A review of estimation of rainfall and evaporation over Lake Victoria

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Abstract

With its area covering 68,800 km^2, a shoreline length of about 3,450 km around a basin area of about 258,700 km^2, a mean depth of 40 meters and sometimes up to a maximum of 84 meters, Lake Victoria's hydrology has been one of the most difficult and controversial to understand.

Of the most interesting aspect of the hydrology is the sudden rise that the lake underwent in a matter of a few months in 1961 by almost 2.5 meters following a long period of near constant levels about the mean earlier in the last century.

Many scholars and researchers and consulting firms have attempted to explain this sudden jump with very few of them towing a common line. Several theories were advanced ranging from increased rainfall, effect of Owen Falls dam, and the invalidity of the "Agreed Curve" developed from the stage-discharge ratings curves of the then Rippon falls before inundation.

Following the inception of the Lake Victoria Water Resources Project funded by FAO and now the LVEMP, increased automated instrumentation was installed in the islands and around the shores of Lake Victoria. A lot of data has been collected in the islands and this paper intends to throw light, using this data, to two of the most controversial elements of the hydrology of Lake Victoria. That is rainfall and evaporation over the lake.

The paper reviewed previous efforts and estimations of rainfall and evaporation over the lake and tackled the present state using measured rather than estimated data like the previous authors. Results of the analysis show that for example in the period of 1st August 1998 to 31st May 2001, there was more water loss to evaporation than a gain from rainfall over the lake. In the same period, too, rainfall input nearly equaled inflow from the catchments with rainfall over the lake slightly more than catchment input into the lake. In summary the relative percentages of the main hydrologic processes of Lake Victoria in millimeter depth in the above period are: 43.8% of evaporation loss; 31.9% of rainfall over the lake; 14.2% of outflow at Jinja and 10.1% inflow from catchments surrounding the lake. The paper looks at time series variations in order of importance of the processes and the results are shown in the body of the paper. Further research on the rest of the elements of the water balance of Lake Victoria is expected to be stimulated following this work.

Keywords: Agreed curve, water balance, rainfall, evaporation, Lake Victoria

Introduction

Lake Victoria is the largest lake in Africa and the second largest in the world. Between 1961 and 1964 the levels of the lake rose by about 2.5 meters following a long period of near constant levels earlier this century, Sene and Plinston (1994); Piper *et al.* (1986) and Flohn (1987) have linked this rise to an unusually heavy rainfall in East Africa in late 1961 and early 1962 and corresponding increases in the direct rainfall on the lake and the tributary inflows to the lake. However, Sene and Plinston (1994) noted that lake levels have remained high since that time leading to doubts about the likely future behavior of the lake.

Several possible reasons have been proposed to account for the increase in the lake levels. Shalash (1980) suggested that the levels have remained high due to the operating policy employed at the Owen Falls Dam since 1954. He assumed that the release from the dam is lower than they would have occurred if the dam had not been built. Some other authors suggested that it is the changes in land use that are affecting flows to the lake. However Sene and Plinston (1994) concurred with Kite (1981) and Piper *et al.* (1996) that considering regional rainfall evidence, which experienced several percentage rises, it was excessive rainfall that apparently caused the increase in Lake Victoria levels.

Several attempts to model the effect of increased rainfall on the lake have been made by many authors with varying degree of success. Kite (1981) was able to achieve a satisfactory water balance of the lake and in some periods to reproduce it.

The observed variations in the lake levels recently, Piper *et al.* (1996) achieved a more satisfactory balance over a larger period from 1925 to 1978 by using an alternative model with additional data.

Sene and Plinston (1994) have attempted to investigate further using two new water balance models. They aimed at also extending the modeling period. The authors also attempted the use of an idealized model in order to investigate the response characteristics of the lake to sudden changes in the net inflow.

The authors used observed records of lake levels, tributary inflows and lake out flows as components of the water balance equation. A nine parameter conceptual rainfall runoff model was used to estimate missing runoff data; while outflow records were estimated using Agreed Curve up to 1954, there after releases at Owen Falls Dam, formed the main source of data.

However, the biggest challenge to Sene and Plinston (1994) was the estimation of lake rainfall and to relate it to higher rainfall over the lake. To meet the challenge, the above authors used two approaches; one for annual water balance and the other for monthly water balance.

