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Constituent budget and flushing model of a tropical fresh water lake: case study of Oguta lake, southeastern Nigeria

C. A. Ahiarakwem*, G.I. Nwankwor and A.I.Opara.

Department of Geosciences, Federal University of Technology, Owerri, Nigeria.

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ABSTRACT

The water budget, constituent budget and flushing model of Oguta Lake were determined using Atomic Absorption Spectrophotometer (AAS), digital meters and standard equations. Results revealed that the total annual water inflow into the lake is about 29,461,800m^3 while the total annual outflow is about 13,476,300m^3 which implies a water storage of 16,185,500m^3/year. The investigation further revealed that about 87.6% of the total water inflow into the lake comes from channel flow from Rivers Njaba, Utu and Awbana while about 70.2% of the water outflow is from channel outflow. Similarly, there seems to be continuous loading of constituents into the lake but at a very low rate; the low loading rate is actually attributed to the moderately high flushing rate of constituents in the lake. Total alkalinity has the highest loading rate (0.40 mgl^{-1}/year) while phosphate has the lowest (0.003 mgl^{-1}/year). The results also showed that the highest annual maximally flushed constituent in the lake is bicarbonate while the lowest is magnesium. The lake witnessed low influx of nutrients (phosphate, nitrate and dissolved silica) during the study period thus indicating low level of eutrophication. Excessive flushing rate can cause nutrient imbalance and this can alter the resource status and usefulness of the lake. In conclusion, the constituent budget and flushing model of the Oguta lake are therefore favorable for water supply , irrigation activities and fisheries development.

Introduction

Oguta Lake is the largest natural fresh water resource in Imo State, Southeastern Nigeria. It is located in a low – lying platform (about 50m) within approximately latitudes 5^0 41^1 and 5^0 44^1 North and longitudes 6^0 45^1 and 6^0 51^1 East (Fig.1). The maximum and mean depths of the lake are 8.0 and 5.5m respectively while the length of the shoreline is 10km. The surface areas of the lake during the dry and wet seasons are 1.8 and 2.5km^2 respectively. The lake is believed to have originated from a natural depression.

Although some studies (Ahiarakwem, 2007; Ahiarakwem, 2011; Nwadiaro and Umeham, 1985;Odigi and Nwadiaro, 1988) have been carried out in some aspects of the lake. However, the water budget, the constituent budget and flushing rate of the lake are yet to be fully established. The Lake Chad in North Eastern Nigeria, for instance is currently witnessing a rapid decline in water storage and this has been linked to the effect of climate change. There is need therefore for regular monitoring of the water budget of our surface water resources as this could help in detecting the ones that are having water budget deficit. Water budget analysis is therefore essential in sustainable development of water resources. Similarly, the constituent budget of a tropical lake is essential in the monitoring of the nutrient balance of lakes and other surface water resources. Excessive loading of nutrients can cause water pollution; it can also cause nutrient (chemical) imbalance of the water resource. High influx of nutrients (phosphates, nitrate and dissolved silica) into surface water resources causes eutrophication. In addition, the flushing rate gives an idea of the quantity of nutrients that are released from surface water resources; hence another way of monitoring nutrient imbalance in water.

The Oguta Lake is of tremendous benefit to the local community and environs as well as the Imo State Government of Nigeria. To the former, it is the main source of domestic water supply and is also useful for transportation, recreation, fishing and sand mining activities. To the latter, it provides a focal point for research, tourism development and other recreation activities.

Climate, geomorphology and geology of the study area

The study area (Fig. 1) is located within the equatorial rain forest belt with a mean annual rainfall of 2,500mm, most of which falls between the months of May and October. This period is characterized by moderate temperatures and high relative humidity. The months of November to April have scanty rains, higher temperatures and low relative humidity (National Root Crop Research Institute, 2011). The vegetation cover of the area is characterized by shrubs, short trees, Indian bamboo, palm trees and raffia palms. However, most of the rain forest has been removed due to human activities in the study area (such as oil and natural gas exploration/exploitation as well as construction of civil structures).

