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Full Length Research Paper

Water balance of selected fluviatile lakes in the upper Benue valley, Adamawa State, Nigeria

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Water Balance Evaluation is an important inventory activity used for continual assessment of water gains and losses in a hydrological basin or water body for the purpose of sustainable uses. In this paper, attempts have been made to present the Water Budget of Lakes Gwakra and Geriyo in the Upper Benue Valley of Adamawa State, Nigeria. The study aimed at determining the gains and losses of the lakes in 2013, 2014 and 2015 Hydrological Years. The studied lakes were selected on the basis of situation on the left and right banks of the course of River Benue in the study area, as well as on the basis of size and relevance in terms of usage. The Derived Water Balance Model used in the study incorporated Direct Precipitation, Evaporation, Surface Inflow, Abstraction, Surface Outflow and Groundwater flux as Net Residual Flux (NRF). The values of the components were computed using data obtained by standard measurements. The results obtained showed high values of Surface Inflows (4.91mcm to 6.86mcm), moderate values of Direct Precipitation (1.16mcm to 2.53mcm) and low values of change in storage (-0.02mcm to 0.06mcm). The high values of NRF obtained indicated high porosity of the area's geological structure and poor storage capacity of the lake basins. Engineering works and water conservation strategies are recommended for sustainable water storage by the lakes.

Keywords: Lakes, water balance, gauged inflow, net residual flux, abstraction.

INTRODUCTION

Among relevant lake management practices is Periodic Water Balance Estimation. It is an important tool for assessing the current status and trends in water resource availability in an area over a specific period of time (Stauffer, 2010). The study of the water balance structure of lakes, river basins, and ground-water basins forms a basis for the hydrological substantiation of projects for the rational use, control and redistribution of water resources in time and space (Sokolov & Chapman 1974). Therefore, the amount of water available in a lake for any kind of use at a given period greatly depends on the balance between amounts gained and lost by it; simply expressed mathematically as:

$$I - O = \pm (\Delta S) \quad (1)$$

Where I is Inputs; O is Outputs; and ΔS is Change in Storage. Water Balances vary widely in size and complexity, depending on the availability of data and the objectives of the analysis (WRIA 54 Watershed Planning, 2014). As such, interactions between lakes and other related components of the hydrologic cycle (atmospheric water, surface water and groundwater) have been established using different kinds of Water Balance Models (Ayenew, 2009; Hayashi and Van der Kamp, 2007; Reddy 2008; Kumambala and Ervine, 2010; Ufoegbune *et al*; 2011 and Dawek and Ferencz, 2013).
Prior to the work of Kumambala and Ervine, (2010) on the Water Balance of lake Malawi, which combined the

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studies of water balance model with effects of climate change on water resources, all the previous studies on the water balance of the lake were based on net balance between inflow from the lake catchment (Q_{in}), Rainfall (R_L), Evaporation ($Evap_L$) over the lake and Shire river outflow (Q_{out}), expressed by Kumambala and Ervine, (2010) as:

$$\Delta S = R_L + Q_{in} - Evap_L - Q_{out} \quad (2)$$

EstimatingWater Balance of Selected Floodplain Lake Basins in the Middle Bug River valley, Dawek and Ferencz, (2013) presented Water Balance equation for floodplain lakes and river valleys simply as:

$$(P-E) + (I-O) \pm \Delta S=0 \quad (3)$$

Where P is direct precipitation into the lake, E is evaporation from Lake Surface; I is water inflow into the lake basin; O is water outflow from the lake; and, ΔS is changes in lake storage. In a detailed approach, Reddy (2008) noted that the Water Balance for a lake at any given time interval can be expressed as:

$$S_1+P+V_{si}+V_{gi}-V_{so}-V_{go}-E-TR=S_2 \quad (4)$$

Where $S_1$is lake Storage at the beginning of the time interval; P is Precipitation falling into the lake; V_{si} is Volume of Gauged Inflow; V_{gi} is Volume of Groundwater Inflow; V_{so} is Volume of Surface Outflow from the lake; V_{go} is Volume of Groundwater Outflow; E is Evaporation; TR is Transpiration losses and S_2 is Storage at the end of the time interval. All these quantities must be expressed in units of volume (m^3) or equivalent depth (mm) over a referenced area (Reddy 2008).

