CHAPTER 3

Meteorology and Hydrology of the Lake Victoria Basin: Kenyan Sector

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ABSTRACT. *This study reports of the results of extensive field monitoring of river flows and lake levels, rainfall and evaporation. The study's aim was to elucidate main trends and periods of meteorology and hydrology as revealed by time series of rainfall, evaporation, river discharge and lake levels and which could be used as input towards computation of nutrient and sediment load introduced into Lake Victoria.*

Hydro-metrological data for the period running 1950-2004 were analysed and form the basis for computing the pollution loadings (catchment and atmospheric) into the lake and as well as calculation of the lake water balance. Continuous rainfall and evaporation records were applied and data gaps filled were necessary. Full records of land discharges were obtained from rainfall records using the NAM model. Model performance was evaluated on the ability to simulate the total flow for catchments, rather than the peak and minimum flows, for pollution estimation.

The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

INTRODUCTION

The association between hydrology and the eutrophication of the lake is the recognition that pollution loadings from the catchment of Lake Victoria are mobilized and transported in response to the hydrological cycle. In order to determine the dynamics of river driven pollution loading, it is important to first study the hydrological and meteorological behaviour of the whole catchment area, especially so in terms of rainfall, evaporation and river discharges which are inter-related. It is because of this need that this study has been undertaken by the Lake Victoria Environmental Management Programme's Meteorology/Hydrology task whose main duty is to determine an estimate of the total discharges to and from the lake on a daily basis. In addition this data contributes to determination of the regional water balance of the lake.

The study has been carried out through extensive field monitoring of river flows and levels, rainfall and evaporation through a network of existing stations with the aim of;

- Generating continuous daily evaporation records for the period 1950 – 2004
- Calculating discharges in the rivers on the basis of rating curves and measured gauge heights.
- Performing Rainfall – Runoff Modelling to extend and fill gaps in river discharge records from 1950-2004.
- Calculating final discharges for each individual river catchment or basin.

This is a follow up of what LVEMP had done earlier in developing an initial estimate of the total water balance from 1950 to 2000. In the earlier estimate; a lot of gaps in data were noted and the NAM Rainfall-Runoff model was used to fill these. It was therefore expected that actual observed data would be collected thereafter so as to induce more reality in the analysis and hence results of the study. To a large extent, this has been achieved and where difficulties have been experienced in getting observed data, methods which had been developed during the earlier study including correlation of existing stations to nearby stations by mass curves were engaged especially in filling rainfall gaps. Much about this will be mentioned later on in this paper.

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In methodology section, the manner in which the series were generated is discussed. The implication of the results in the eutrophication related processes in the lake are also discussed in this report.

Study area

The study area is all that Kenyan catchment area in which all rivers flow into Lake Victoria. This is the area from which rivers carry water, nutrients, sediments and pollutants into the lake and covers about 42460 km^2 on the Kenyan side (Fig. 1).

Among the five drainage basins in Kenya, Lake Victoria drainage basin is of special interest: Nearly half of the country's population lives in this basin, which is endowed with abundant water and other natural resources, e.g. drinking, domestic, agricultural and industrial water use, fisheries, biodiversity, hydropower, among others. While some of the resources have been exploited, many are still undeveloped. However, the lower reaches of the basin have serious environmental and health problems that affect development.

Development in agriculture, industry and urban centers has had adverse effects on water resources in the basin. Consequently, the lake ecosystem has undergone significant changes, particularly during the last five decades.

The main rivers and their discharge percentages are: Nzoia - 39%, Gucha-Migori - 20%, Sondu - 14%, Yala - 13%, Nyando - 6% and Sio-4%. The remaining

4% comes from various streams such as Awach Seme, Awach Kibos, Awach Kano (clustered as North Awach) and Awach Tende and Awach Kibuon (clustered as South Awach) (LVEMP 2002). There are also several seasonal rivers and streams originating from areas with high rainfall.