The modern Niger delta started its growth after the Paleocene transgression which was followed by a cycle of deposition in the Eocene and continued till the present day (Hospers, 1965). The local geological setting of Oguta Lake indicates that it falls within the Benin Formation which consists of friable sands with intercalations of shale/clay lenses and some isolated units of gravels, conglomerates and very coarse sandstones (Ananaba et. al ., 1993). It is Pliocene to Miocene in

Tele:
E-mail addresses: cosahia@yahoo.com

age and has a mean thickness of about 800m around the study area (Avbovbo, 1978). The surface geology of the Oguta area shows that it is characterized by ferruginized sands that are occasionally pebbly and massively bedded (Odigi and Nwadiaro, 1988).

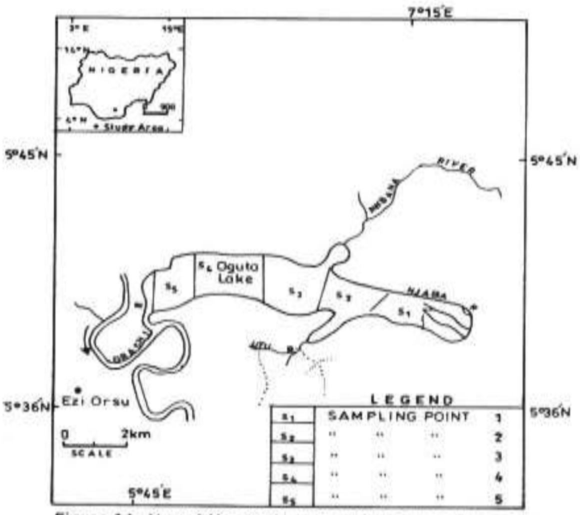

Figure 1 : Map of the study area showing sampling points

Three rivers are associated with the Oguta Lake. Two of the rivers (Njaba and Awbana) flows into the Lake while the third (Utu) flows into the lake only during the rainy season (Fig. 1). The Orashi River flows past the lake at its southwestern end. The Oguta Lake is believed to have originated as an ox- bow lake from the Orashi River (Odigi and Nwadiaro, 1988). Apart from these rivers, there is also input from precipitation (rainfall) as large volumes of runoff and storm water flows directly into the river.

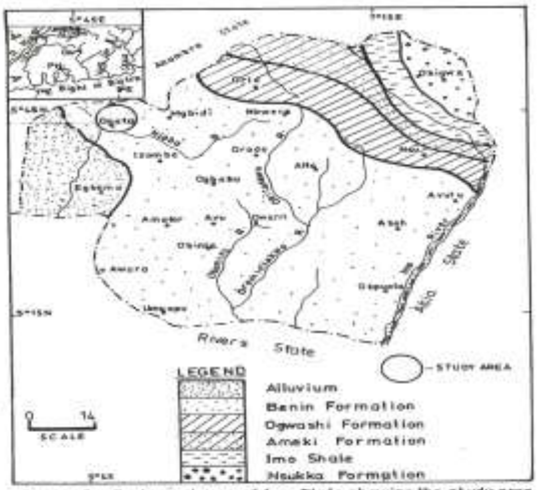

Figure 2 Geological map of Imo State showing the study area

Materials and methods

Surface water samples were obtained at five gage stations (S_1 to S_5) located at equal distances of 2 km along the stretch of the lake (Fig. 1). Sampling was carried out at these gage stations in April, 2011 and July, 2011 thus covering the two nominal seasons (dry and wet seasons). The samples were obtained with the aid of sterilized 1.5 plastic bottle; the sample bottles were corked under water immediately after collection so as to prevent oxidation of the constituents. The sample bottles were sent to the laboratory for analysis of major cations and anions using Atomic Absorption Spectrophotometer (AAS) while total alkalinity was analyzed in-situ using digital meters. Bio-chemical oxygen demand (BOD_5) was determined after incubating the sample in the dark at 20^oC for five days and measuring the amount of oxygen that has been consumed. The constituents considered in the constituent budget are sodium, calcium, magnesium, potassium, bicarbonate, sulphate, chloride, nitrate, dissolved silica, bio- chemical oxygen demand, dissolved oxygen and total alkalinity. The constituent budget (C_b) is expressed as shown in equation 1 (Clark et. al., 1977) .