Lakes Gwakra and Geriyo are fluviatile lentic water bodies formed by fluvio-geomorphologic processes on the floodplains of the middle course of the River Benue in Jimeta and Girei Local Government Areas of Adamawa State, respectively. Being fed by Precipitation, Stream and Groundwater Inflows, the lakes serve as important water bodies for various uses, most especially in dry seasons when other alternative water sources are scarce. Among the major demands from the lakes are water supply for domestic uses, livestock consumption, irrigation agriculture as well as socio-cultural needs which include periodic fishing and recreation. However, little or no management attention is given to these vital water resources for sustainability. It is on this basis that this paper attempts to provide three years (2013, 2014, and 2015) water balance evaluation of the lakes for the first time.

MATERIALS AND METHODS

The section of the Upper Benue Valley Area of Adamawa State within which lies the studied lakes is located between latitudes 09˚ 14' 00"N and 09˚ 25' 00"N of the equator and between longitudes 12˚ 21' 00"E and 12˚ 37' 00"E of the prime meridian (Fig. 1), The valley is an extensive floodplain characterized by two major forms of Quaternary marine deposits – Benue valley alluvium and recent river alluvium (Bawden and Tuley, 1966) underlain by Cenomanian Bima Sandstone sedimentary rock formation. The area is further dissected by numerous ephemeral streams and runoff channels; some of which flow directly into the lakes.

The climate of the area is typically tropical, marked by distinct wet seasons (April - October) and dry seasons (November – March). While March and April are the hottest months of the year with monthly mean temperatures up to about 42.8˚C and November and December as the coldest with monthly mean of about 18˚C (Adebayo, 1999). However, the area is relatively warm throughout the year. Annual total rainfall for 2013, 2014 and 2015 hydrological years were recorded at 827.40mm, 1015.30mm and 979.00mm respectively, while Pan evaporation amounts were recorded at 2419.84mm, 1663.27mm and 1643.96mm respectively (Upper Benue River Basin Development Authority Yola, 2015).

Lakes Gwakra and Geriyo were purposively selected for the study based on their apparent sizes, and relevance in terms of multiple uses. The lakes are situated on the northern and southern banks of the Benue River respectively (Fig. 1). While Lake Gwakra is fed by flows from Falai and Jiberu inlets which originated from the Benue River and Bagale Hills respectively, while Lake Geriyo is fed by flows from Wauru Jabbe and Demsawo inlets originating from municipal drains.

Relevant data on morphometric characteristics of the lakes were obtained by standardized field measurements as provided by Yonnana (2015). Surface Area (A) values of the lakes at the beginning and the end of each hydrological year were obtained by field mapping, using the Area Tool of Garmin e-trex Global Positioning System. Depths (z) of the lakes at numerous points and regular intervals were obtained by Sounding Rod Method (Basak, 1994), while Mean Depths (z_{mean}) were calculated using Statistical Mean Formulae;

$$z_{mean} = \frac{\sum z}{n} \quad (5)$$

Data on other relevant water budget parameters as Precipitation, Evaporation were obtained from the Meteorological Unit of Upper Benue River Basin Development Authority, Yola while data on Surface Inflows into the lakes were obtained by direct field measurements using MFP126-S Advanced Stream Flow-Meter and the Float-Area Method of Runoff measurement. Estimated Inflow amounts were computed as follows:

$$V=\frac{86400QN}{10^6}=0.0864QN \quad (6)$$

Where V is volume of inflow in million cubic meters (mcm); $0.0864Q$ is total discharge in cubic meters per day; and N is estimated number of flow days in the

