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HYDROLOGICAL ASSESSMENT OF WATER RESOURCES AND ENVIRONMENTAL IMPACT ON AN URBAN LAKE: A CASE STUDY OF ELEYELE LAKE CATCHMENT, IBADAN, NIGERIA

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ABSTRACT

Previous assessment of the effect of land use changes on water quality of Eleyele lake Ibadan, Nigeria revealed that pollutants are being washed by rainfall runoff into the lake which indicated the need for further study. In this study, Universal Soil Loss Equation (USLE) was used to estimate the quantity of soil that is being lost into the lake using parameters derived from an earlier study. The result revealed that 2080 kg of soil is being washed into the lake annually. Tests to determine the water quality of the two streams that flow into the lake and, the outflow were done. The results showed that between 6 and 95% of the pollutants washed into the lake were retained or converted to sediments which may cause it to eutrophicate in the future. To compute water accounting for the lake watershed, precipitation over the area was calculated, discharge measurements on the two rivers that empty into the lake and outflow from the lake were done, and also, the evaporation/evapotranspiration were determined. The results showed that 59% of the gross inflow was available for potable water supply while 30.3% of the total outflow was uncommitted. Evapotranspiration (including lake surface evaporation), municipal/industrial and total outflow were 1.0, 59 and 31% respectively. Management plan and useful recommendations have been suggested to improve the reliability of the lake.

Keywords: Eleyele lake; urban water resources; water quality; pollution; Ibadan Nigeria

INTRODUCTION

Inadequate sustainable policies to control human activities such as agriculture, energy use, fishing, urbanization and industrial development have caused great losses to water and soil resources. The ever growing populations with policies encouraging economic activities have resulted in a heavily growing demand for water. Sustainable development presupposes that man consumes natural resources to such extent, which allows its regeneration. If the natural resource is over-exploited beyond the capacity to regenerate, then the environmental balance is tilted thereby causing ecological disturbance (FAO 1986). The need for sustainable management of land and water resources emerged during the last few years when the impacts of climate changes became evident and water shortages were being viewed to have been caused by the non-rational uses (Molden, 1997). Sustainable water management plans are being stressed to cover both human induced and ecological water needs as well as the preservation of water quantity and quality in storages. A multi disciplinary approach is required for tackling numerous problems of water resources management. Designing and implementation of sustainable water

management plans can provide adequate solutions to water deficiency problems. But lack of data and the use of non- physical scientific methods are constraints to quantification of a specific hydrologic regime. Extensive analysis and study of the catchment characteristics, long and reliable time series data and proven adaptive scientific methods can eliminate these uncertainties. This study intends to present the challenges being faced by Eleyele Lake as an urban lake that is subjected to environmental impacts that may affect its functions as a source of raw water supply to Ibadan city and management plan that should be considered to preserve its functions.

Study Area

Eleyele lake catchment is located in Ibadan city, Nigeria on latitude 7^0 30'N and longitude $3^0$54'E (Figure 1). The reservoir has a catchment area of about 323.8 km^2, and an impoundment area of 156.2 hectares with a storage capacity of 29.5 million litres of water. Eleyele catchment has mean and median elevations of 88.0m and 87.6m (amsl) respectively. The general elevation of the entire catchment is about 198m (amsl) and generally, the slope is gentle (Nwa, 1979). Eleyele catchment falls within an area that receives a mean annual rainfall of 1981.2mm and a mean annual temperature of 28.8^{0}C. The original vegetation at Eleyele consisted of woody species such as *Albizia glaberimma, Alchornea laxiflora, Cissus arguta*, among others (Nwa, 1979).