$$C_b = C_u - C_o = \frac{\Delta Ic}{\Delta t} \quad \ldots\ldots(1)$$

where, C_u= constituent input per time ;C_o = constituent output per time;$\Delta Ic =$ change in the concentration of constituent and $\Delta t = \text{time interval of interest}$ .The change in the concentration of constituents was determined by comparing the current chemical data with that of Umeham and Nwadiaro (1985).

The water budget of Oguta Lake was computed using both approximate methods and standard equations (Clark et. al., 1977). The general equation for computation of water budget is as given below:

$$(I_o + I_s + I_g + P + R) - (E + T + G_s + Q_s + W) = S \quad \ldots\ldots(2)$$

Where I_o = Overland flow, I_s = Channel inflow, I_g = Groundwater inflow, P =Precipitation, R= Return flow, E= Evaporation, T= Transpiration, G_s= Seepage, Q_s= Channel outflow, W= Withdrawal and S = Storage. Some of the components (return flow, overland flow, evaporation and transpiration) were estimated using approximate methods because of the paucity of hydrological gage stations at the lake. The channel inflows into Oguta Lake were from Rivers Njaba, Utu and Awbana. The channel inflow (I_s) was computed using equation 3 below.

$$I_s = AV \quad \ldots\ldots(3)$$

Where A = Channel area and V = Velocity of the river. The channel inflow for the respective rivers are given as: $I_{s\ (Awbana\ River)} = 0.18\ m^3/s = 5{,}676{,}000\ m^3/year$, $I_{s\ (Njaba\ River)} = 0.50\ m^3/s = 18,\ 760{,}000\ m^3/year$, $I_{s\ (Utu\ River)} = 0.15\ m^3/s = 2{,}365{,}200\ m^3/year$.In addition, precipitation (P) was estimated using the surface areas in wet and dry seasons as in equation 4 below

$$P= (S_w - S_d) \times D \times 180 \quad \ldots\ldots(4)$$

Where S_w and S_d= surface area of the lake during wet and dry seasons respectively, D = Mean depth of the lake, P= $700m^2$ x5.5m x 180=693,000 m^3/year, Overland flow (I_o) and Return flow (R) were assumed to be 20% and 10% of precipitation respectively. Accordingly, I_o = 138,500m^3/year while R= 69,300m^3/year. Similarly, Groundwater inflow is given as:

$$(I_g) = Q/2A \quad \ldots\ldots(5)$$

Where A= width of flow area and Q= flow per unit length; I_g= 0.875m^3/s = 2,759,400m^3/year; E = 277,100m^3/year and T= 138,600m^3/year.Evaporation (E) and Transpiration (T) were assumed to be 40 and 20% of precipitation respectively. Seepage (G_s) was computed using equation 6 below:

$$G_s = KH/2A \quad \ldots\ldots(6)$$

Where, K= Hydraulic conductivity, H= Water level difference ,A=Width of channel; $G_S = 1x$ 10x 0.001m^3/s= 315,600 m^3/year. The Channel outflow (Q_s) is estimated from equation 7 as follows:

$$Q_s = AV \quad \ldots\ldots(7)$$

Where A= channel outflow area and V= Velocity. Quantitatively, the channel outflow (Q_s)= 1m ^{2} x 0.30m^2/s= 9,460,000m^3/year. Finally, Withdrawal (W) was estimated as shown below:

$$W= D_w \times 365days \quad \ldots\ldots(8)$$

Where D_w = daily water withdrawal. Substituting numerical values in equation 8, the Withdrawal was estimated as (W) = 9,000m^3/day x365 =3,285,000m^3/year. The velocity values used in the water budget analysis were computed using tracer method while the water depths were determined using Reuther probe. The dimensions of the channels were measured with the aid of graduated tape and speedboats.