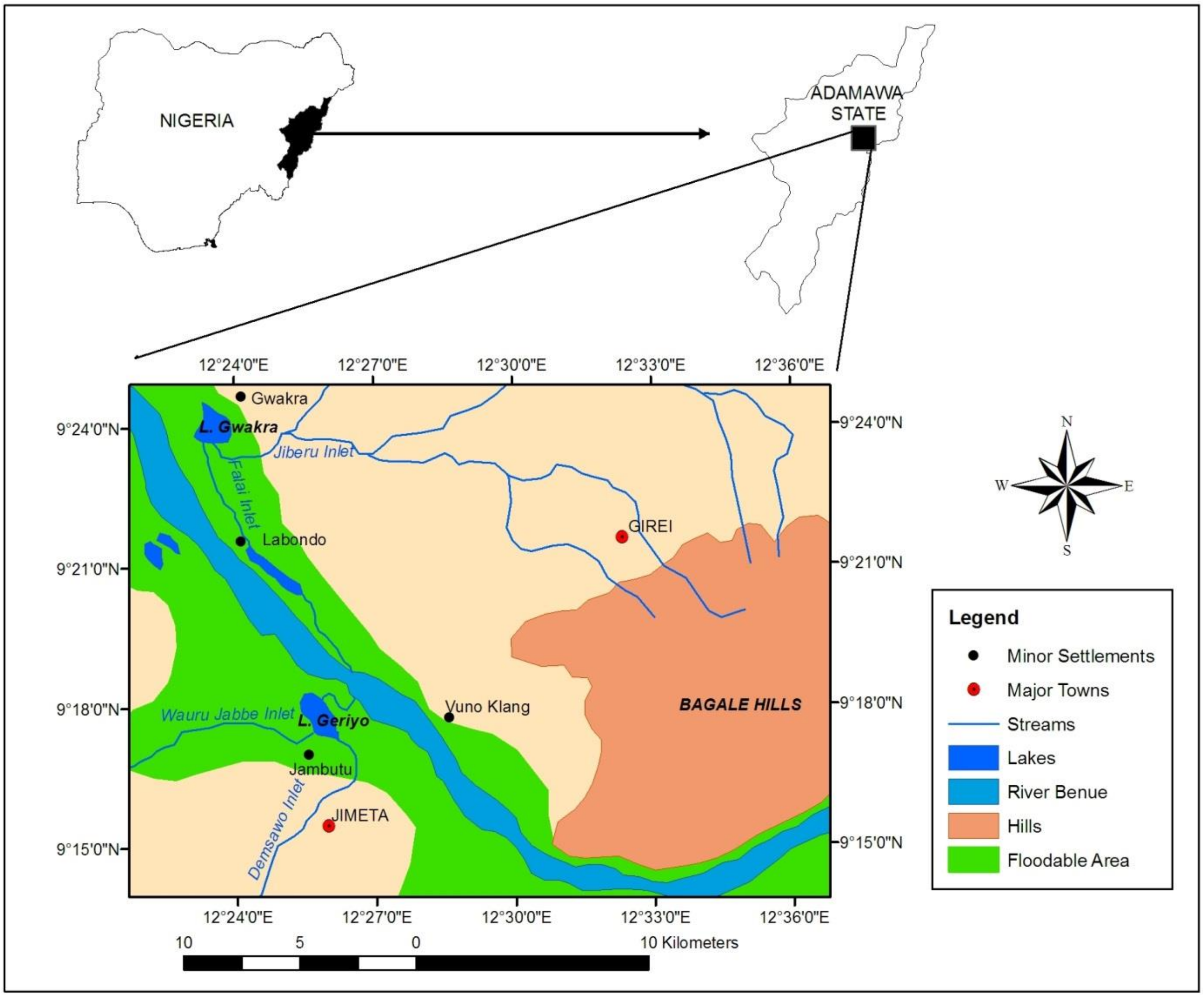

Figure 1. The Study Area
Source: GIS Laboratory, ADSU Mubi (2015).

hydrological year. Direct Precipitation over lakes surfaces and Evaporation from the lakes (in mcm) were estimated using the following formulae as described by Reddy, (2008).

$$P_L = A_0 \times \frac{P}{1000} \times 10^{-6} \quad (7)$$

$$E_L = A_0 \times \frac{e}{1000} \times 0.75 \times 10^{-6} \quad (8)$$

Where P_L is Precipitation over lake surface (mcm); p is annual precipitation amount obtained from the nearest meteorological station (mm); A_0 is lake surface area (m^2); E_L is evaporation amount from lake surface (mcm); e is annual evaporation data from the nearest meteorological station (mm); and *0.75* is pan coefficient for lake evaporation (Marohasy, 2011). Lake storages at the beginning and end of each hydrological year were obtained as products of lake surface area and annual mean depth as provided by Taube (2000), while yearly abstractions from Lake Geriyo were evaluated using pumping rates information obtained from the Geriyo Irrigation Project.