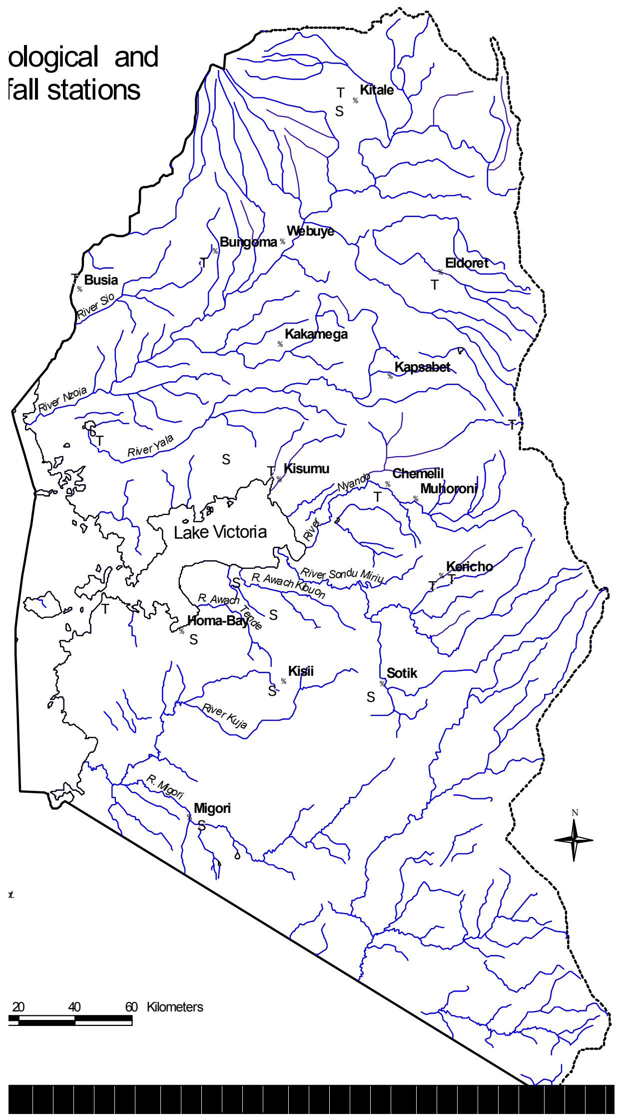


FIG. 1. Meteorological and rainfall stations.

Methods

To meet the objectives of this study, the following methods are used;

Hydrology

Between the years 2000-2005, over 950 river discharge measurements were done on 52 selected river-gauging stations all over the catchment.

Three methods were used to obtain discharges;

1. The conventional current meter 'mid-section' method was used. In this case, the river section is divided into approximately twenty (20) segments in which velocity, depth and width are measured and then the formula

   $$Q = AV$$

   is applied for the calculation of discharge.

   Where Q = Discharge in m^3s^{-1}
   A = Wetted cross-sectional area in m2
   V = Velocity in ms^{-1}
2. A modern and more convenient and safe method in deep and wide sections of rivers was the use of Rio Grande Acoustic Doppler Current Profiler (ADCP) which outputs discharge results directly.

3. The Float and Flume method, used where the above equipment was not available, is a simple manual method conducted on a reach with perceived uniform cross-section and flow.

Rainfall Runoff Modeling

River discharges were also computed from time series of rainfall and evaporation using the NAM model (Danish Technical University). This is a lumped model run on excel spreadsheets which assumes a single unit with homogenous characteristic of the flow throughout the system. The model was applied to daily values of rainfall and evaporation series (1950-2004). The manner in which the rainfall and evaporation series were generated is explained below.

Rational formula

The following rationale formula was applied to compute runoff in ungauged basins around the lake shore:

$$Q = CA(R - K)$$

Where

Q = flow in m^3/s,
C = constant coefficient,
A = catchment area in km^2,
K = lumped rainfall loss parameter which also acts as a monthly threshold value for the generation of Q and
R = autoregressive weighted monthly rainfall.

