaces due to rising temperature have contributed to lower water levels by increasing evaporation rates (Gronewold et al., 2013). Lower water levels in Agulu lake would yield reduced outflow from the lake which has strong downstream implications for Idemili river. Lake Superior has been reported to have experienced a reduction in net basin supply due to increasing evaporation and decreasing precipitation and runoff (ELPC, 2019). Beyond hydrological impacts of increasing air temperature on lakes, there are associated biogeochemical processes and biological influences such as expanding the temperature range of operation of some invasive species within the lake ecosystem. These four components were employed as component defining variables in building a multivariate linear model. The principal component regression (PCR) results on the four component defining variables (CDVs) from each component show that all of them operating together contributed 99.1% to the hydrologic response of the lake. We found a good linear correlation between the predicted and observed annual lake outflow ($r=0.99$, $P<0.05$). The PCR model was assessed using NSE, RSR and PBIAS. The model assessment indices were 0.991 (NSE), 0.097 (RSR), and 0.0396 (PBIAS) and generally showed that the model was very good and reconstructed the annual lake outflow of Agulu lake well. Although the model works

well in terms of assessment statistics, the model could be improved. There is still need for continued measurement of some of the estimated data

## 5.0 Conclusion

Climatic, morphometric and anthropogenic factors identified as potential factors impacting on the hydrodynamics of Agulu lake were isolated and they consist of nine variables. Water abstraction was used a proxy for anthropogenic impact on Agulu lake. Four independent variables were extracted from these nine variables using principal component analysis (PCA). These four variables revealed that morphometric parameters of the lake, hydrological input, temperature and evaporation were responsible for the hydrologic behaviour of the lake in relation to lake outflow. These parameters account for 96.231% of the variance in the hydrodynamic conditioning of the lake. A multivariate regression with the principal components (principal component regression) as independent variables was conducted to clearly indicate their level of impact on the lake outflow. Results showed that all of these variables operating together contributed 99.1% to the hydrologic response of the lake. There was a good linear correlation between the predicted and observed annual lake outflow ($r=0.99$, $P<0.05$). The PCR model assessment indices showed an NSE, RSR, and PBIAS of 0.991, 0.097, and 0.0396 (PBIAS). We conclude that the key variables impacting the outflow conditions of Agulu Lake are the morphometry of the lake, hydrologic variables of rainfall and runoff, temperature, and evaporation in the order of their impact. In the absence of continuous measuring of flow from the catchment of the lake, the multivariate model output has shown the model as good for reconstructing the annual lake outflow of Agulu Lake. We also recommend the need for establishing a hydrologic station in the lake vicinity for continued monitoring of flow from the lake into Idemili River.

## References

Abraham T., Woldemicheala, A., Muluneha, A and Abateb, B (2018). Hydrological responses of climate change on Lake Ziway Catchment Central Rift Valley of Ethiopia. *J. of Earth Sci. and Climate change*, 9(6), Pp 1 – 16.

Adeyeri, O.E., Laux, P., Arnault, J., Lawin, A.E and Kunstmann (2020). Conceptual hydrological model calibration using multi-objective optimization techniques over the transboundary Komadugu-Yobe basin, Lake Chad Area, West Africa. *J. Hydrol*: Regional Studies, 27

Ayenew T. and Gebreegziabher Yemane (2006) Application of a spreadsheet hydrological model for computing the long-term water balance of Lake Awassa, Ethiopia, Hydrological Sciences Journal, 51:3, 418-431, DOI: 10.1623/hysj.51.3.418

Bellin, A., Majone, B, Cainelli, O., Alberici, D. and Villa, F. (2016). A continuous coupled hydrological and water resources management model. *Environ. Model. Softw*. 75, 176 – 192.

Egboka, B. C. E., Nfor, B. N., and Banlanjo, E. W. (2006). "Water Budget Analysis of Agulu Lake in Anambra State, Nigeria". *J. Appl. Sci. Environ. Mgt*., vol. 10 (3) 27 – 30.

Environmental Law and Policy Centre (ELPC) (2019). An assessment of the impacts of climate change on the Great Lakes.