The water balance model used for this study as expressed in equation (9), is a derived form of equation (4), in which Abstraction for external uses was incorporated and Transpiration from aquatic plants of the lakes considered as a component of Evaporation, while Groundwater fluxes and other ungauged surface fluxes were collectively estimated as NRF without separating inflows from seepages as described by Ayenew, (2009) owing to measurement difficulties.

Table 1. Hydrological characteristics of Lake Gwakra and its environs

Year	Mean Depth (m)	Initial Surface Area (Ha)	Final Surface Area (Ha)	Initial Storage (mcm)	Final Storage (mcm)	No. of stream flow days	Stream mean flow Depth (m)		Stream mean Width (m)		Stream mean Velocity (ms^{-1})	
							1*	2*	1*	2*	1*	2*
2013	0.75	140.66	137.21	1.05	1.03	95.00	0.31	0.32	5.50	5.10	0.17	0.19
2014	0.77	135.44	131.37	1.04	1.04	101.00	0.38	0.34	5.80	5.70	0.19	0.19
2015	0.73	130.75	131.22	0.95	0.96	98.00	0.30	0.33	5.60	5.30	0.17	0.19

1*=Falai Stream Inlet 2*=Jiberu Stream Inlet

Table 2. Hydrological characteristics of Lake Geriyo and its environs

Year	Mean Depth (m)	Initial Surface Area (Ha)	Final Surface Area (Ha)	Initial Storage (mcm)	Final Storage (mcm)	No. of stream flow days	Stream mean flow Depth (m)		Stream mean Width (m)		Stream mean Velocity (ms^{-1})	
							1*	2*	1*	2*	1*	2*
2013	0.70	282.22	251.01	1.96	1.76	95.00	0.35	0.27	5.80	6.20	0.18	0.16
2014	0.68	246.73	256,37	1.68	1.74	101.00	0.37	0.30	6.00	6.50	0.19	0.18
2015	0.64	258.31	250.21	1.65	1.60	91.00	0.34	0.25	5.80	6.00	0.18	0.15

1*=Wauru Jabbe Inlet 2*=Demsawo Stream Inlet

$$NRF = (V_{si} - V_{so}) + (P_L - E_L) - (S_2 - S_1) - A \quad (9)$$

RESULTS AND DISCUSSION

Estimated Water Balances of the lakes for 2013, 2014 and 2015 hydrological years are presented on Tables 3 and 4, respectively. In 2013 hydrological year, Lake Gwakra had an initial storage of 1.05mcm. The Surface Inflow from the Jiberu Inlet contributed an estimated amount of 4.93mcm of water into the lake. In addition, Direct Precipitation input into the lake was estimated at 1.16mcm. At the end of the hydrological year, the lake lost about 2.55mcm of its water to Evaporation. No outflows were recorded, while Abstractions were very negligible and as such built up in the NRF. At the end of the hydrological year, the volume of the lake was estimated at 1.03mcm, giving rise to a deficient change in storage of -0.02mcm and a NRF of 3.56mcm. This low NRF compared to those of the subsequent years was highly influenced by the lake evaporation recorded in the year.