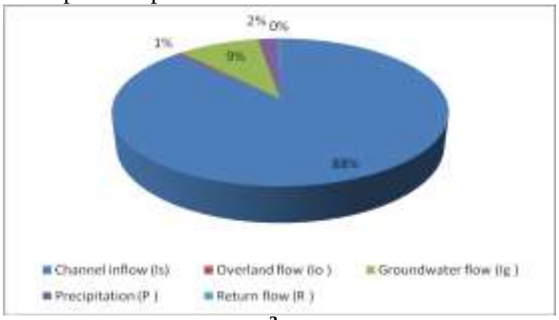

Fig.3a.Water Inflow (m^3/year) of the Oguta Lake

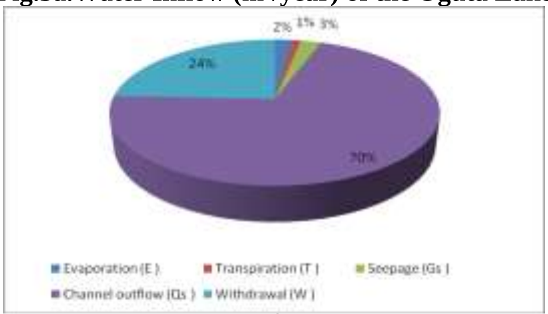

Fig.3b.Water Outflow (m^3/year) of the Oguta Lake

Finally, the annual maximal flushing rate of the considered constituents of Oguta Lake were computed on the basis of both total outflow from the lake and the difference in water volume between dry and peak rainy seasons. A total outflow value of 9,775,600m^3/ year as determined in the water budget analysis of the lake (Ahiarakwem, 2007) was used while 693,000 m^3/year representing the water volume difference between the dry and peak rainy seasons was also used (Ahiarakwem, 2007). Other parameters (Clark. et. al., 1977) employed in the computation of flushing rate are:

1. Mean concentration of constituents at the beginning of the year (T_1)
2. Current mean concentration of constituents (T_2)
3. Added inflow concentration ($T_2 - T_1$)
4. Mixed mean concentration of constituents
5. Quantity of constituents flushed (mixed mean concentration x outflow volume)

Results and discussion

The water budget analysis of Oguta Lake is summarized in Table 1 below. The water inflow into Oguta lake comes from channel inflow, precipitation, overland flow , groundwater and return flows (Table 1). These sources contributes an annual inflow of about 29,461,800m^3 . The channel inflow into the lake comes from Rivers Njaba, Utu and Awbana and contributes about 87.6% of total water inflow. Groundwater contributes about 9.37% of total inflow into the lake. Generally, the water inflow in decreasing order is, channel inflow > groundwater flow > precipitation > overland flow > return flow. The volume of inflow into the lake shows that the lake is adequately recharged. It is important to note that poor recharge of surface water resources is the main cause of poor water storage. In some situations the inflow may be lower than outflow resulting in water budget deficit. Although most tropical lakes are adequately recharged (Oliver, 2005), the current climate change challenges calls for regular water budget analysis of our surface water resources such as Oguta Lake.

Similarly, the water outflow from Oguta Lake are from evaporation, transpiration ,seepage, channel outflow and withdrawal (table 1). The total annual outflow from the lake is about 13, 476,300m^3. The channel outflow from the lakes contributes about 70,2% of total outflow while water withdrawal represent about 24.4%. The water outflow from various sources in decreasing order is: channel outflow > withdrawal >seepage > evaporation >transpiration. The current climate appears to have adverse effect on outflow; this is because the rains continued up to December in 2011 and reduced evaporation as well as transpiration. Oliver (2005) observed that most African (tropical) lakes are characterized by high evaporation and transpiration. Lake Chad which is currently facing serious decline in water storage is characterized by high evaporation and transpiration.