This model was particularly useful in obtaining runoff for the clustered river systems such as the North Awach catchment comprising of rivers Nyamasaria, Awach Seme, Kisian and Murguruge and the South Awach catchment comprising of rivers Awach, Tende and Awach Kibwoun.

Rating Curves

Using discharge measurement data collected at the principal stations along the major rivers within the catchment during the period 2000-2004, rating curves have been generated using a simple EXCEL Macro spreadsheet with appropriate formulas (Fig. 2).

Quality control measures include comparison with the conventional "hydata generated" curves at the Ministry of Water and Irrigation Headquarters in Nairobi and comparison with observed discharges (Fig. 3).

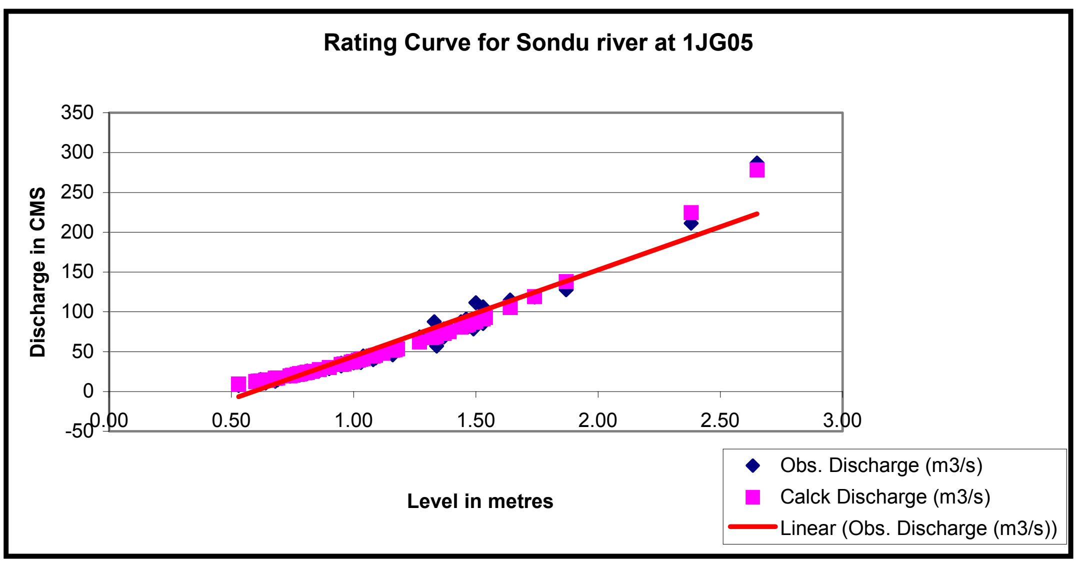


FIG. 2. Rating Curve generated for Sondu River

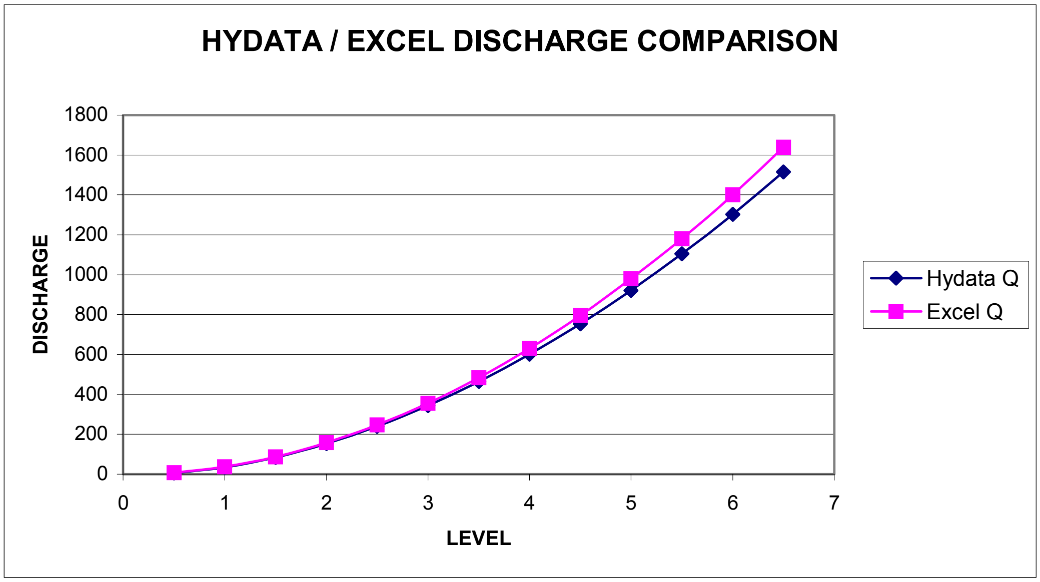


FIG. 3. Comparison of EXCEL and HYDATA generated rating curves.

River and lake water levels were gathered using the manually read staff gauges and the modern digital data loggers located at the principal stations shown in Table 1.

TABLE 1. Shows the principal stations used in this study

River Basin	Basin Area (Km^2)	Gauging Station		Catchment area U/S of station (Km^2)	Type of Station	Remarks
		Reg. No.	Location/name			
SIO	1450	1AH01	MUNDIKA	1450	STAFF	
NZOIA	12,676	1EF01	RWAMBWA	12,676	STAFF & LOGGER	
YALA	3,351	1FG01	YALA TOWN	2,388	STAFF & LOGGER	
NYANDO	3,652	1GD03	OGILLA	2,625	STAFF & LOGGER	
NORTH AWACH	1,985	1HA09	NYAMASARIA		STAFF	
		1HB05	AWACH SEME		STAFF	
SOUTH AWACH	3,156	1HE01	AWACH TENDE	585	STAFF	
		1HD09	AWACH KIBUON	536	STAFF	
SONDU	3,508	1JG05	SONDU MARKET	3,287	STAFF	
GUCHA-MIGORI	6,600	1KB05	WATHONGER	6,600	STAFF & LOGGER	
LAKE VICTORIA		1HB04	KISUMU	-	STAFF & LOGGER	

Rainfall

As a follow up of an earlier study (LVEMP 2002), most of the rainfall stations representing individual river catchments have been retained. In a few cases, where some stations have been decommissioned, nearby stations with the required data have been adopted in this analysis (Table 2).

