CHAPTER THREE

Hydro-meteorological observations over the Ugandan portion of Lake Victoria

**Okonga, J. R. and Sewagudde, S.M.*

Water Resources Management Department
Directorate of Water Development
P.O. Box 19 Entebbe, Uganda

**Correspondance : okonga.wrmd@dwd.co.ug*

ABSTRACT. *Quantification of lake water inflows and outflows is essential for understanding the quality and hydro dynamics of a lake system. Hydro-metrological data for the period running 1950-2004 was analysed to provide flows for estimating pollution loads into Lake Victoria from the Ugandan side of the lake. These would also form input to the lake water balance. Continuous rainfall and evaporation records were generated. Full records of land discharge were obtained through modelling using the Nedboer-Afstroemning Model (NAM). Model performance was evaluated on the ability to simulate the total flow rather than the peak and minimum flows for pollution estimation.*

Results indicated that Uganda's land catchment annual contribution to Lake Victoria is about 312 Million m^3/s, forming about 1.3% of the total land discharge. The mean annual rainfall over the Ugandan side of the lake is about 2020 mm and this forms 35.2% of the mean annual lake rainfall. No significant trends in rainfall were observed over the period of study. Evaporation was less than rainfall by a factor of 0.66 implying that the Ugandan sector of the lake plays an important part in determining the positive tendency in the lake's net basin supply.

Examination of the lake levels in relation to the River Nile outflow shows that there has been a close relationship between the levels and amount of water released through the Owen Falls dam implying that the natural process of the lake has always been followed. However this relationship was interrupted since 2000, which partially explains the drastic fall in Lake Victoria levels. The disparity between the two parameters continued and reached its peak in July 2004.

INTRODUCTION

There are concerns that the ecosystem and water quality of Lake Victoria is changing and changes have been observed in recent years. The knowledge of the changes in the pollution loadings to the lake is necessary in order to identify the root cause of this deterioration. But pollution depends on the meteorology and hydrology of the lake (discharges to the lake from the catchment and the atmosphere). An estimate of the total water balance for the lake over the past 50 years is considered in order to establish the water budget of Lake Victoria basin, that is, all discharges to and from the lake on daily basis. The estimates are required for: rainfall onto, and evaporation from the lake-surface; discharges to the lake from all rivers and its catchments and discharge from Lake Victoria into the Victoria Nile.

The principal objective of understanding the meteorology and hydrology of Lake Victoria is to establish the nature of hydrologic regime within the lake for purposes of using the quantified dynamics for managing the lake and its catchments. It is also to establish pollutant loads into the lake in order to explain the changing water quality and come up with mitigation measures to salvage the deteriorating environmental integrity. Table 1 presents the basic geographical information for Lake Victoria. Understanding of the lake ecosystem involves estimation of pollution loading into it.

TABLE 1. The Basic geographical information of Lake Victoria (Source: LVDP)

Country	Lake Surface area		Catchment area		Lake Shoreline	
	Km^2	%	Km^2	%	Km^2	%
Tanzania	33,756	49	79,570	44	1,150	33
Uganda	31,001	45	28,857	15.9	1,750	50
Kenya	4,113	6	38,913	21.5	550	17
Rwanda	0	0	20,550	11.4	0	0
Burundi	0	0	13,060	7.2	0	0
Total	68,870	100	180,950	100	3,450	100

This involves estimation of pollution loading per unit time into the lake from the catchments and the atmosphere, which involves computing discharge into and out of the lake, determination of rainfall over the lake, while linking it to atmospheric deposition and estimation of evaporation over the lake.

Accordingly the main tasks involved under meteorology and hydrology of the lake is to quantify discharges into the lake from catchment runoff and rainfall over the lake; as well as output processes of evaporation and the River Nile outflow at Jinja. Analysis of trends in the flow quantities, rainfall and evaporation, would assist in drawing conclusions on future pollution loading into the lake and to manage the lake basing on the dynamics of the regime.

Lake Victoria Basin and monitoring stations in Uganda

The Uganda part of Lake Victoria basin is marked by shallow shoreline littoral zones with moist catchments to the north and north east. The north-west and western parts are semi-arid in the cattle corridor. The lake surface area is 31,001 Km^2 (45%) with a shoreline length of 1,750 Km (50%) making Uganda have the longest contact with the lake of the 3 countries that share it (Table 1).

Table 2 presents the Uganda river catchments. Ugandan catchments cover 27,924 Km^2 (5.9 %) making Uganda the least contributor of water to Lake Victoria, from water sheds. The significance of these observations is reflected on the vulnerability that faces the lake from the Uganda side.

TABLE 2. Uganda river catchment areas

River Basin	River Basin area (km^2)	Gauging Station	Catchment area upstream of gauging station (km^2)
Bukora	8392	81270 Bukora 81224 Ruizi 81216 Kakinga	7395
Katonga	15244	81259 Katonga 81271 Kisoma	13930 2.6
			Sub catchment areas
		Katonga Catchment	13930
		Areas downstream of all river gauging stations from Katonga	209
		Kisoma and Sango Bay	1105
			15244
N. Shore Streams	4288	(none)	

MATERIALS AND METHODS

Historical records from 1950-2000 were used to study the meteorology and hydrology of Lake Victoria. From 1950 to 1967, data records were scattered with a lot of missing gaps. From 1968-1978, during the hydro-meteorological survey of Lakes Victoria, Kyoga and Albert in Upper Nile (Hydromet Survey Project), better quality data set was collected. There after, data collection again collapsed due to logistical problems, necessitating estimation and gap filling. Gap filling was necessary to create continuous record data set that could be used to derive statistical and analytical values. Data collected during LVEMP period was of better quality and with fewer gaps. Different treatments were given to rainfall, evaporation, and river discharge data on the basis of their physical differences. Data for temperature and wind were not infilled but were used to establish the patterns of their dynamics.

Rainfall

Rainfall data for the period from 1950 to 2004 was used. A limited number of rainfall stations were selected depending on their representativeness of each of the sub catchments in relation to the geographical coverage, data quality and rainfall characteristics. Figure 1 shows the location of rainfall stations that were selected for data collection.

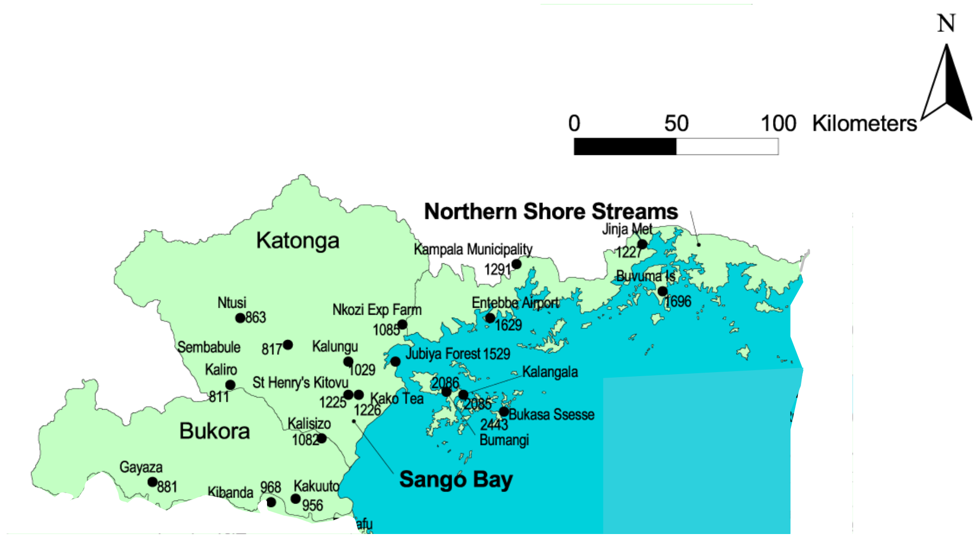

FIG. 1. Sub catchments and location of rainfall stations used on the Uganda side.