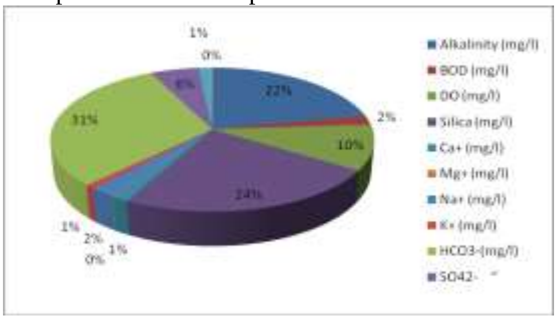

Fig.4a.Constituent Budget of Oguta Lake (From Nwadiaro and Umeham ,1985)

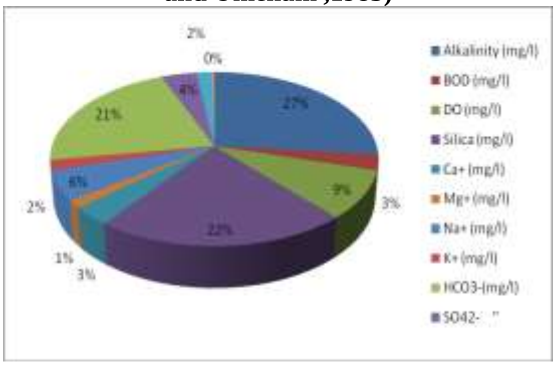

Fig.4b.Constituent Budget of Oguta Lake (From the present study)

The determination of water storage is a major objective of water budget analysis. The storage of a surface water source such as a lake is the difference between the total water inflow and the total outflow. A water budget surplus occurs when the total inflow outweighs the total outflow; the reverse gives a water budget deficit. The total annual water inflow into the lake is about 29,461,800m^3 while the total outflow is about 13,476,300m^3 which gives a water storage of 16,185,500m^3. This is considered high and makes the lake the most voluminous freshwater resource of Southeastern Nigeria. The water storage of Oguta Lake indicates a water budget surplus; it also shows the dominance of water inflow over outflow. This is typical of most Nigerian surface water resources (Oliver, 2005; Oteze, 2006). The water storage of Oguta Lake is therefore favorable for both domestic and commercial water supply as well as for sustainable transport, tourism, fishing and sports development. The storage is also useful for development of the lake as an inland port.

The results of the constituent budget is shown in table 2 while the flushing rates based on total outflow volume and the volume difference between dry and peak rainy seasons are shown in tables 3 and 4 respectively .The result of the constituent budget shows that total alkalinity has the highest loading rate (0.49 mgl^{-1}/year) while phosphate has the lowest (0.003 mgl^{-1}/year).The low loading rates of phosphate, nitrate and dissolved silica (table 2) indicates low level of eutrophication in the lake.

This is in conformity with earlier report that only about 0.50% of Oguta Lake has been affected by eutrophication (Ahiarakwem,2007). Generally, the constituent budget indicates continuous loading of constituents into the lake but at a very low rate. This low rate may in fact be due to the moderately high flushing rate as exhibited by the flushing rates of bicarbonate and dissolved silica (tables 3 and 4). The constituent budget shows that the considered constituents conformed with the World Health Organization (WHO, 2006) drinking water standard; hence the budget is favorable for domestic water supply, fisheries development and irrigation activities.

The flushing rate based on water volume difference between the dry and peak rainy season gave higher values than that obtained based on the water outflow from the lake (table 3). The flushing rate based on the water outflow from the lake appears to be more reliable than that based on the water volume difference between dry and peak rainy season because the former takes cognizance of evaporation and seepage.

It is however, interesting to note that both methods revealed that the largest quantity of constituents flushed annually is bicarbonate while the lowest is magnesium. This can be useful in the monitoring of the nutrient balance of the lake as well as in fisheries development. The flushing rate of the lake is considered to be moderately high and this is typical of most African lakes (Oliver, 2005).