TABLE 2. Rainfall and Evaporation stations used in the study

River Basin	Station Number	Name	Rain/Evap	Reference Station for correlation
Sio	8934161 N/R 8934161 N/R	Alupe Nzoia Sugar, Bungoma Alupe Nzoia Sugar, Bungoma	R R E E	
Nzoia	N/R 8935133 8834098 8934140 N/R 8935133 8934140	Nzoia Sugar, Bungoma Eldoret Kitale Kadenge Nzoia Sugar, Bungoma Eldoret Kadenge	R R R R E E E	
Yala	8935133 8934140 9034011 8935133 8934140	Eldoret Kadenge Maseno Eldoret Kadenge	R R R E E	
Nyando	N/R 9035244 9035263 9034025 9035263 N/R	Chemelil Sugar Co. TRI Kericho Tinderet Tea Estate Kisumu Met Tinderet Tea Estate Chemelil Sugar Co	R R R E E E	
North Awach	9034025 8934140 9034011 N/R	Kisumu Met Kadenge Maseno Icipe, Rusinga	R R R R	
South Awach	N/R 9034084 9034018 9134009 9034139	Icipe, Rusinga HomaBay Gendia Muhuru Ringa, Oyugis	R R R R E	
Sondu	9035244 9035013 N/R 9035244 N/R	TRI Kericho Sotik Chemelil Sugar Co TRI Kericho Chemelil Sugar Co	R R R E E	
Gucha Migori	9134025 9134009 9034092 9134009 9034092	Migori Muhuru Kisii Muhuru Kisii	R R R E E	

At these stations, daily data is generated as an input into the rainfall-runoff model for generation of discharges. All rainfall measurements have been subjected to quality control checks to identify erroneous data i.e. by visual examination of raw and plotted data, calculation of statistical means, maximum and minimum, comparison with data from adjacent station and calculation of accumulated mass curves. Gap filling has been done by correlation to adjacent stations for the few cases where it is necessary. This is done by taking close stations with longest data where a double mass curve is evaluated for the subject station and the reference station, a trend line fitted to the curve after which the resultant equation is applied to fill gaps in the subject station (Figs. 4-6).