The data were subjected to quality control checks including, visual examination of raw and plotted data, descriptive statistical tests (means, running means, maximum, minimum and standard deviation). Comparison with data at adjacent stations, calculation of cumulative mass curves to identify changes in measurement technique and changes in instrument location was also done.

The gaps in the time series were infilled for each of the time series of the selected stations. For each of the sub catchment, one or more reference stations were selected. The criterion was that such a station had the longest, continuous, high quality record in the locality. A double mass curve was then plotted for the subject station in relation to the reference station to which a trend line was fitted. It is this trend line that was used to infill gaps at the subject station. For incidents where both stations lacked data, the technique of gap filling using ‘typical years” was used. This technique was particularly developed for this project and proved to be effective. Three categories of a ‘typical year’ were developed, that is, ‘wet year’, ‘average year’ and ‘dry year’. Their selection was as follows:

“Wet year”	lake level rises by more than 0.2 m approximately.
“Average year”	lake level changes by not less or more than 0.2m approximately
“Dry year”	lake level falls by more than 0.2 m approximately.

The measured station rainfall was then examined. The same categories of typical years was used except that the criterion of selection was based on maximum, average and minimum annual rainfall for the wet, average and dry years respectively.

Estimation of lake rainfall

In the estimation of rain fall over the lake, the lake area was divided into polygons (boxes) representing rainfall influences from the stations selected. In this method, each rain polygon (box) had a reference rainfall station. Table 3 shows the rainfall boxes for the Ugandan portion of Lake Victoria. The mean annual rainfall in each box was computed using the rainfall isohyetal curves derived by drawing curves that link stations with similar average rainfall totals. Then the daily rainfall in each box was calculated from equation 1:

$$R_{box} = R_{ref} \times MAR_{box} \big/ MAR_{ref} \text{ .... } \mathbf{1}$$

Where R_{box} = Daily rainfall over the box
R_{ref} = Daily rainfall at reference station
MAR_{box} = Mean annual rainfall in the box
MAR_{ref} = Mean annual rainfall at reference station

Finally the average daily rainfall for the lake was calculated as the sum of the areal weighted means of the daily box rainfalls (Equation 2).

$$Lake \quad Rain = \sum_i (R_{box} \times Weight) \text{ .... } \mathbf{2}$$

TABLE 3. Rainfall boxes for the Uganda part of the Lake Victoria

Box No	Name	Weight	MAR_{box}	MAR_{ref}	R_{ref}	Mean annual lake rain for each box
1	Kalangala	0.509	2100	2085	2202	1128
2	Bumangi	0.105	1800	2086	2103	191
3	Entebbe	0.116	1950	1629	1642	229
4	Buvuma	0.270	1696	1696	1751	473
			MAR for Uganda Sector of the lake = 2020			

Evaporation

A similar approach as for rainfall was used for quality control and gap filling of evaporation time series. Firstly, the use of correlation was limited by the fact that evaporation is mainly measured at synoptic meteorological stations, which are few, and as a result the stations are scattered far apart. Secondly, there is no well defined method for assertion of a dry or wet year for evaporation. This method is further justified by the fact that evaporation varies less over space and time.

Estimation of lake evaporation

A similar approach as that used for estimating lake rainfall was applied in the estimation of the lake evaporation. Table 4 shows the Uganda part lake evaporation boxes. Pan Evaporation data was used for the pre-LVEMP period whereas for major part of LVEMP period, data from Automatic Weather Stations (AWS) were used except for Entebbe Weather Station. The AWSs digitally recorded several hydro-meteorological parameters including but not limited to maximum, minimum and average temperatures, rainfall, wind speed and direction as well as solar radiation. The presence of data for these parameters facilitated the use of Hargreaves equation (Equation 3) to calculate lake evaporation.

$$E_o = 0.0023(T_{avg} + 17.3)(T_{max} - T_{min})R_a \quad \text{………………..} \ 3$$

Where E_o = evaporation
T_{avg} = average daily temperature
T_{max} = Maximum daily Temperature
T_{min} = Minimum daily Temperature
R_a = Solar Radiation

TABLE 4. Evaporation boxes for the Uganda sector of the lake.

Box No	Name	Weight	[1]MAE_{box}	[2]MAE_{ref}	E_{ref}	Mean total annual lake evaporation
1	Bukasa	0.539	1250	1108	1100	668
2	Entebbe	0.067	1350	1399	1411	91
3	Koome	0.395	1450	1245	1250	575
		Mean annual sector Evaporation				1334

[1]Mean annual evaporation total; [2]Reference station

Temperature and wind

Long term continuous monitoring of temperature and wind was not undertaken except for a brief period under the Hydromet Survey Project. The Water Resources Management Department and the Uganda Meteorological Department had only brief periods of temperature and wind data collection over the Lake Victoria Basin. Available data are therefore scattered and un-matching. Continuous data exist for the LVEMP period especially data for Automatic Weather Stations. Therefore, only temperature data from the LVEMP period was analysed.

River discharge

The most critical aspect in river flow analysis is having a complete reliable data set covering the period of interest. Rainfall-Runoff modelling, an effective tool for gap-filling river discharge time series, was used to overcome the limitation. It was also decisive in estimating flows in ungauged catchments.

In particular, the NAM model (Nedboer-Afstroemning Model) was used for this purpose. The NAM model is a conceptual lumped model. It considers the entire catchment as a single unit with uniform properties. The model conceptualizes water flow into a number of reservoirs with the parameters partly reflecting the physical properties of the watershed.

Model adjustments during calibration were based on obtaining a best fit between the modelled and measured, accumulated runoff, peak flows, recession curves and low flows. However given the purpose of the quantified flows, that is, to estimate the total pollution loading into the lake, the most important factor considered was the ability of the fine tuned model to predict the accumulated runoff. The gauging stations for the 2 sub catchments (Rivers Bukora and Katonga) are not at the river mouths (as the river enters into the lake). The final river discharge from these catchments was computed by increasing the gauging station discharge in the same proportion as the catchment areas, as:

$$\text{Basin discharge} = \text{Gauging Station discharge} \times \left(\text{basin area} \middle/ \text{gauging station area} \right) \ldots\ldots 4$$

For the northern streams which are ungauged, the runoff was estimated by running the NAM model with the same parameters as for Bukora catchment which has similar hydrological characteristics.

Lake levels

The Lake Victoria water level in Uganda is measured at two points, namely Entebbe and Jinja. The zero datum elevations of the two stations above mean sea level (MSL) are 1123.432 m and 1122.887m for Entebbe and Jinja respectively in reference to the Khartoum datum. The stations supplement each other in terms of quality checks and gap filling. An appreciably long daily water level data set (from 1948 to 2005) for Lake Victoria exists. However, major gaps exist from 1978 to 1979 where no data was recorded at both stations due to logistical problems at the time. These gaps were filled using Kisumu levels; where data during the period was available.