The approaches the authors employed were:

- Use of annual water balance simulations by averaging annual rainfalls for eight land based stations and then applying a simple multiplying factor to account for the difference between the lake and lakeshore for the period 1969 - 1978. This period was considered by the authors to have data for other water balance components with reasonable accuracy. Following Piper *et al.* (1986) the authors assumed the annual lake evaporation to be 1600 millimeters. A factor of 1.18 was used to correct annual rainfall data for the period 1900-1990 and corrected to net rainfall (rainfall minus evaporation) again assuming an average annual evaporation of 1600 millimeters.

- Use of monthly simulations to estimate net rainfall directly. Sene and Plinston (1994) noted that this approach had the advantage of avoiding the need to specify the monthly lake evaporation. The authors calibrated the model using the period 1969-1978. For each month, they developed a straight-line correlation between average lakeshore rainfall and the implied net rainfall.

After the attempts, Sene and Plinston (1994) concluded that the obscured variation in lake levels in this century was linked to variations in lake rainfall.

The above work was a classic example of the attempts made to establish the role of rainfall in the balance of the lake Victoria. However, like many works before theirs, estimates dominated the data quest.

A recent attempt by Kimaite (1996) adopted mean monthly rainfall data from a World Meteorological Organization (WMO) publication where rainfall was computed from isohyetal maps. For evaporation, the author used Morton's model with meteorological data inputs from some stations in the islands and shores of Lake Victoria.

Several other water balance studies were done on Lake Victoria with a view of determining the role of Evaporation and rainfall in the dynamics of Lake Victoria and to particularly explain the rise of 1961-1964. They are: Hurst (1952), De Meredieu (1961) and De Baunly and Baker (1970).

The objective of this paper is therefore to break the sequence of using estimated data and to use observed data to try to bring into more light the actual role of rainfall visa avis evaporation over Lake Victoria. This is expected to stimulate further and extensive studies on the subject of the water balance of Lake Victoria.

Materials and methods

Source of data

Data used in this study for estimating rainfall and evaporation have been primarily taken from Automatic weather stations (AWS's) in and around Lake Victoria. The AWS's were set up during the Japanese Government funded FAO Project - the Lake Victoria Water Resources Project - in 1998. One of the aims of the project was to improve on the hydrometric network in an around Lake Victoria with the intention to collect data so as to better understand the hydrology of Lake Victoria. Some network data were got from the national networks of Kenya and Tanzania. This data were compiled during a recent Hydrology/Meteorology working session in Eldoret Kenya under the aegis of LVEMP. The Table 1 below summarizes the stations used. Data used was restricted to the period 1998 to 2001. This was the period when there was an entirely good data.

Data processing and quality control

The choice of the study period was based on the following premises:

1. Good and reliable data collected during the FAO project and LVEMP using AWS;

2. The pre-1998 period has some improved estimates of evaporation and rainfall as a result of water balance studies of Lake Victoria against which this study is basing its comparative review.

Table 1. Network stations used for computation of eEvaporation and rainfall

No.	Station Name	Rainfall	Evaporation	Country
1	Bufumira	✔		Uganda
2	Bukakata	✔		“
3	Bukasa AWS	✔	✔	“
4	Bumangi	✔		“
5	Buvuma	✔		“
6	Kalangala	✔		“
7	Lwazimurule	✔		“
8	Mugoye	✔		“
9	Lolui AWS	✔	✔	“
10	Entebbe International Airport	✔	✔	“
11	Masaka AWS	✔	✔	“
12	Nabuyongo AWS	✔	✔	Tanzania
13	Ukerewe AWS	✔	✔	“
14	Ukerewe Islands	✔		“
15	Ukara Mission	✔		“
16	Buno Island	✔		“
17	Lukuba	✔		“
18	Bukerebe	✔		“
19	Mwanza International Airport	✔		“
20	Musoma Meteorological Station	✔	✔	“
21	Ilemera	✔		Kenya
22	Maseno	✔		“

Historical data from stations listed above were scrutinized and checked for overlaps and omissions. Extreme values not corresponding to those from neighbouring stations were removed and in-filled using double mass plotting, correlation and back substitution method. Only partial data from stations with many gaps and anomalous repetitive values were selected and combined with the rest. Recorded data from AWS was regarded as principal stations against which data from other non-AWS networks were calibrated and corrected.