Conclusion

The water budget analysis of Oguta Lake shows that about 87.6% of total annual water inflow comes from channel inflow contributed by Rivers Njaba, Utu and Awbana. However, about 70.2% of the total annual water outflow is from channel outflow. The analysis indicates a water storage of about 16, 185,500 m^3/year.

Similarly, the constituent budget of Oguta Lake indicates continuous loading of nutrients but at a very low rate. The low rate may in fact be due to the moderately high flushing rate. Total Alkalinity has the highest loading rate (0.40 mgl^{-1}/year) while phosphate has the lowest (0.003mgl^{-1}/year). The flushing model shows that the largest quantity of constituents flushed is bicarbonate while the lowest is magnesium; the flushing rate is considered to be moderately high.

The constituent budget and flushing model is quite favorable for water supply, fisheries development and irrigation. This study has revealed that the water budget, the constituent budget, the flushing model and the water storage of Oguta Lake are favourable for water supply, transport, tourism, fishing, sporting and farming activities; the storage is also good for sustainable inland port development.

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References

Ahiarakwem, C. A., 2007. Water Quality Assessment and some Geochemical Modes of Oguta Lake, Southeastern Nigeria. Unpubl. Ph. D Thesis, Federal University of Tech., Owerri, Nigeria. 225p

Ahiarakwem, C. A., 2011. Vertical Variations of some Chemical Parameters in a Tropical Lake: case study of Oguta Lake, Southeastern Nigeria. Water Resources Journ. Of Nigerian Assoc. of Hydrogeologists (NAH). Vol. 21, pp.26- 37

Ananaba, S. E., Onu, N. N and Iwuagwu, C. J., 1993, Geophysical study of the gravel deposits in Ihiagwa, Owerri, Nigeria. Journal of Mining Geology, Vol.29 (2),pp.95-100

Avbovbo, A. A., 1978. Tertiary Lithography of the Niger Delta. Bull Assoc. Petr. Geol. 62: pp.295-300

Hospers, J., 1965. Gravity field and structure of the Niger Delta of Nigeria, West Africa Bull Geol. Soc.. America, vol.76: pp.107-422.

Lozan Consultants, 1976. Preliminary study of the possibility of using Oguta lake as a port :A report to the Government of East Central State,86 p.

National Root Crop Research Institute, Umudike, Abia State, 2011. Climate Data.

Nwadiaro, C. S and Umeham, S. N., 1985. The chemical hydrology of Oguta Lake, Imo State, southeastern Nigeria. Arch. Hydrobiol. 105 (2); pp.251 – 267.

Nwadiaro, C. S., and Idabor, P., 1990. The proximate composition and nutrient elements of the unusual algal jellies of Oguta lake, southeastern, Nigeria. Rev. Ges. Hydrobiol. 75.

Odigi, M. I and Nwadiaro, C. S., 1988. Geophysical limithology of lake Oguta, Imo State, Southeastern, Nigeria. Arch. Hydrobiol. 105: pp. 250-267

Oliver, R. N., 2005. Lakes of Nigeria: In Nigeria Geography Stubs, 5p.

Oteze, O. E., 2006. Management Approaches for Nigeria,s Water Resources. Nig. Journ. Of Min. & Geol. Vol. 42(1), pp. 21- 30

Prat, L., Pavanello, R and Pessarns, 1970. Assessment of water Quality by a single Index of Pollution Research 5: PP. 741 – 748.

Turekian, K. K., 1972. Chemistry of the Earth .Holt, Rinehart and Wiston, New York.540p

Visser, S. A., 1974. Composition of waters and rivers of east and west Africa, J. Trop. Hydrobiol. Fish 3.

Wetzel, R. G. and Lickens, 1979. Limnological analysis. Publ. Saunders Co. Ltd. Philadephia, N. Y., USA.327p

World Health Organization (WHO), 2006. Drinking Water Guidelines, Geneva, 6p.