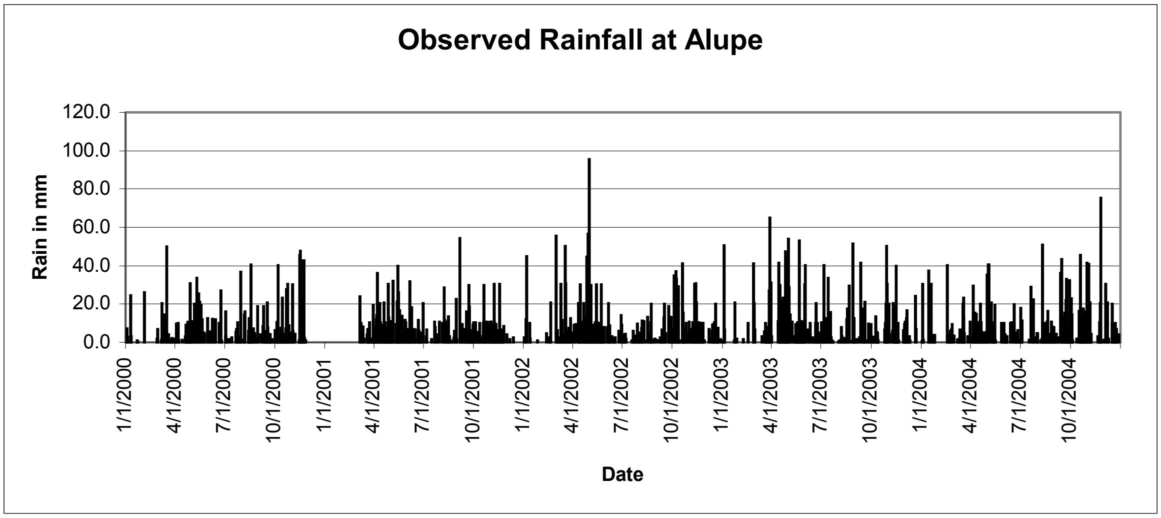


FIG. 4. Observed rainfall at Alupe from January 2000-December 2004 (with one month missing)..

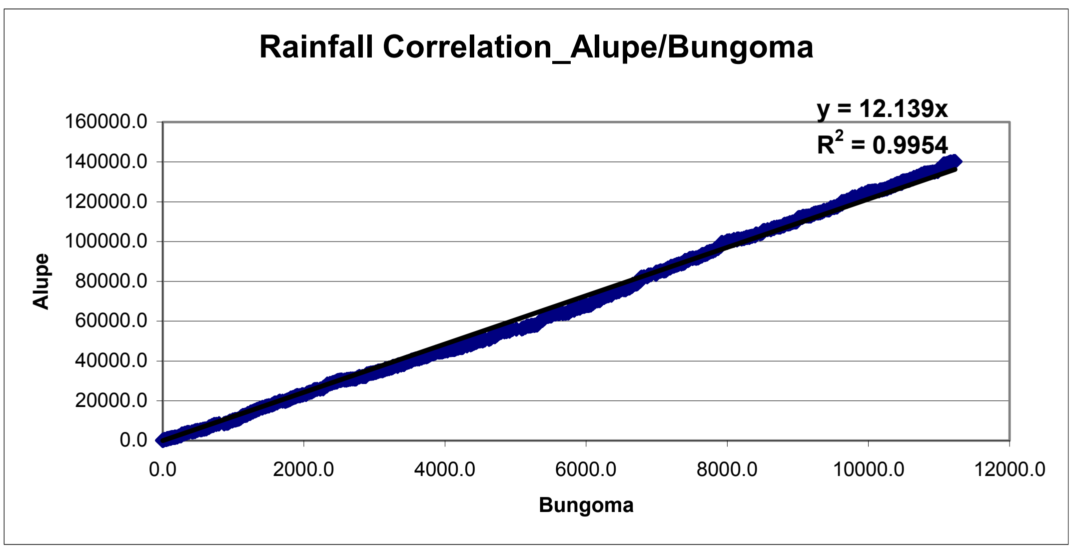


FIG. 5. Linear correlation and regression between Alupe and Bungoma rainfall.