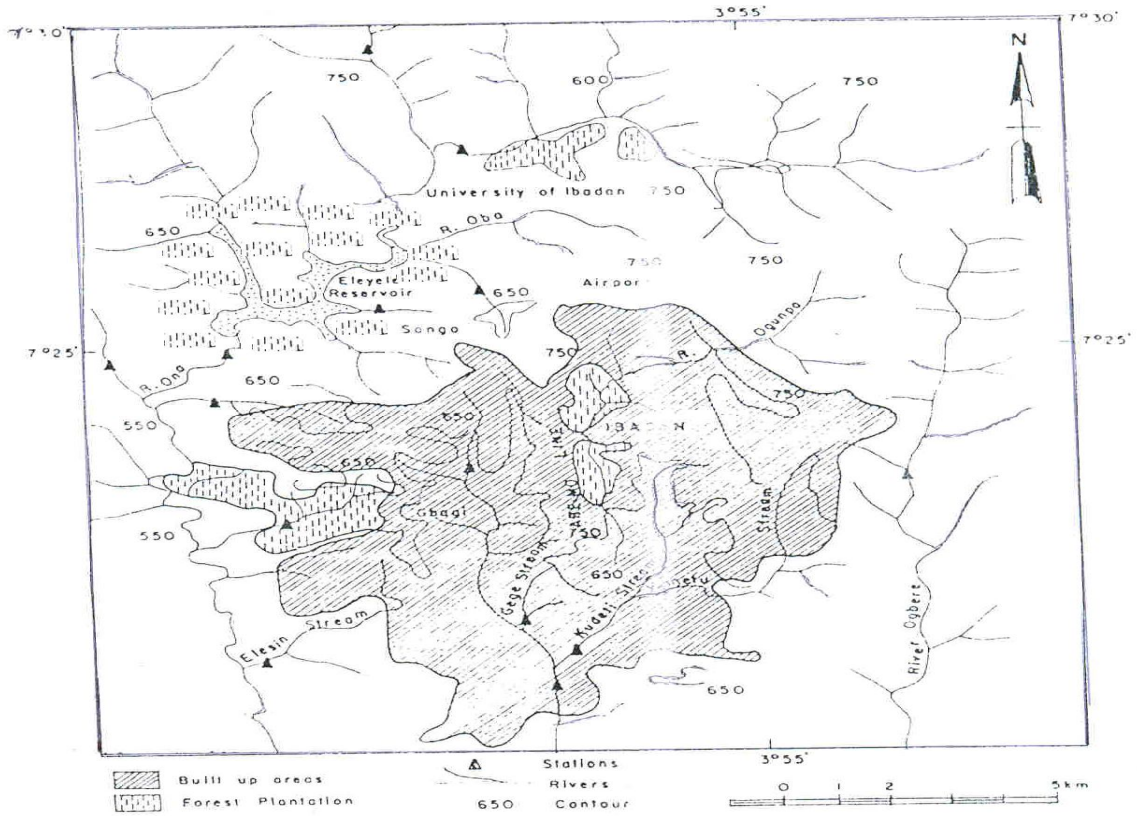

Figure 1: Eleyele catchment in Ibadan, Nigeria

The artificial lake was created in 1962, through an impoundment on Ona River with intention to provide raw water that would be treated for potable water supply to Ibadan city. A weir was constructed across the Ona river down stream its confluence with Alagbaa River. Soon after impoundment, the Department of Forestry (DOF) planted a forest reserve around Eleyele Lake and much of its catchment to protect it from siltation. Also the teak forest was aimed at providing wood fuel for thermal electricity plant located at Oke Are, within Ibadan city (now out of use) and telephone/electricity poles. A study was carried out by Agbola (2003) to assess the impact of land use changes on Eleyele catchment. This study has provided a basis for introducing a further evaluation through the use of some other techniques for assessing changes that may occur in the catchment as regards water quantity, water quality and catchment ecosystem.

MATERIALS AND METHODS

A field study was carried out on the catchment to collect information on the physiographic setting of the catchment, the population of the residents living there and the socio-economic activities that were being generated by them.

Soil loss estimation

The soil loss due to rainfall on different vegetal covers and bare soil in the catchment were estimated. Experimental plots 1.8m x 1.8m was located on grass covered area, shrub/bush and teak plantation. The teak plantation was composed of trees spaced at 2.0 x 2.0m with experimental plots of sizes 1.8m x 1.8m located between the trees. The quantity of soil loss into the lake from the respective experimental plots was estimated from linear measurements of parameters that are necessary for universal soil loss equation (USLE). Wischemeir and Smith (1965) expressed the universal soil loss equation as:

$$A = RKLSCP \quad \ldots (1)$$

Where:

A = mass of soil loss per unit area.

R = rainfall factor,

K = soil erodibility factor,

L = length of slope factor,

S = slope gradient factor,

C = crop management factor,

P = factor related to erosion control practices.

The values of parameters K, C, and P were based on values derived locally from previous researchers' studies (Babalola, 1988; Mondjalis *et al.,* 1978). Similar measurements were taken in other areas of different land uses such as agriculture, quarrying and human settlements on the catchment. This was to provide relevant information about the natural disturbance regimes that were taking place on the catchment and separate them from the new disturbances resulting from population growth. These considerations are very crucial for formulating/designing management systems (Nakamura, *et al.,* 2000).