Håkanson L. (2005) The importance of lake morphometry and catchment characteristics in limnology – ranking based on statistical analyses. *Hydrobiologica*, 541:117-137.

Håkanson L. (2005) The importance of lake morphometry for structure and function of lake. *Interational review of hydrobiology* 90(4), 433-461.

Ilyin L.V. and Ilyina O.V. (2022). Hydromorphological Parameters of lakes of Shatsk national nature park (1933-2021). *16th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment*, Nov 2022, volume 2022, pp 1-5.

Kiani T., Ramesht M.H, Maleki A. and Safakish F. (2017) Analysing the impacts of climate change on water level fluctuations of Tashk and Bakhtega Lakes and its role in environmental sustainability. *Open Journal of Ecology, 7, 158-178.*

Ma L., Wu J., Liu W., Abuduwaili J. (2014). "Distinguishing between anthropogenic and climatic impacts on lake size: a modeling approach using data from Ebinur Lake in arid northwest China".

Mbanguka, R.P., Steve W. Lyon, Karin Holmgren, Marc Girons Lopez and Jerker Jarsjö **(2016)** Water Balance and Level Change of Lake Babati, Tanzania: Sensitivity to Hydroclimatic Forcings. *Water*, 8, 572; doi:10.3390/w8120572

Mehner T. and Brucet S. (2022). Structure of fish communities in lakes and its abiotic and biotic determinants. In Mehner and Tockner (eds), Encyclopedia of Inland waters (2nd edition), Elservier, 2:77 – 88

Moriasi, D., Arnold J., Van Liew M., Binger R, Harmel, R., and Veith T (2017). Model Evaluation Guidelines for Systemic Quantification of Accuracy in Watershed Simulations. T.ASABE, 50: 850 – 900.

Nash J.E. and Sutcliffe J.V., "River flow forecasting through conceptual model. Part 1 - A discussion of principles," *Journal of Hydrology*, vol. 10, pp. 282-290, 1970

Nzoiwu C.P. (2023). Development of water balance hydrological model and response to climate change in Agulu Lake, Anambra State, Nigeria. Unpublished PhD dissertation. Nnamdi Azikiwe University, Awka.

Nzoiwu, C.P., Ezenwaji E.E. and Ezeonyejiaku, C.D. (2023). Bathymetric analysis of Agulu Lake in Nigeria using south SDE acoustic echo sounder. Manuscript Submitted for publication.

Nzoiwu, C. P. and Ezenwaji, E. E. (2017) "Contributions of Anthropogenic Factor to the Observed Surface Area Variation of Agulu Lake, Anambra State". *J. Geogr., Meteorol. and Env. (JGME).* Vol. 2 (1) pp 38 – 45.

Nzoiwu, C.P., Ezenwaji, E.E. and Okoye, A.C. (2017). A Preliminary Assessment of the Effects of Climate Variability on Agulu Lake, Anambra State, Nigeria. *American Journal of Climate Change, Vol.6 (4),* Pp. 694 – 710.

Nzoiwu, C.P., Ezenwaji, E.E., Enete, C.I. and Igu, N.I. (2017). **"**Analysis of Trends in Rainfall and Water Balance Characteristics of Awka, Anambra State". *Journal of Geography and Regional Planning.* Vol. 10(7), pp. 186-196: DOI:10.5897/JGRP2016.0603

Penman, H.L (**1948)**. Natural evaporation from open water, bare soil and grass. Proc. R. Soc. Lond. Ser. A Math. Phys. Sci., 193, 120–145.

Politi, E., Cutler, M. E. J., & Rowan, J. S. (2012). "Using the NOAA Advanced Very High-Resolution Radiometer to characterise temporal and spatial trends in water temperature of large European lakes". Remote Sensing of Environment, 126, 1-11.

Tan Q. and Liu Y. (2020). Spatiotemporal variation and climatic response of water level of major lakes in China, Mongolia and Russia. *Open Geosciences*, 12:1200 – 1211.

Ufoegbune, G. C., Yusuf, H. O., Eruola, A. O. and Awomeso, J. A. (2011). Estimation of Water Balance of Oyan Lake in the North West Region of Abeokuta, Nigeria. *British Journal of Environment & Climate Change 1(1): 13-27*