Estimation of rainfall over Lake Victoria

Twenty-two rainfall stations spaced within and around Lake Victoria (Table 1) were used to determine rainfall over Lake Victoria. The arithmetic averaging method was used to do the computation. The lake rainfall was calculated as the arithmetic average of the data from the 22 stations recorded by either the ordinary rain gauge or the AWS, using the expression below:

$$\overline{P_L} = 1.10 * [\tfrac{1}{M} \sum_{j=1}^{m} P_j] \qquad 1$$

where P_j, is the rainfall value at the j^{th} station and m is the number of stations used. $\overline{P_L}$ is the lake rainfall over Lake Victoria. An approximation of ten percent gauge catch error correction was added to cater for rain gauge errors such as wind splash, exposure, evaporation and obstructions. This is because it has been shown by several researchers that a standard daily gauge in its conventional setting catches 6-8% less rain than a properly installed ground level gauge (Elizabeth M. Shaw, 1991).

Estimation of evaporation over Lake Victoria

A number of methods exist for computing open water evaporation. Some are empirical while some take into account the physical processes involved. However, it is the data availability that often limits the choice of any method to use.

In this study, a temperature-based method was used to compute open water evaporation over Lake Victoria.

The Hammon's model was used. In this method, the Hammon's model (Hammon, 1961) modified by Haith and Shoemaker (1987), determines evaporation as follows:

$$Ep = \frac{2.1 H_t{}^2 e_s t}{(T_t + 273.2)} \qquad 2$$

where H_t is the average number of day light hours per day during the month in which day t falls, and $e_s(T)$ is the saturated vapor pressure at temperature T ^oC [Kpa]. H_t was calculated by using the maximum number of day light hours on day t, H_t, which is expressed as:

$$H_t = \frac{24\omega_s}{\pi} \qquad 3$$

and;

$$e_s(T) = 0.6108 \exp(\tfrac{17.27 T^o C}{237.3 + T^o C}) \qquad 4$$

The data used to compute lake evaporation include average temperature, maximum and minimum temperature, average relative humidity, solar radiation, wind speed and sunshine hours. While data from AWS had evaporation computed by automated in-built system, data from non-AWS stations were computed using Hammon's model. Results from this model were found to be comparable to the AWS values.

Rainfall and evaporation over Lake Victoria

Rainfall and evaporation over Lake Victoria represent two of the most important independent hydrologic processes within the lake. Whereas rainfall serves as a major unregulated input into Lake Victoria, evaporation is a major uncontrollable loss of water from the lake. Other processes like catchment inflow and lake outflow are regulated processes whose quantities are greatly influenced by man and are not a focus of this paper.

Annual patterns

The annual patterns of rainfall and evaporation over Lake Victoria are similar and bimodal. For the period considered under this study, the mean annual rainfall total over the lake was at 1176.8-millimetre depth, while that of evaporation was at 1617.8 millimetres deep. This means that the natural loss of water over Lake Victoria due to evaporation is about 40% more that the input from rainfall.

The March peak was higher than the November peak. There was a low rainfall spell during the period June-July. This pattern closely follows the apparent movement of the sun north and south of the equator through the Inter Tropical Convergence Zone (ITCZ). When the sun is around the equator, which passes near the northern shores of the lake, intense heating on the water surface creates warming that expand air above the lake. This expansion creates a low-pressure cell over the lake that in turn sucks moisture-laden air masses than deposit moisture in form of rain. From Figure 1, it can be seen that in March and two months after September equinoxes, the rainfall peaks are realised. It is not clear why the second peak of November comes two months after the September equinox.