RESULTS

Temperature variability

Observed records show that temperature reaches a maximum in February, just before the March equinox (date when sun is overhead equator or the tropics of Cancer and Capricorn) and gets its lowest records in July after the June equinox. Figure 2 shows variation of maximum, minimum and average daily temperatures over the Uganda part of the lake.

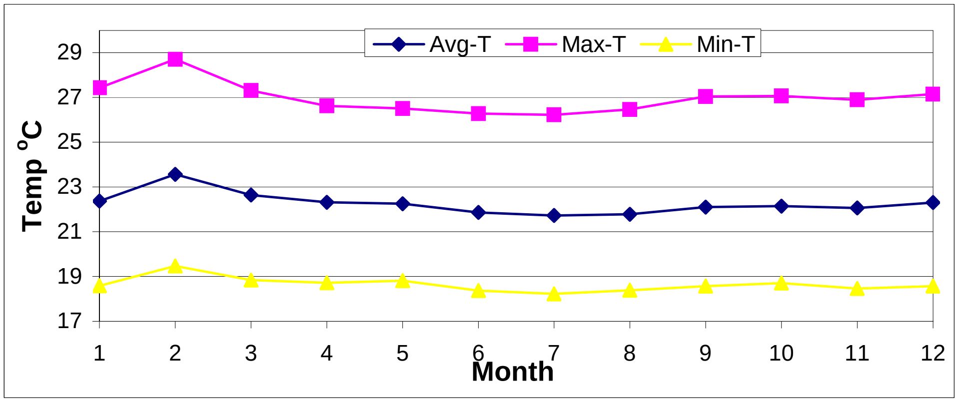

FIG. 2. Maximum, minimum and average temperatures over the Uganda part of the basin.

Wind patterns

Wind over Lake Victoria closely follows the pattern of the apparent movement of the sun across the equator through the Inter Tropical Convergence Zone (ITCZ). The ITCZ and its influence affect the regime of most of the meteorological parameters including rainfall, wind speed and direction, and temperature.

Figure 3 indicates two strong seasonal wind patterns that influence the hydraulic processes of the lake. In the months of January-February and June-September, the wind pattern is predominantly East West, parallel to the equator, with origins from the Nandi hills in western Kenya. These are fairly dry winds. The moisture they pick are deposited to the western catchments especially Bukora catchment.

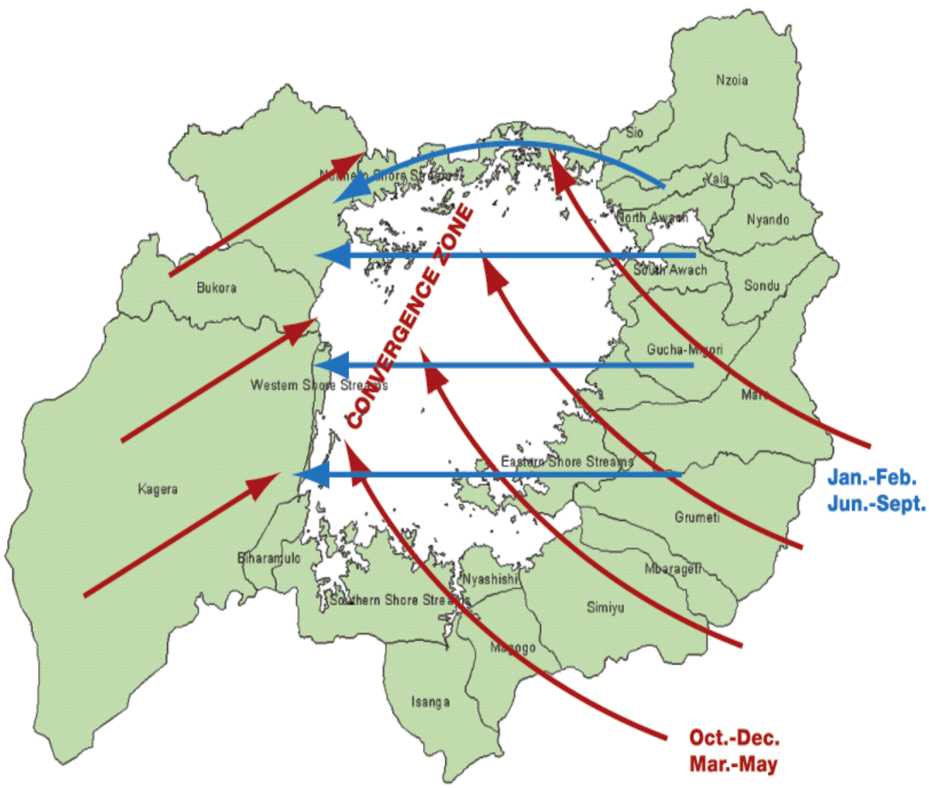

FIG. 3. Seasonal wind patterns influencing the hydrological processes in Lake Victoria Basin (adopted from the Intergrated Water Quality and Limnology Study of Lake Victoria 2002).

During the period of March-May and October-December, the wind pattern changes towards the northern parts of the lake.

Catchments and lake rainfall on Lake Victoria, Uganda

The rainfall pattern over the lake and land areas of the basin exhibits a typical bimodal characteristic. The pattern shows that the lowest rainfall amounts fall in the months of August and September for pre-LVEMP and LVEMP periods. The Second and equally severe low spell occur in February each year for both periods. On the other hand, peak rainfall totals annually occur in April for both pre-LVEMP and LVEMP periods. This pattern closely resembles the wind pattern described in Figure 2 where the winds in January-February and June-September are predominantly westerly. In the month when peak rainfall occurs, seasonal winds are observed to be a convergence of southwesterly and south easterly. This observation reveals a strong influence of winds on rainfall incidence in and around Lake Victoria. Figure 4 shows plots of the monthly mean rainfall totals for the pre and LVEMP periods.