In 2014 and 2015 hydrological years, direct precipitations over the lakes were evaluated at 1.37mcm and 1.28mcm respectively owing to increases in the area's annual rainfall. Surface inflows for the years also were evaluated at 6.86mcm and 5.23mcm respectively for the same reason. Lake Evaporation amounts were less (1.68mcm and 1.61mcm) in 2014 and 2015 compared to the value obtained in 2013. Changes in storages for the years were p -0.03mcm and 0.01 respectively, with NRFs of 6.58mcm and 4.89mcm accounting for groundwater inflows, seepages and minute abstractions. The high groundwater inflow and seepage characteristics of the lakes are to a greater extent tied to the highly permeable sandstone and the porous recent alluvium deposits that make up the lake's basin geologic structure. The implication is that wet seasons, the permeable and porous geologic structure of the lake basin and its surroundings permits high levels of groundwater flows into the lake. In the dry seasons, the same permeability characteristics enhance seepages out of the lake. The negative changes in storage recorded in 2013 and 2014 hydrological years indicated excessive water loses in Lake Gwakra.

The results also showed that Lake Geriyo (in 2013) had an initial storage of 1.96mcm (Table 4). It then received a total Surface Inflow of 5.20mcm from Demsawo and Wuro-Jabbe inlets. The second major source of water for the lake was direct precipitation over the lake's surface, which accounted for 2.34mcm supply. Evaporation from the lake's surface and Abstraction for irrigation and other uses were found to be the main components of water losses, which accounted for 5.12mcm and 2.22mcm

Table 3. Water Balance of Lake Gwakra (in mcm) for 2013, 2014 and 2015 Hydrological Years

Lake	S_i	S_f	ΔS	V_{si}	P_L	E_L	V_{so}	A	NRF
2013	1.05	1.03	-0.02	4.93	1.16	2.55	Nil	Negligible	±3.56
2014	1.04	1.01	-0.03	6.86	1.37	1.68	Nil	Negligible	±6.58
2015	0.95	0.96	0.01	5.23	1.28	1.61	Nil	Negligible	±4.89

Source: Computations based on Field Survey
KEY: S_i = Initial Storage; S_f = Final Storage; ΔS = Change in Storage; V_{si} = Volume of Surface Inflow; P_L = Precipitation Input; E_L = Lake Evaporation; V_{so}= Volume of Surface Outflow; A = Abstraction; NRF = Net Residual Flux.

Table 4. Water Balance of Lake Geriyo (in mcm) for 2013, 2014 and 2015 Hydrological Years

Lake	S_i	S_f	ΔS	V_{si}	P_L	E_L	V_{so}	A	NRF
2013	1.96	1.76	-0.20	5.20	2.34	5.12	Nil	2.22	±0.40
2014	1.68	1.74	0.06	6.63	2.50	3.07	Nil	2.18	±3.55
2015	1.65	1.60	-0.05	4.91	2.53	3.18	Nil	2.20	±2.11

Source: Computations based on Field Survey
KEY: S_i = Initial Storage; S_f = Final Storage; ΔS = Change in Storage; V_{si} = Volume of Surface Inflow; P_L = Precipitation Input; E_L = Lake Evaporation; V_{so} = Volume of Surface Outflow; A = Abstraction; NRF = Net Residual Flux.

respectively. At the end of the year, the lake's final storage was estimated at 1.76mcm resulting to a negative Change in Storage of -0.06mcm and a low NRF of 0.40mcm owing to high evaporation and abstraction rates.

The patterns of the lake's water balance in 2014 and 2015 hydrological years were similar to those of lake Gwakra; showing increases in inputs and decreases in outputs owing to increase in the area's annual rainfalls and drops in evaporation amounts (Table 4). However loses for Geriyo. Loses to direct evaporation from the lakes were higher than corresponding direct precipitation inputs, indicating aridity conditions in the area. Changes in the lakes' water storages were generally very low, indicating some form of normality in water balance. However, the NRF for Lake Geriyo in 2013 was very low (±0.40mcm). This is clearly accounted for by the high

Lake Evaporation rate (5.12mcm) that occurred in the year which to greater extent affected the amount that would have been lost by Groundwater seepage. It is then postulated from this scenario that a greater proportion of the NRFs amounts to loses as seepage. The compositions of the lakes' water budget were similar to those of the Ethiopian Rift Lakes (ERL) described by Ayenew, (2009) but varied in quantity on the basis of lake sizes (the ERL are comparably larger in size than the studied lakes).