Table 1. Water Budget Analysis of Oguta Lake Showing Water Inflow and Outflow

Water Inflow (m^3/year)	Water Outflow (m^3/year)
Channel inflow (Is) 25,801,600	Evaporation (E) 277,100
Overland flow (Io) 138,500	Transpiration (T) 138,600
Groundwater flow (Ig) 2,759,400	Seepage (Gs) 315,600
Precipitation (P) 693,000	Channel outflow (Qs) 9,460,000
Return flow (R) 69,300	Withdrawal (W) 3,265,000
Total inflow 29,461,800 m^3/year	Total outflow 13,476,300m^3/year

Table 2. Constituent Budget of Oguta Lake

	Constituent		Time	□I_c		WHO (2006)
Parameters	A (1985) T_1	B (2011) T_2	Interval (□t)	(B- A) $T_2 - T_1$	$\Delta I \frac{c}{\Delta t}$	
Alkalinity (mg/l)	11.83	22.10	26	10.27	0.40	
BOD (mg/l)	1.10	2.45	26	1.35	0.06	
DO (mg/l)	5.53	7.45	26	1.55	0.06	
Silica (mg/l)	12.76	18.13	26	5.37	0.21	
Ca^+ (mg/l)	0.80	2.91	26	2.11	0.08	
Mg^+ (mg/l)	0.05	1.12	26	1.07	0.04	150
Na^+ (mg/l)	1.20	4.60	26	3.40	0.13	500
K^+ (mg/l)	0.50	1.62	26	1.12	0.04	50
HCO_3^-(mg/l)	16.50	17.90	26	1.40	0.05	500
SO_4^{2-} ‘’	3.0	3.39	26	0.39	0.02	400
NO_3^- ‘’	0.76	1.49	26	0.66	0.03	40-70
$P0_4^{3-}$ ‘’	0.10	0.19	26	0.09	0.003	10
Cl^-	0.80	1.09	26	0.29	0.01	500

Table 3.Annual maximal flushing Rate of Oguta Lake based on total outflow.

Parameter	BOD	DO	Solica	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	NO_3	$P0_4^{3-}$	Cl^-
(Mean -Con.) at t_1 (mg/l)	1.10	5.53	12.76	0.80	.05	1.20	1.50	16.50	3.0	0.76	.10	.80
Inflow con. (mg/l)	1.35	1.55	5.37	2.11	1.07	3.4	1.12	1.40	1.39	0.66	.09	.29
Outflow vol. x10^3 (m^3)/yr.	9,776	9,776	9,776	9,776	9,776	9,776	9,776	9,776	9,776	9,776	9,776	9,776
Mean mixed con. (mg/l)	1.16	5.60	13.02	0.90	.10	1.36	0.55	16.56	3.02	0.79	.104	0.81
Const. qty. flushed in kg/yr.	11,340	541746	127,283	8,798	978	13,295	5,376	1,652,290	29,523	7,723	1,018	7,919

Table4. Annual Maximal Flushed Quantity based on difference in water volume between Dry and Peak Rainy Seasons

	BOD	DO	Silica	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	NO_3	$P0_4^{3-}$	Cl^-
Mean con.,t_1 (mgl/l)	1.10	5.53	17.76	0.80	.05	1.20	1.50	16.50	3.0	0.76	.10	.80
Inflow con. (mg/l)	1.35	1.55	5.37	2.11	1.07	3.4	1.12	1.40	0.39	0.66	.09	.29
Water vol. x10^3	693	693	693	693	693	693	693	693	693	693	693	693
Mean mixed con. (mg/l)	1.16	5.60	13.02	0.90	100.10	1.36	0.55	16.56	3.02	0.79	.104	0.81
Const. qty. flushed(Kg/y)	803.9	3880.8	9022.9	623.7	69.3	992.5	381.2	11476.1	2092.9	547.5	72.1	567.3