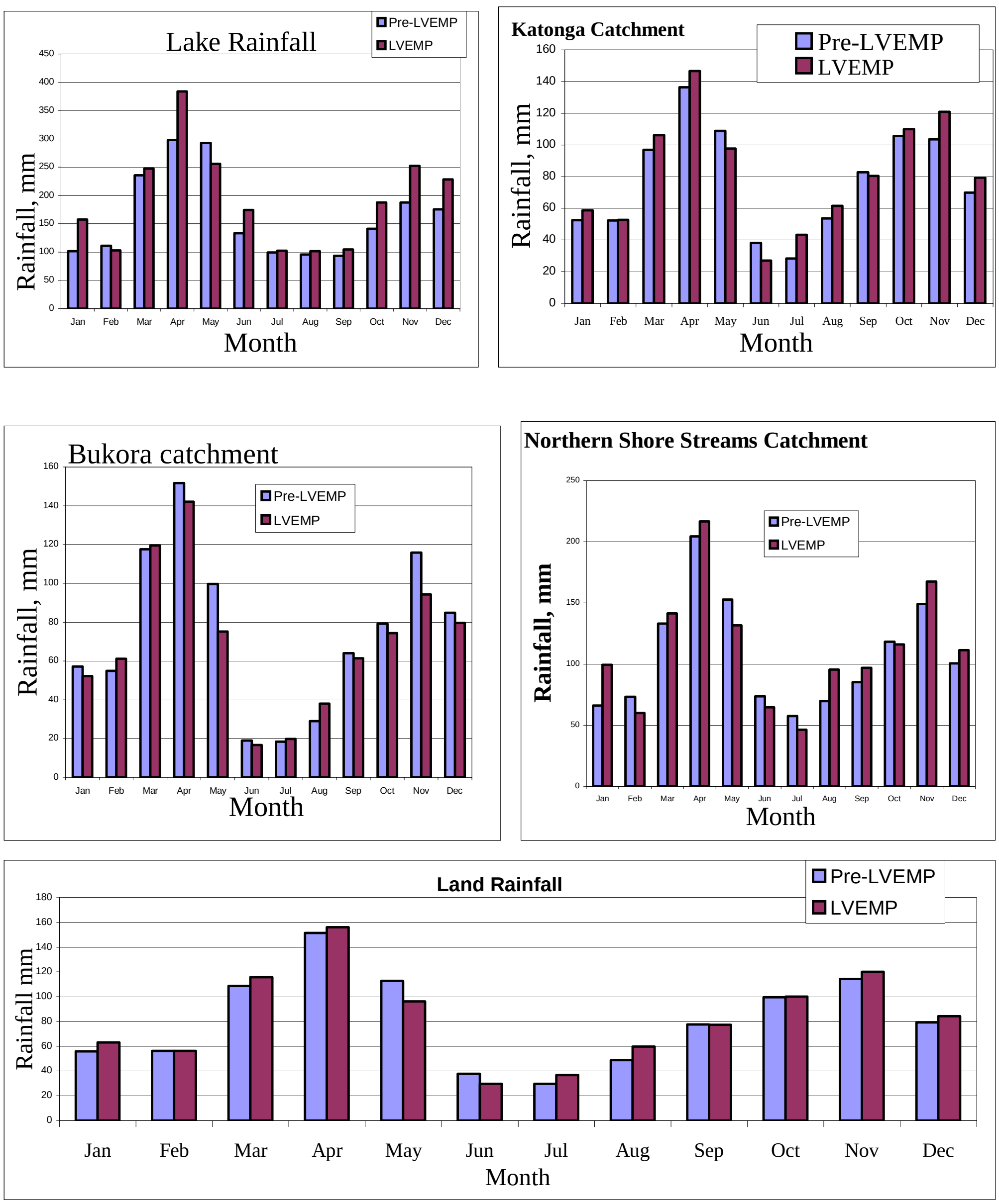

FIG. 4. Monthly rainfall totals for the pre and LVEMP periods.

Table 5 shows the rainfall statistics for both periods. On a catchment basis, the Bukora watershed reported 5% less rainfall than the average for the pre-LVEMP period, nevertheless its accumulated monthly rainfall was fairly consistent for both periods except for the months of May and November in which the amount of rainfall recorded for LVEMP period was about 20mm below average (Table 5). For River Katonga and the Northern Shore Streams, the accumulated monthly rainfall was generally above average for about 67 % of the year, predominantly from the month of June through January of the preceding year. The monthly total rainfall for the two watersheds was below average by 25% and 20% of the time respectively (Table 5).

The monthly lake rainfall showed close agreement for both periods with monthly variations of ±40mm of the average monthly rainfall except for the month of March in which 92mm in excess of the average was received.

TABLE 5. Annual mean, maximum and minimum rainfall (mm) for the pre and LVEMP periods.

	Bukora	Katonga	Northern Shore streams	Average	Lake Rain
Pre-LVEMP Average	882	948	1307	984	2011
Average LVEMP	838	1048	1426	1043	2241
% of Average	95	111	109	106	111
Monthly maximum (pre-LVEMP	1375	1340	2290	1379	3114
Monthly maximum (LVEMP)	1035	1265	1734	1244	2868
Monthly minimum (pre-LVEMP)	674	560	916	664	1374
Monthly minimum (LVEMP)	677	810	1111	873	1378

Spatially, the rainfall pattern shows influence of relief and location with regard to rainfall incidence (Figure 5). The highest rainfall in Uganda (including the rest of Lake Victoria Basin) is received around the Ssesse Islands. This reaches totals of about 2,400 mm annually. On reaching land to the west and north-west of the lake, most of the moisture is deposited and the rain shadow effect is felt from Bukakata towards River Bukora and some parts of River Katonga.

Annual depth of precipitation during the LVEMP period was higher than average (for the period of 1950 – 1995), with the exception of the Bukora catchment in the south west of the country where 95% of the mean annual rainfall was recorded. River Katonga and the Northern shore stream catchments recorded 11% and 6% above the mean annual rainfall respectively. This brings the overall catchment rainfall performance to 105% of the mean annual rainfall for the period 1950-95. It must however be noted that the LVEMP period was short as compared with the rest of the time. In this case, its records suffer less from attenuation effects than that of the longer period.

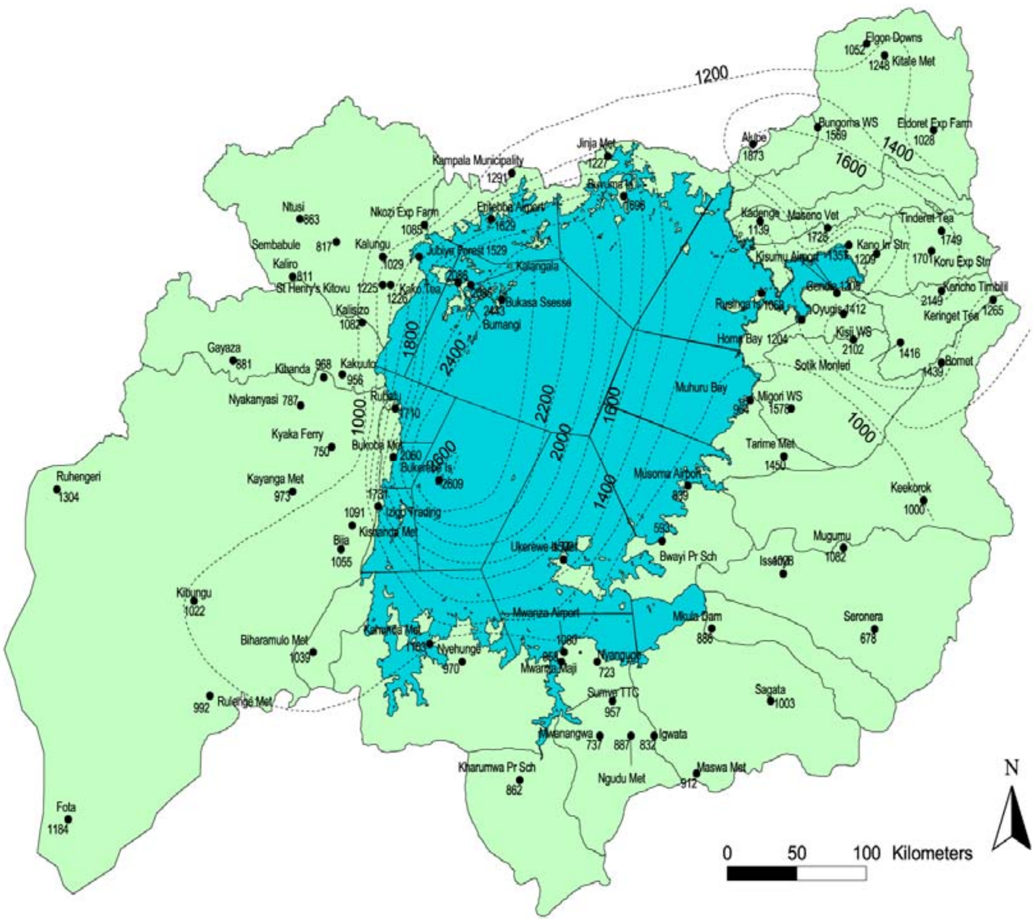

FIG. 5. Rain boxes and spatial rainfall variation over Lake Victoria and its immediate surrounding (adopted from the Intergrated Water Quality and Limnology Study of Lake Victoria 2002).