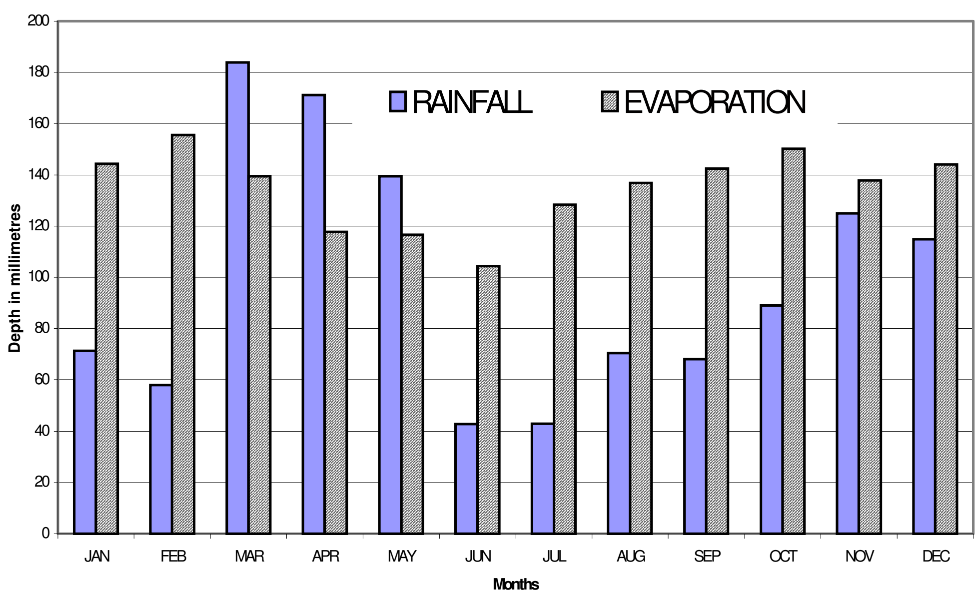

Figure 1. Comparative histogram of annual rainfall and evaporation

The annual evaporation pattern as mentioned earlier is similar to that of rainfall. However, evaporation peaks in February and October. The losses due to evaporation exceed rainfall input in all the months of the year save for the period of March – May. The month of June has the lowest evaporative rate because during the time when the Sun is around the Tropic of Cancer, it is furthest from Lake Victoria.

Cumulative analysis

A cumulative comparative plot of evaporation and rainfall over Lake Victoria show a big departure. Figure 2.0 show that there is a big divergence indicating the magnitude of evaporative excess over rainfall over the lake.

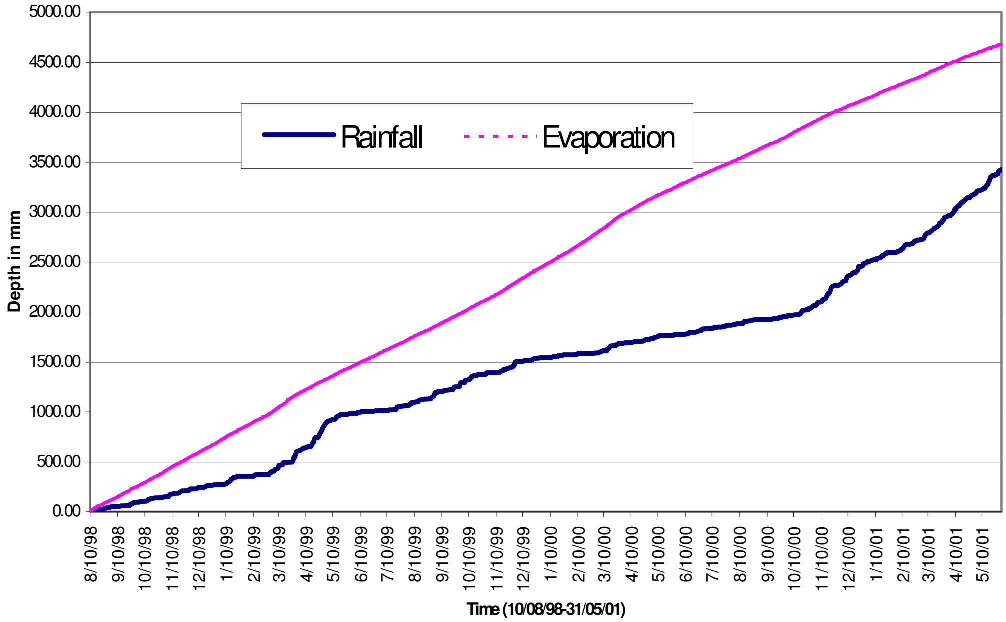

Figure 2. Comparative cumulative double mass plots

Time series patterns

The rainfall time series for the period under study reveal in Figure 3 that the year 2000 (November) had below average rainfall as compared to 1999 and 2001. Heavy rains in 1999 are typical of the *El Nino* rains that commenced in late 1998. From December 2000 till May this year, heavy rains have characterised the pattern, but with lower peaks as compared to the 1999 peaks.