CONCLUSION

The deficits in the lakes' storages as presented by the negative values of change in storages (Tables 3 and 4) are strongly tied to annual variability in rainfall and semi-arid conditions of the area. In addition, increased water NRFs for Lake Geriyo were generally lower than those of Lake Gwakra mainly due to urban anthropogenic influences such as trapping of ground water in numerous bore holes and wells as well as abstractions of the lake's water for irrigation and construction works in Jimeta metropolis.

Generally, stream inflow amounts were greater than direct precipitation. Evaporation was the major apparent means of water lose for Lake Gwakra, while its combination with Abstraction make up major observed

abstractions rates, development of more groundwater sources (wells and bore holes) and excessive lake evaporation rates in the future are bound to have significant influence on Net Residual Fluxes of the lakes.

The implication of the low storage changes computed for the lakes is that the lakes are of poor storage capacities and therefore cannot provide for sustainable water supply most especially at periods of prolonged drought. Their shallow basin morphologies as stated by Yonnana et al (2015) and situation over loose alluvium deposits underlain by highly permeable sandstone geologic structure are responsible for the poor storage capacities. Therefore appropriate engineering work on the lake basins and water conservation strategies on the lakes are required for sustainable water storage.

REFERENCES

Adebayo, A. (1999). Climate. In Adebayo, A.A and Tukur, A.L (eds) Adamawa State in Maps. Yola: Paraclete Publishers.

Ayenew, T.(2009). Natural Lakes of Ethiopia. Addis Ababa, Addis Ababa University Press. p84.

Basak, N. N. (1990). Surveying and Leveling. New Delhi, McGrawhill Publishing Company Limited; 475-476.

Bawden, M. G. and Tuley, P. (1966) The Resource of Southern Sardauna and Southern Adamawa Provinces, Northern Nigeria: Land resource Study No. 2. Land Resources Division/Overseas Development.

Dawek, J. and Ferencz, B. (2013).Water Balance of Selected Floodplain Lake Basins in the Middle Bug River valley. Hydrology and Earth science Discuss*.* 10; 10061-10082. Doi: 10.5194/hessd-10-10061-2013.

Hayashi, M. and Van der Kamp, G. (2007).Water Level Changes in Ponds and Lakes: The Hydrological Processes. In Johnson, E. A and Miyanishi, K. (eds). Plants Disturbance Ecology*:* The Process and the Response*.* Elsevier Inc.

Kumambala, P.G. and Ervine, A. (2010). Water Balance model of Lake Malawi and its Sensitivity to Climate Change. The Open Hydrology Journal*.* 4; 152-162.

Marohasy, J. (2011). Calculating Evaporation form the Lower Lakes. Retrieved May 07, 2012 from http://www.mythandthemurray.org.

Reddy, P.J.R. (2008). *A Text book of Hydrology*. New Delhi; University Science Press. 215.

Sokolov, A. A.; Chapman, T. G. (1974): *Methods for water balanced computations.* Paris: The Unesco Press. URL [Accessed: 17.11.2010].

Ufoegbune, G.C., Yusuf, H.O., Eruola A.O. and Awomeso, J.A. (2011) Estimation of Water Balance of Oyan Lake in the Northwest Region of Abeokuta, Nigeria. British J. Environ. and Climate Chang. 1(1); 13-27.

Upper Benue River Basin Development Authority Yola, (2015). Meteorological Data.

WRIA 54 Watershed Planning (2014). Water Balance Chapter 4. Retrieved December 06 fromwww.spokanecounty.org/wqmp/project54/.../level1 chapter4.pdf.

Yonnana, E. (2015). Assessment of Hydrogeomorphic Characteristics of Lakes in the Upper Benue Valley, Adamawa State, Nigeria. Unpublished PhD Thesis submitted to the Department of Geography, Modibbo Adama University of Technology, Yola.

Yonnana, E., Tukur, A. L and Mubi, A. M. (2015) Morphometric Characteristics of Selected Fluviatile Lakes in the Upper Benue Valley, Adamawa State, Northeastern Nigeria. J. Geography and Regional Planning 8(3); 56-64. Doi: 10.5897/JGRP2014.0470. www.academic journals.org/*JGRP*