Evaporation / Evapotranspiration

Open water surface evaporation was estimated from the US Class "A" Pan installed at the Department of Geography, University of Ibadan. The records of daily pan evaporation data were collected and analyzed to obtain mean and median values. The taxonomy of the aquatic plants that are growing on the lake surface was obtained from the

Herbarium room, Department of Botany, University of Ibadan. Water lysimeter experiment was performed at the Department of Civil Engineering, The Polytechnic Ibadan and values of daily water loss through the aquatic plant species were obtained. The data were combined together to estimate daily water loss from the lake by Evapotranspiration.

Water quality

Water samples were obtained from Ona and Alagbaa Rivers; and on the spillway. These studies were carried out between the rainy months of May and September 2002. Standard methods were used (APHA-AWWA-WEF 1992) to analyze the water samples and determine the level of parameters. The physico-chemical parameters identified include pH, conductivity, total solids, and calcium, iron and magnesium ions.

Water accounting

A water accounting study was conducted to determine the catchment's future development concerning economic activities, human population and the ability of the catchment to meet future water demands. The water accounting was based on a water balance approach that considers the inflows and outflows from the catchment. The gross inflow into the catchment was taken as the total amount of water received from precipitation, surface runoff and subsurface sources. Water depletion is taken as total water used or removed from the lake. Daily inflow into the lake from Ona and Alagbaa Rivers were measured using Baystroke Current Meter. At the point of discharge measurement on each river, the cross sectional dimensions were measured and converted into area. The instantaneous discharge was calculated from the relationship:

$$Q = A.V \quad \ldots (2)$$

Where:

Q = instantaneous discharge

A = area of cross section of river channel

V = velocity (average) of flow

Daily outflow of water from the reservoir was measured using the impoundment weir across the river. The discharge across the weir crest under aerated free fall condition at the downstream was determined from the relationship:

$$q = 2.8 y_0^{1.5} \quad \ldots (3)$$

Where:

q = discharge per meter length of weir crest

y_0 = depth of water at the brink of the weir

Daily records of water abstraction from the lake and treated for supply to the city were taken from Water Corporation of Oyo State. The performance indicators for water accounting were calculated according to concepts presented by Willardson *et al.* (1994) and Keller and Keller (1995). The water accounting figures and water demand rates were used for the projection of the respective present values into the forthcoming decades. The water demand for both economic and domestic uses were estimated into year 2050 and incorporated in the management scenarios.

Water management plan

After studying and analyzing the hydrologic regime of Eleyele catchment, the entire necessary component for the formation of a sustainable water management plan was quantified. The process for designing alternative scenarios was based on the following principles:

- Present and future water demands must be met.
- Annual water balance must be positively maintained.
- Lake capacity may be altered and reservoir operation may be managed to eliminate flooding and downstream drought.
- Environmental protection must be considered along with other measures.
- Public and the local authorities participation should be encouraged at all levels of planning processes.

RESULTS AND DISCUSSIONS

At the time of this study, the population of the residents of the three major communities in Eleyele catchment, that is, Eleyele, Apete and Ijokodo were found to be 8,428; 6,980; and 46,435, respectively, giving a total of 61,845 inhabitants in the study area and this was found conforming with the figures of 1991 census at a annual growth rate of 1.5%. The socio-economic activities of the inhabitants included farming, fishing, sand mining, car washing, vehicle repair and block making. These activities generated different forms of waste and many cases of refuse dumps were observed to be located among houses.

Computation carried out using the USLE showed that an average of 2080kg of soil was being washed annually into the lake. It was also found that erosion rate was lower in grass-covered areas than in areas covered by teak trees. Though higher than grass covered areas, erosion rates in agriculture/farmland areas were less than that in areas covered by teak trees. The ground under teak trees was bare so, splashing of heavy drops of intercepted rain water from leaves encouraged high rate of soil loss. The emerging socio-economic trend in the catchment according to the data recorded in the last decade revealed annual steady increase for cultivated land areas and number of small-scale industries as well as housing units. This has reduced the buffer zone planted with teak trees within the catchment to 45% as at the time of this study. Soil washed into the lake is expected to reduce its storage capacity due to the increase sediment load of the water flowing into the lake which would consequently increase the cost of treatment.