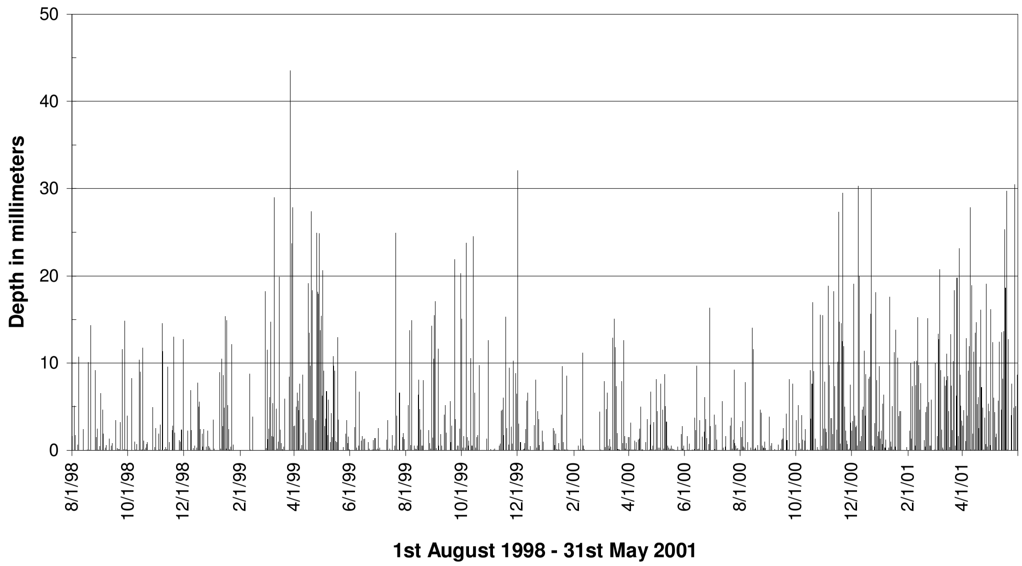

Figure 3. Lake Victoria rainfall in mm depth

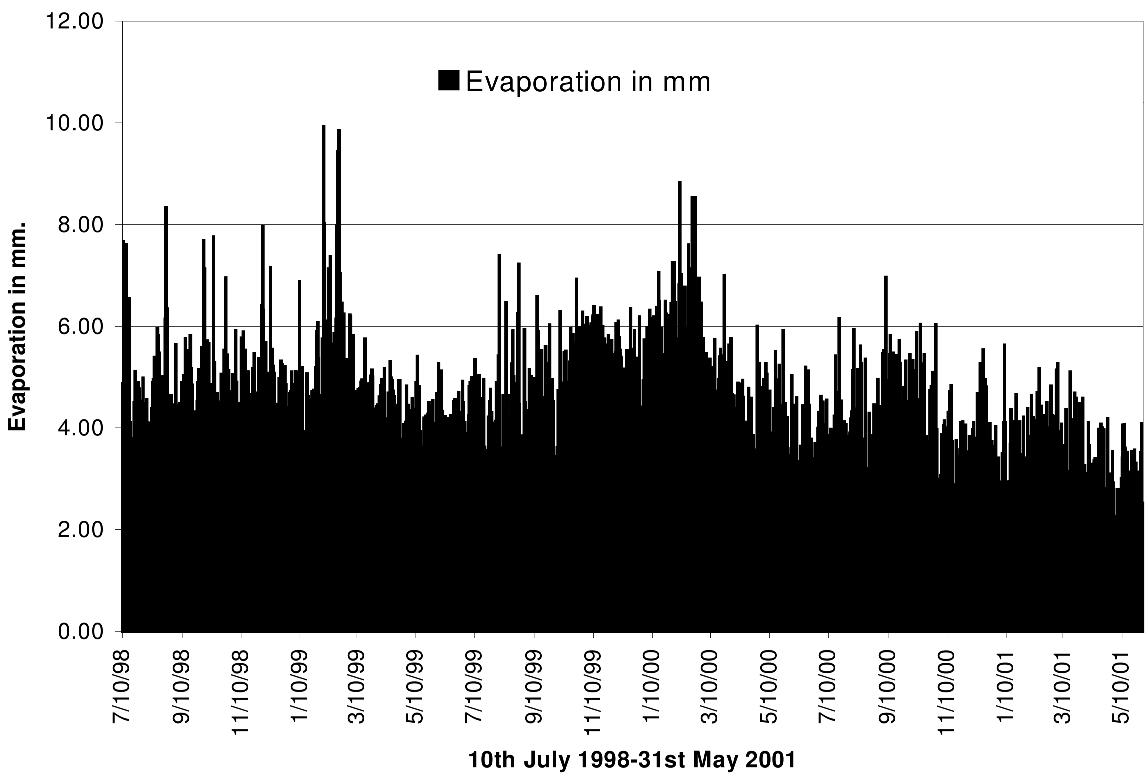

Figure 4. Lake Victoria evaporation in mm depth

Contrary to rainfall time series, the evaporation time series reveal a sinusoidal pattern with persistently high values (Figure 4). However, there is an interesting pattern to watch. From the end of the year 2000 till May 2001, Lake Victoria received a comparatively higher rainfall and correspondingly lower evaporative losses. Could it be that there will be a net gain in the system?

Annual water balances

A number of water balance studies have been made on Lake Victoria as mentioned earlier. Also, as indicated earlier, estimates dominated the procedures. This work attempts to do an annual water balance of Lake Victoria with nearly all components observed save for basin inflow, that is adopted from one of the previous studies. The table 2.0 below indicates an annual water balance of Lake Victoria for the period August 1998 to May 2001.

Table 2. Annual water balance of Lake Victoria.

No.	Hydrologic process	Depth (mm) expressed over 68,800 Km^2 of Lake Victoria
1	Rainfall over Lake Victoria	1176.8 millimetres
2	Inflow from the catchments	371.9 millimetres[1]
3	Evaporation from the lake	1617.8 millimetres
4	Outflow at Jinja	523.7 millimetres
5	Change in lake level (observed)	-680.0 millimetres
6	Change in lake level (model)	-592.0 millimetres
7	Error of estimate	13%

[1]Source: Kimaite (1996).

The error of estimate of 13% could probably be due to the use of catchment figures quoted above which were derived from 1971, 1972, 1973, 1975 and 1976 estimates by the author. This period is well outside the period used in this paper. However, within the precincts of this paper, the estimate is considered reliable.

The relative percentages of the quantities of hydrologic processes are: rainfall at 31.9%; inflow from the catchments at 10.1%; evaporation at 43.8% and outflow at 14.2%. This means that 76 % of all water input into Lake Victoria is from rainfall over the lake and 60% of all the losses is due to evaporation. The reciprocal is true for catchment inflow and outflow at Jinja respectively.