Lake rainfall

The estimate of lake rainfall for the Uganda sector of the lake puts the mean annual rainfall at 2020mm occurring over the lake. Annual Lake Rainfall during the LVEMP period was 11% above the mean annual lake rainfall. According to the weights awarded to each of the lake's rain boxes, Uganda's annual contribution to the lake is approximately 35.2% of the total mean annual lake rain which translates into 711mm of rainfall.

On average, Kalangala rainfall box received the highest rainfall of the four Uganda rain boxes for the period 1950 – 2004. Bumangi, Buvuma and Bukasa rainfall boxes closely followed the one of Kalangala. Given Kalangala's size, which is reflected in its weight, it greatly influenced the final value of the mean annual areal lake rainfall for the Uganda portion of the lake. Although Bumangi was next to Kalangala in as far as the received rainfall at the reference station is concerned, its contribution to the mean annual lake rainfall was greatly undermined by its size and hence weighting factor. For instance, Bumangi received 20% above that of Buvuma rainfall, but its contribution to the mean annual rainfall was only 40% relative to Buvuma.

Lake evaporation estimation

Computation of lake evaporation suggests that evaporation tendencies are relatively homogeneous compared to rainfall. The deviation from the mean annual evaporation boxes is 155mm as compared to 270mm for the mean annual rainfall boxes. For that reason the effect of the box size influences the total lake evaporation to a small extent. Results show that evaporation from the Uganda part is less than rainfall by a factor of 0.66 and accounts for 29.9% of the lake evaporation. Since the estimated mean annual evaporation is far less than the mean annual rainfall and considering that evaporation and rainfall are the main determinants on the Lake Victoria water balance, it can be deduced that the Ugandan portion plays an important part in determining the positive tendency in the net basin supply for the lake.

River discharges

The NAM model results show that comparison plots of the modelled and measured discharge prove that the model simulated the flows quite satisfactorily for all the catchment. Figure 6 shows an example of the results of calibration of the NAM model on River Katonga. It can be seen that the model suitably reproduces the peaks and low flows. The accumulated observed and simulated discharges are in close agreement as shown in the cumulative plot.

Quantification of flows was the purpose of determining the sediment and nutrient loading into the lake. Since the model could accurately reproduce the accumulated discharge then it is logical that the total loading into the lake will be adequately estimated to a significant degree of accuracy. Figure 7 presents the mean flow for Rivers Bukora, Katonga, Northern shore streams and the total land contribution.

Computation of the mean discharge illustrates that the Uganda part of Lake Victoria catchment contributes about 312 million m^3/s to the lake which is approximately 1.3% of the total land catchments discharge. The average annual flow and contribution of each catchment is presented in Table 6. Further scrutiny shows that of the three Ugandan catchments, Katonga has the highest variation in monthly flows with a standard deviation of 1.74 m^3/s and the northern streams having the least variation in monthly flows with a standard deviation of 0.52 m^3/s.

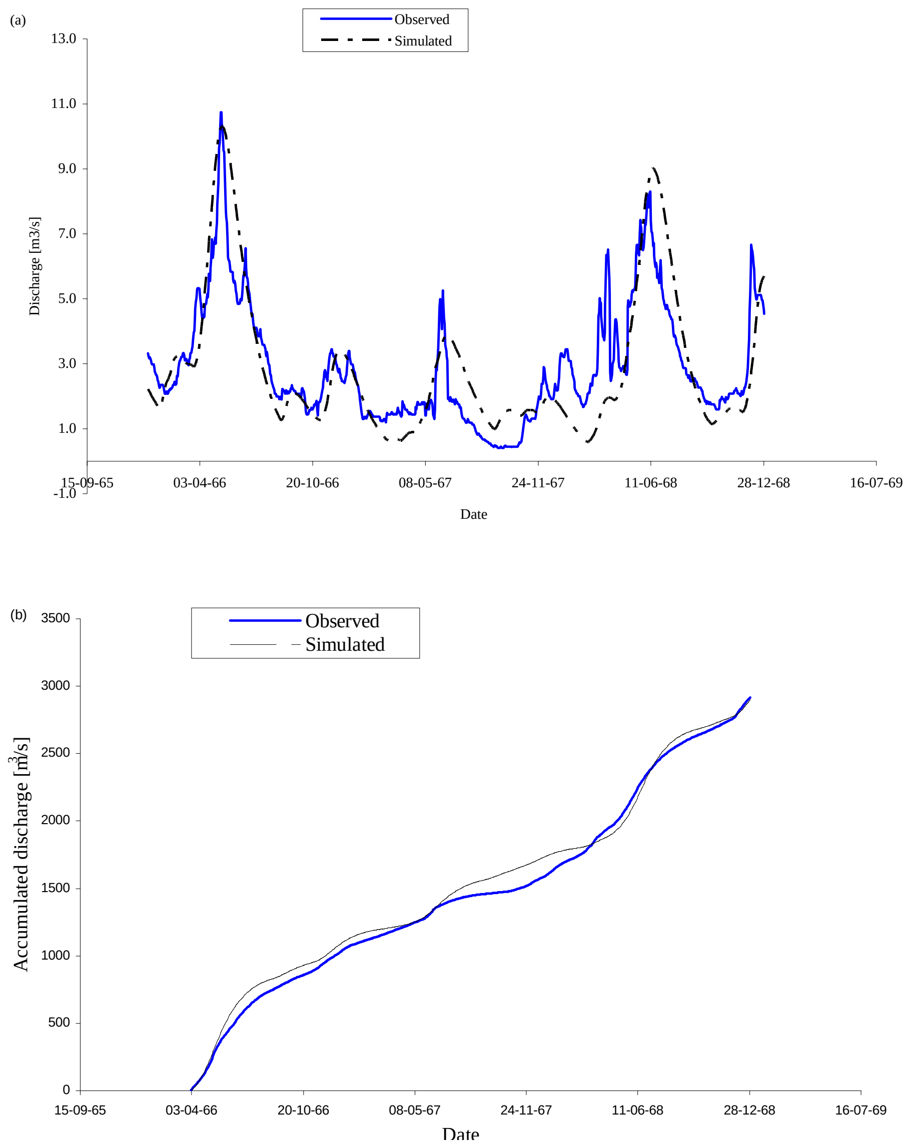

FIG. 6. Observed and simulated discharge of River Katonga (a) Discharge (b) Accumulated discharge over time in the 1960s.