The results of the analysis carried out on water samples (Table. 1) showed the average concentration of the parameters. The inputs of pollutants (from Alagbaa and Ona Rivers) into the lake compared to the output (from spillway) give a strong indication that complex chemical reactions might be taking place in the reservoir. The soluble nutrients washed into an aquatic system as a result of soil erosion increase the nutrient status of the system (Woodwell, 1970; Snell 1985). Sediment which accumulates on the bed of lakes, lagoons and reservoirs also greatly influences the chemistry of the ecosystem (Glymph 1973). With these actions, Eleyele Lake may soon start to exhibit symptoms of eutrophication. To protect the lake and prolong its lifespan, the steps that can be taken include:

- Blending of the vegetation species; a mixture of trees, grasses and shrubs should be planted on the buffer areas.

Table 1: Mean values of physico- chemical parameters of water samples on Eleyele Lake

Parameters	Locations		
	Ona	Alagbaa	Spillway
Colour (T. U)	60	37.5	22
Alkalinity (mg/l)	91	48	50
Hardness (mg/l)	91	39	54
Calcium (mg/l)	18.9	16	9.8
Sodium (mg/l)	36	19	23
Magnesium (mg/l)	36	29	28
Chloride (mg/l)	30	9.7	13
Iron (mg/l)	45.7	23	0.5
Silica (mg/l)	22.0	13	12.0
Nitrate (mg/l)	28	16	2.2
Total solid (mg/l)	200	105	108
pH	7.5	7.7	7.3
Dissolved O_2 (mg/l)	24	23	4.2

- Planted vegetation should be arranged and spaced to provide adequate ground cover. This can be achieved by adequate spacing of tall trees to allow for shrubs and grasses between them as undergrowths.
- Forest management plan should be introduced to maintain a balance between exploitation and re-vegetation of the catchment area.
- A catchment protection plan should be prepared for Eleyele catchment to address land re-acquisition, forestation and monitoring. This plan should involve public participation for sustainability. Government should offer political will to support the protection plan. Informative campaigns about the environmental problems and their effects on both humans and ecosystems should be conducted so as to increase people's awareness on these issues.

Furthermore, existing and future potential disturbances on the lake environment are being depicted as shown by the results obtained from these studies. The result obtained from water accounting exercise indicates some changes in water use patterns in the future. For example changes in catchment vegetation have been found to have an impact on catchment's water accounts. The water account in Eleyele catchment for 2001/2002 is shown on Table 2. For the water accounting year 2001-2002, the study showed that the volume of water in Eleyele reservoir was about 11.5 x 10^6 m^3. The estimated annual inflow for the same period was 118 x 10^6 m^3 while the respective outflow was 36.7 x 10^6 m^3(30% of gross inflow). The annual evaporation from open water in the lake was estimated as 0.9 x 10^6 m^3 (0.8% of gross inflow) while Evapotranspiration from riparian vegetation was estimated to be about 0.4 x 10^6 m^3 (0.3% of gross inflow). The water abstracted and treated for supply to the city of Ibadan to meet domestic, municipal and industrial demands in the same period was about 69 x10^6 m^3 (Fig. 2). The treated water could only meet the demand of less than 3% of the city under the pipe reticulation connected to it. The water that spilled across the weir was the excess that could be stored but yet, was still recognized as con-

tributing significantly in regulating and maintaining downstream ecosystems. In the dry months of November to March, the abstraction from the lake had significant effect on the lake level because of reduced inflow. Consequently, the lake's water level lowered significantly during the dry season and caused low flow and drought condition downstream. By the result of water accounting, Eleyele is an open basin with about 14.8 x 10^6 m^3 (12.4% of gross inflow). This indicates that if appropriate management strategies are put in place, part of the available water can still be used abstracted to meet municipal/industrial purposes.