Previous water balance studies of Lake Victoria

As cited earlier, a number of water balance studies were conducted on Lake Victoria covering different periods. For purposes of comparison, these studies are reviewed below.

Studies on the Nile Basin by Hurst in 1952 put the balance of the lake as follows:

Rainfall over the lake	1420 millimetres
Inflow into the lake	230 millimetres
Evaporation from the lake	1350 millimetres
Outflow from the lake	305 millimetres

De Meredieu (FAO, 1961) put the balance as follows:

Rainfall over the lake	1145 millimetres
Inflow into the lake	215-260 millimetres
Evaporation from the lake	1130 millimetres
Outflow from the lake	305 millimetres

De Baunly and D. Baker (1970) put the balance for 1960-1961 as follows:

Rainfall over the lake	1826 millimetres
Inflow into the lake	349 millimetres
Evaporation from the lake	1453 millimetres
Outflow from the lake	567 millimetres

From the above comparative review, it is clear that the main hydrologic processes are at constant interplay within a narrow relative limit of proportions. The result of the interplay is seen from the variations in the lake Victoria levels, which in the past 100 years has fluctuated by more than 2.5 metres.

Conclusions

The above work looks at the magnitudes of the main non-controlled hydrologic variables in Lake Victoria. Rainfall and Evaporation are the major players in the water balance of Lake Victoria with proportionally high degree of influence. Interplay between losses and gains into Lake Victoria manifest itself in the lake levels. Although catchment input and outflow at Jinja play a proportionally less significant role in the balance, man nevertheless controls them. Any adverse actions in the catchments of Lake Victoria that can decrease or increase flow or storage features of the lake and changes in release patterns at Jinja can easily trigger an imbalance in the lake with a subsequent adverse rise or fall in the lake levels. Uganda's energy production is primarily dependent on the height of water levels of Lake Victoria. If the catchment activities are not well controlled, then this could spell catastrophe for the riparian stakeholders.

References

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