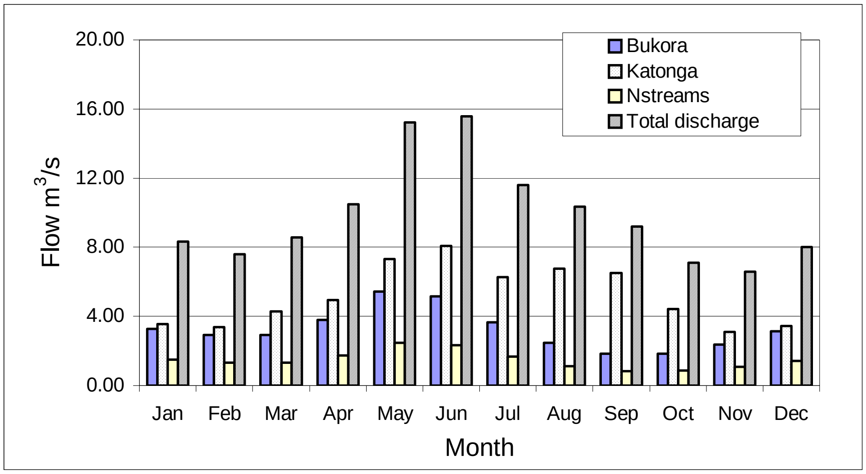

FIG. 7. Mean flow for Rivers Bukora, Katonga, Northern shore streams and the total land contribution.

TABLE 6. Monthly means from rainfall-discharge modelling 1950-2005 for all catchments and total national contribution.

	River Bukora	River Katonga	Northern shore streams	Whole Uganda Catchment
Area (km^2)	8392.00	15244.00	4288.00	27924.00
Average flow (m^3/s)	3.24	5.17	1.48	9.89
Std (m^3/s)	1.15	1.74	0.52	2.96
Max m^3/s)	5.45	8.10	2.46	15.59
Min m^3/s)	1.84	3.11	0.85	6.59
Annual flow (MCM)	102.00	163.00	47.00	312.00
Flow (mm)	12.20	10.70	10.90	11.20
Annual Rainfall (mm)	882.00	938.00	1295.00	976.00
Runoff coefficient	1.38	1.14	0.84	1.14

The maximum and minimum monthly flows for River Bukora and the Northern streams show similar trend (Figure 8), especially during the months of May and September respectively. On the other hand the maximum and minimum monthly flows for River Katonga are realised in the subsequent months, namely the June and November respectively.

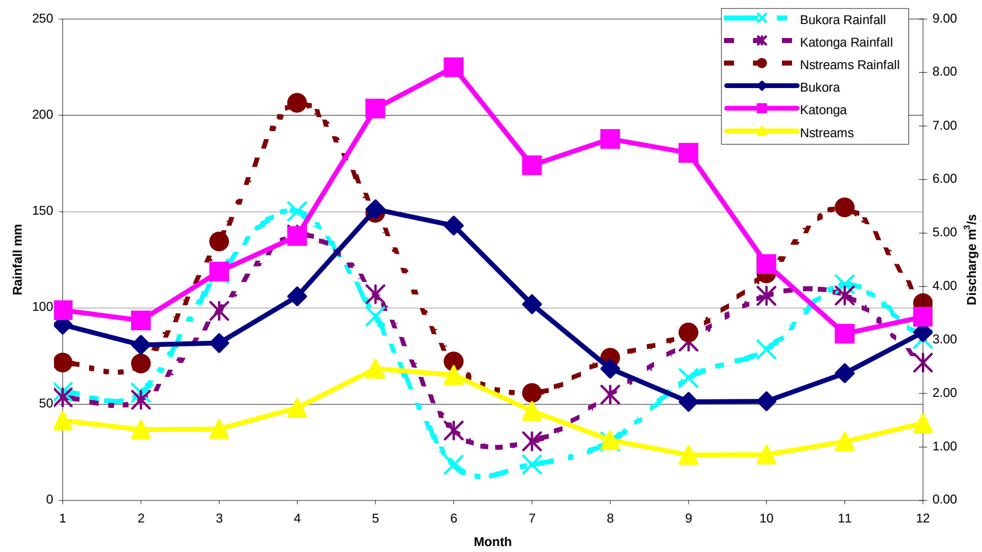

FIG. 8. Comparison of mean monthly rainfall and discharge for Rivers Bukora, Katonga and Northern Shore Streams for the period 1950-2004.

A comparison of runoff and rainfall shows that in general the Uganda catchments have a low rainfall to runoff conversion ability. The runoff coefficient ranges between 1.38-0.84 % with Bukora having the highest, followed by Katonga and last of all the Northern Shore Streams.

Lake Victoria levels

Prior to 1961 the average annual Lake Victoria level was 1133.93m above mean sea level (AMSL). Following the intense rains of 1961 through 1964, the lake level rose by 2.34m in a period of two and half years. The lake has since remained at relatively higher levels at an average of 1134.97m (AMSL) for the period 1960-2004 as exhibited in Figure 3.9. The long-term average lake level (1950-2004) is 1134.77m (AMSL). For the last 40 years, the lake levels have exhibited a significant downward trend with drastic drops occurring in the period 2001 - 2004. The year 2004 (in November) recorded the lowest level at 1133.96m which picked up to 1134.l8m at the end of the year.

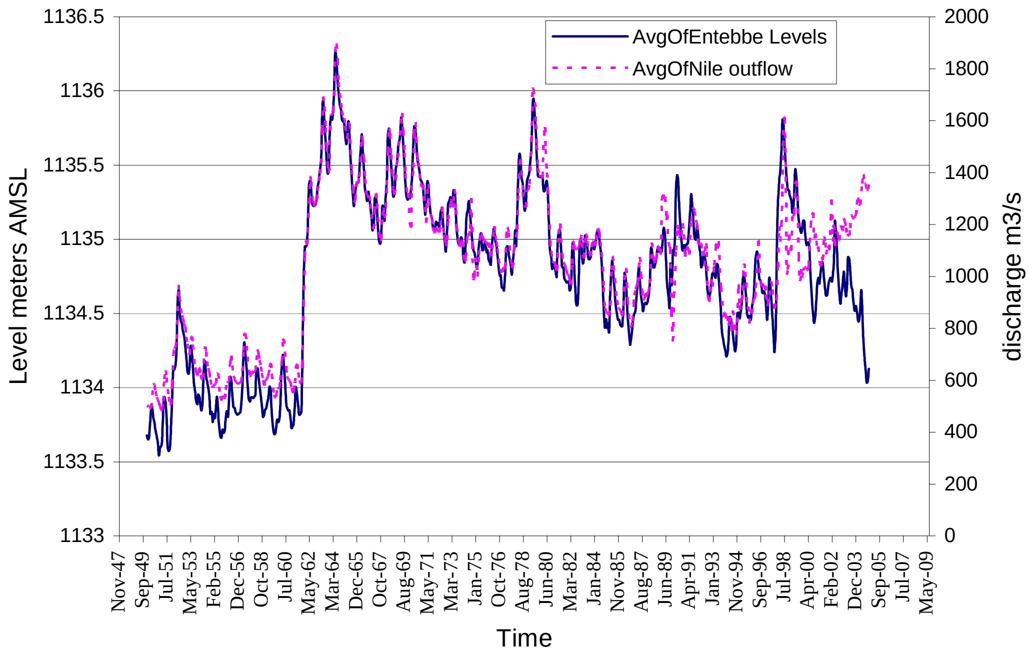

FIG. 9. Lake Victoria levels and the River Nile outflow.