Alternative Scenarios

After the hydrologic component of the catchment have been studied and quantified, then three alternative scenarios was considered and formulated. The selected alternatives have been assessed on the basis of environmental impacts and found to satisfy sustainability needs under prevailing circumstances. The formed management alternatives for demand of water to be met by 2050 are briefly described as follows:

- The present hydrological status covers all human water needs in the section of the city but supply of treated water need to be expanded.
- Increasing the level of weir so as to increase impoundment and to smooth monthly outflows. Higher storage levels in the lake will help reduce water losses due to spill. This shall maximize total annual withdrawal for corresponding reliability level. This can be used to calculate the operation policy for the

Table 2: Accounts of water in Eleyele catchment for 2001/2002

	Component value (x 106 m3)	Total (x 106 m3)
Inflow		
Gross inflow (Runoff, Precip.		
GW flow)	118	118
Storage change	0	0
Net inflow		118
Depletive use		
Process depletion	71.1 (71.1/118 = 60.3%)	71.1
Evapo + transpiration	1.3 (1.3/118 = 1.1%)	
Municipal & Industrial	69.8 (69.8/118 = 59.2%)	
Non-process depletion	0	
Total depletion		81.3
Outflow		
Total outflow		36.7 (36.7/118=31.1%)
Surface outflow across weir	25.6 (25.6/36.7=69.8%)	
Committed water	0	
Environmental maintenance	3.7 (3.7/36.7=10.08%)	
Uncommitted outflow	25.6 – 3.7	21.9 (21.9/36.7=59.7%)
Available water	118 – 81.3 – 21.9	14.8 (14.8/118=12.4%)
Indicators		
Depleted fraction	81.3/118	0.69
Process fraction (Depleted)	71.1/81.3	0.87
Process fraction (Available)	71.1/14.8	4.8

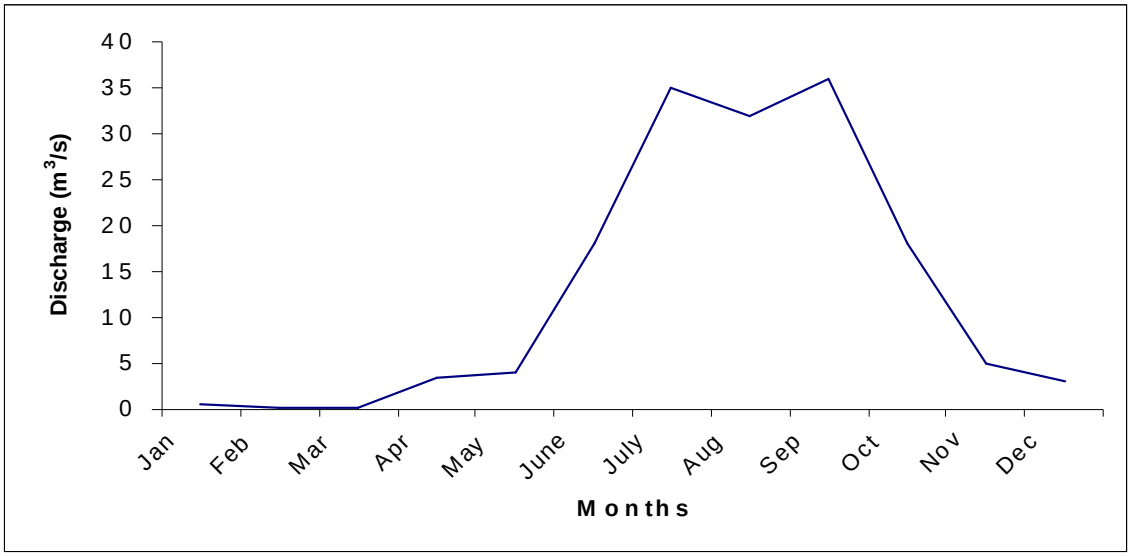

Figure 2: Type Hydrograph of Eleyele Reservoir across the weir

scenario based on the actual water resources potential of the system.

- Another alternative option is the minimization of the water supply failure probability (risk) to meet demand targets. This objective function shall then be used to calculate the management policy that would ensure adequate supply of water to the section of Ibadan city at a high level of reliability.

CONCLUSION

The impact of urbanization on Eleyele catchment and the artificial lake impoundment has been studied. Growing human activities within the catchment have been reducing the level of protection planned for the catchment and the lake. The water quality of Eleyele Lake has been affected by various forms of pollutants that are being washed into the lake and the sediments washed into the lake may soon reduce its capacity.

SUGGESTIONS

Based on the results obtained from these studies, the following suggestions are hereby proposed to improve the sustainability of water resources in Eleyele catchment.

- Acts and regulations supported by adequate enforcement should be used to protect Eleyele catchment. Appropriate institutions and legislation for adequate implementation of the program should be made available as well to support it.
- Contemporary water policies that will provide regulations and directions for the adoption of environmentally friend practices should be formulated for Eleyele catchment.
- Future management plans should incorporate the use of GIS and eco-hydrological models.

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