Figure 9 shows that the stipulated policy was closely followed until 2002 when both the lake level and release became independent variables.

Hydro-meteorological trends over observed historical records

In general, there is an upward linear trend in rainfall on the Uganda Lake Victoria basin. As presented in Figure 10(a), Lake Victoria rainfall exhibits a steeper trend gradient than catchment rainfall. However examination of the LVEMP period [Figure 10(b)] shows that lake rainfall is on a downward trend with a trend gradient about two times the pre-LVEMP period. Catchment rainfall has continued to follow an upward trend but with a gradient of four fold of the pre LVEMP period.

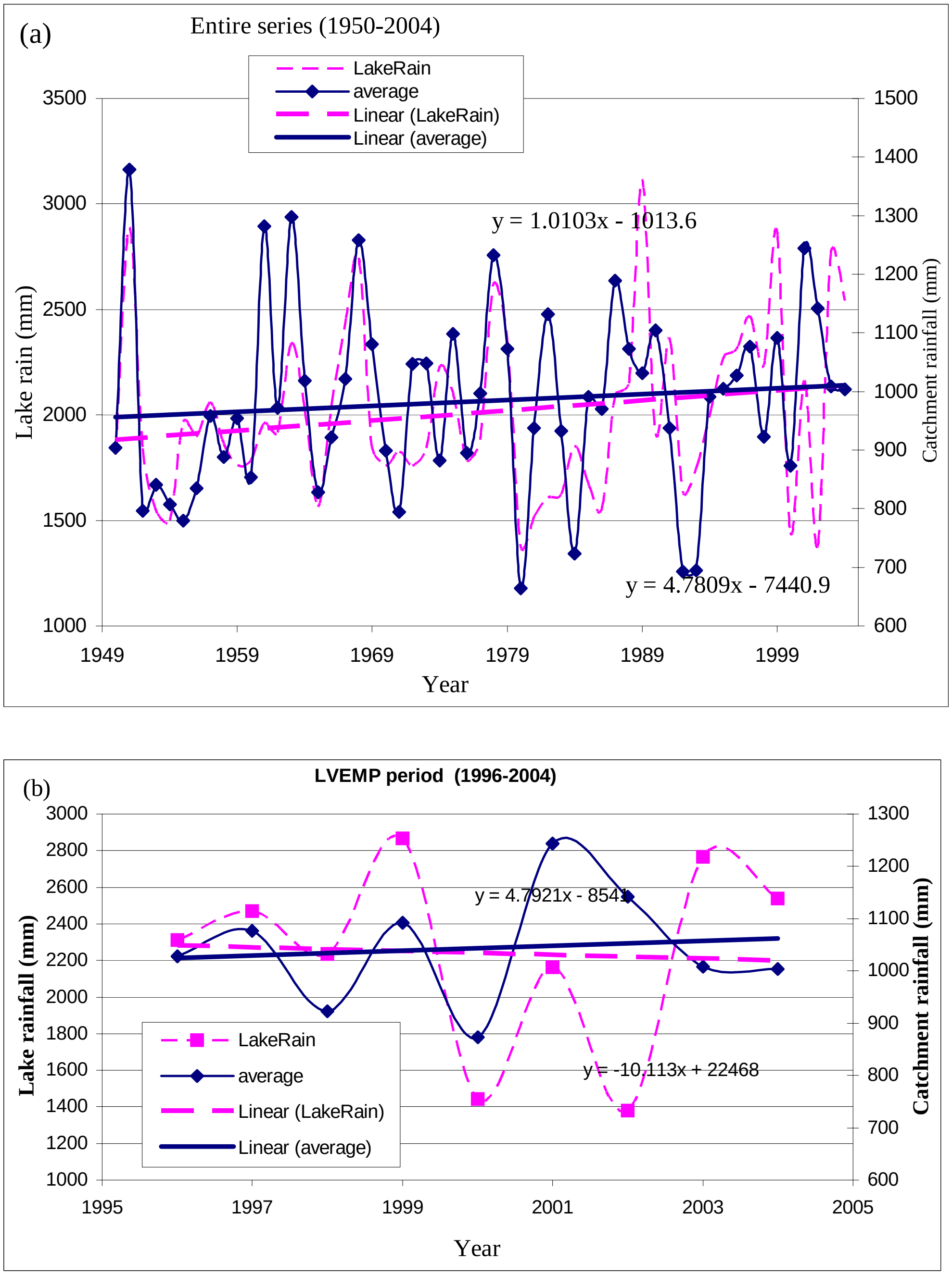

FIG. 10. Annual Lake and catchment rainfall for (a) period 1950 – 2004 and (b) LVEMP period; 1996-2004.

DISCUSSIONS

Comparison of historical and recent climatic data for Lake Victoria demonstrates changes in surface temperature, air moisture, atmospheric transparency, and wind shear from conditions 35 years ago. The changes appear to be part of a global change in climate conditions of the high elevation tropics (Lehman 1998).

Results suggest that temperature varies from one period to another. It is expected that the highest temperatures should occur after the March equinox when the sun is overhead the equator, but the highest temperatures have been observed to occur before the March equinox. One possible explanation is that the dry north-east winds from the Ethiopian highlands exert its greatest influence towards the end of the dry season in February. This probably creates the highest temperatures that are manifested in the records.

The same can explain the low temperatures observed in July. This is when the sun is overhead the tropic of cancer and a predominance of maritime breeze is felt in the lake basin from the cool waters of Lake Victoria. These observations are useful in understanding the limnology of Lake Victoria as well as the quantitative variations of hydraulic and limnological processes in the basin.

The convergence of south-easterly and south-westerly winds in this period account for the heavy rainfall amounts in the northern shores of Lake Victoria. This influence extends from the Ssesse Islands to Katonga Catchment leaving Bukora Catchment a bit arid. The highest rainfall in Uganda (including the rest of Lake Victoria Basin) is received around the Ssesse Islands. This reaches totals of about 2,400 mm annually. On reaching land to the west and north-west of the lake, most of the moisture is deposited and the rain shadow effect is felt from Bukakata towards River Bukora and some parts of River Katonga. Perhaps this explains the occurrence of a cattle corridor in this area. In the Northern Shores, the lacustrine effects do not extend for more than 40 kilometres in most places where arid climate typical of the cattle corridor sets in.

There is an exceedingly high correlation between convective rainfall over Lake Victoria and in the surrounding catchment. This permits the derivation of a relationship between rainfall over the lake and its catchment (Mamoudou and Nicholson 1998). A comparison of runoff and rainfall shows that in general the Uganda catchments have a low rainfall to runoff conversion ability. The runoff coefficient ranges between 1.38-0.84 % with Bukora having the highest, followed by Katonga and last of all the Northern Shore Streams. The low conversion aspect is explained by the vegetation index dominated by vast wetlands fringing the rivers particular at the mouths. These wetlands provide an extensive water surface conducive for massive evaporation.

The water level record of Lake Victoria over decades, centuries and millennia indicates that it responds sensitively to changes in rainfall and evaporation. Even in its modern condition, Lake Victoria is barely an open lake with flushing time of over 100 years (Hecky *et. al.* 2004).

Lake Victoria levels were low during the early 19th century, with peak levels occurring in the late 1870s, and then declined to the 20th century levels (Phoon *et al.* 2004). The decline briefly ceased by the occurrence of high levels in the early 1890s. Lake levels were low during the 20th century. Lake Victoria levels rose significantly in 1961 to 1962.

Lake levels have been observed to have decreased especially after the year 2002. It is probable that the lake level would have finally reverted to its pre–1960 levels which are considered as the natural levels. However this process has apparently been accelerated by the reservoir-release practices at the Owen Falls dam. The Owen Falls reservoir operation policy follows a rule that restricts the amount of water flowing through the dam to that which would have flowed had the dam not been in place. It is represented by a mathematical equation (equation 5) agreed upon between Britain and Egypt in 1954. The equation was derived from water level-discharge relationship established at the then Rippon Falls. It must be noted that when the level-discharge rating was done at Rippon Falls, flow was unregulated, as it is the case now.

As expected if this rule is violated, releases into the River Nile can affect the lake level to a great extent due to the interconnectivity of the hydro-power reservoir and the lake.

$$Q = 132.923(h-8.486)^{1.686} \quad \text{……………… Equation 5.}$$

Where: Q is discharge and
h is elevation (above mean sea level, amsl)

The stipulated release policy was closely followed until 2002 (Figure 9) when both the lake level and release became independent variables. This deviation from the historical release policy partly explains the accelerated drop in water level in the recent years. To obtain a comprehensive explanation to this scenario the net basin supply should be considered. This would require computing all the total land discharge and rainfall over the entire lake as input plus total evaporation as output. The current lake levels suggest that the lake is fluctuating around the average lake level before the 1960s, which is considered to be the natural average level for the lake. The observed minimum lake level in the last 40 years is still within the natural fluctuating band of the lake.

On the other hand, it has been noted that the stipulated release policy does not represent the optimum way of utilising the lake resource. The increasing economic development in Uganda implies increasing power demand. There should always be enough water for power generation so as to meet the demand. To ensure this, there should be storage during periods of high inflow to boost generation during low flows. This calls for regulation of the lake. For minimum disturbance of the annual lake water balance, compensatory release can be made on a seasonal basis.

It is possible that the 1998 intense rains that were associated with the El Nino Southern Oscillation exaggerated the trend gradient given its occurrence almost at the beginning of the study period. There is a significant correlation between the Lake Victoria rainfall series and the lake levels. There is a time lag of 1 to 2 years between rainfall episodes and the water level peaks of the lake (Phoon *et al.* 2004). A second rain peak was observed in 2002; however its magnitude was inferior to the former. Nicholson and Entekhabi (1986) notice that most of the rainfall peaks in the region corresponds to the pacific ENSO years (1951, 1957, 1963, 1972, 1978, 1982) and so on, which are responsible for the inter-annual rainfall variability. A secondary characteristic to this variability is the occurrence of extreme magnitude in individual years such as 1961 in which Lake Victoria levels rose by about 2.4m. Using spectral analysis, Ogallo (1979) and Nicholson and Entekhabi (1986) demonstrated that such occurrences are not completely random but rather follow a preferred time scale of 3 to 6 years. The 5 to 6 year peak was most dominant in the spectrum and they concluded that a forcing mechanism acting quasi-periodically is responsible for the extreme inter annual variation of rainfall in East Africa. It is less than six years since the last extreme rainfall variability occurred therefore it is difficult to ascertain whether the observed downward trend is significant and can be evidence for manifestation of climate change. However given the magnitude of the trend line it is most probable that the slope will flatten out with the occurrence of the next extreme peak rains.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Records over a fairly long period (1950-2005) have been analysed to give knowledge on the hydro-meteorological trends on the present and expected changes in the lake basin in the future. The data filling techniques particularly, the use of typical years was effective in generating continuous evaporation and rainfall time series for use in modelling.

Fine tuned models showed that the peaks and low flows could be correctly reproduced for the three sub catchments. The most important aspect in pollution loading is to quantify the load into the water body therefore any model estimating flow should correctly simulate the total discharge. On this basis it can be concluded that the generated flow series comprising of modelled estimates and actual measurements would estimate the total sediment and nutrient loading into the lake with a significant degree of accuracy.

In general there is an upward trend in rainfall over the Ugandan part of Lake Victoria basin. A downward trend was observed for the LVEMP period however its continuity in this direction could not be established from the short LVEMP period of data. It is expected that the general upward trend will continue for the near future.

The variation in water levels of Lake Victoria is determined by interplay between hydrologic processes that bring water into and take water away from the lake. Presently the declining levels of Lake Victoria are of utmost environmental concern. Observation of records has revealed that since massive storage of 1961-1964 the lake level has been falling to return to the pre 1960 levels, which are considered as the natural lake levels. General absence / limited rains on the lake in recent years resulted in falling of lake levels. Increased outflows at the Owen Falls dam for power generation resulted in a further fall in lake levels by about 0.34 m from 2001 - 2004.

The end of 2004 lake elevation is about the pre-1960 average. This level would have been reached many more years from now. However, the deviation from the historical release policy for the power reservoir operation has partly contributed to the accelerated drop in lake level.

In light of the increasing economic development with regard to hydropower generation, the present release policy at the Owen Falls Dam does not represent the most optimum way to utilising the lake resource. A favourable scenario will be to regulate the lake so that compensatory releases to meet the agreed release policy are done on a seasonal basis.

Recommendations

(a) There should be increased and consistent relevant data collection in Uganda and the riparian countries in general.
(b) There is need to constantly update the water budget for Lake Victoria using national and regional data from the riparian countries.
(c) Efforts should be made to determine the role played by groundwater in the water budget of Lake Victoria.
(d) Efforts should be made to synchronise water quality and quantity data collection to make it possible to relate the water budget to water quality conditions.

(e) Data collection equipment and instruments should be procured and standardized so that uniform data can be collected and used.
(f) More studies on water circulation are required to understand fully the dynamics within the lake.
(g) Gauging stations for the ungauged catchments should be established as soon as possible.
(h) Undertake intensive studies on the possibility of lake level regulation to increase its potential towards sustainable exploitation for social economic development of the riparian states

References

Hecky, R.E., Bootsma, H.A. and Odada, E. 2004. Lake Basin Management Initiative Thematic Paper. African Lake Management Initiatives: The Global Connection. Lake Basin Management Initiative Workshop. http://www.worldlakes.org/projects

Lehman, J.T. 1998. Role of climate in the modern condition of Lake Victoria. Theoretical and Applied Climatology 61(1-2): 29-37.

Mamoudou, B.B., and Nicholson, S.E. 1998. Analysis of Convective Activity and Its Relationship to the Rainfall over the Rift Valley Lakes of East Africa during 1983–90 Using the Meteosat Infrared Channel. Journal of Applied Meteorology 37 (10): 1250-1264.

Nicholson, S.E. and. Entekhabi, D. 1986. The quasi-periodic behaviour of rainfall variability in Africa and its relationship to the Southern Oscillation. Journal of Climate and Applied Meteorology, 34: 331-348.

Ogallo, L. 1976. Rainfall Variability in Africa. Monthly Weather Review 107 (9): 1133– 1139.

Phoon, S.Y., Shamseldin, A.Y and Vairavamoorthy, K. 2004. Assessing impacts of climate change on Lake Victoria Basin, Africa. People-centred approaches to water and environmental sanitation. 30th WEDC International Conference, Vientiane, Lao PDR. http://www.wsp.org