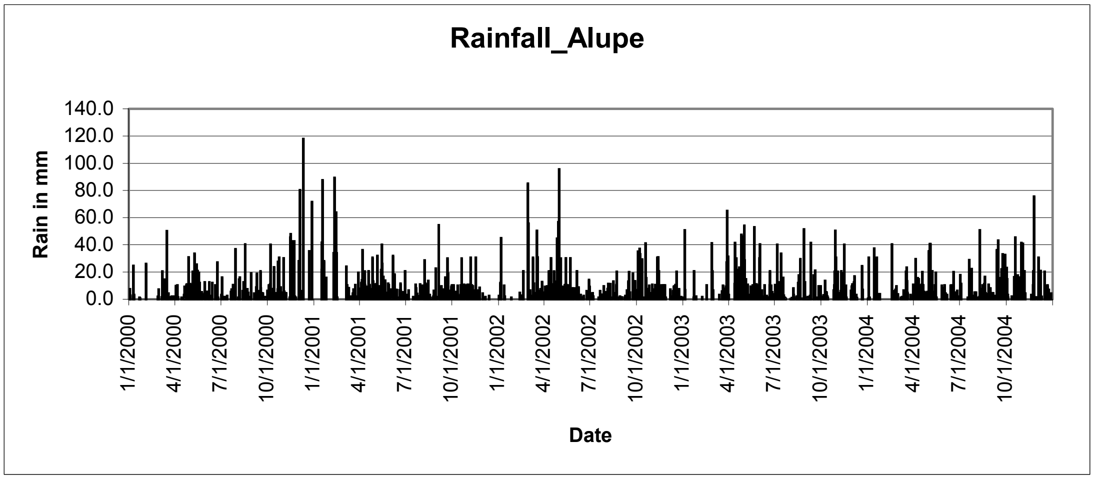


FIG. 6. Final rainfall for Alupe after filling the gap in 2001.

The earlier method of gap filling using typical wet, dry and average years (LVEMP 2000) is not applied here as the gaps are not more than a few months in a year.

From the year, 2000, the study was as much as possible based on observed data, but due to circumstances beyond our control, it was not possible in all cases. We therefore had to depend somehow on stations that are owned and run by other organizations/institutions. In a few cases, some stations that were used in the earlier study were completely abandoned or closed and this forced us to identify nearby existing and reliable stations that could be used for generation of the data. In this study therefore, we have generated daily rainfall data from 2000 to 2004, which is an extension of the earlier study done by LVEMP (2000) covering the period 1950 to 2000. Fig. 6 is an example of a rainfall series for Alupe in which gap filling has been done.

Evaporation

In general, this study has experienced difficulties in obtaining meteorological data because the weather stations that were proposed for installation have not been delivered on time.

Furthermore, observed data generation for 2000-2004 was mainly handicapped by the closure of most evaporation stations within the Lake Victoria catchments due to lack of operational funds by the various institutions that were operating them.

In principle, the method for development of continuous evaporation record is the same as that of rainfall. However, because of the fewer number of evaporation stations, correlation to adjacent stations may be irrelevant since wide distances between may cause some differences.

Some evaporation data is measured at full meteorological stations, most of which are still operational. Daily mean evaporation was therefore used to fill gaps in site records because there is no defined method of choosing evaporation values for typical wet, average and dry years. Fig. 7-8 gives evaporation series for Kitale during 2000-2004 before and after gap filling; this was done by use of average daily evaporation observed over a period of 7 years.

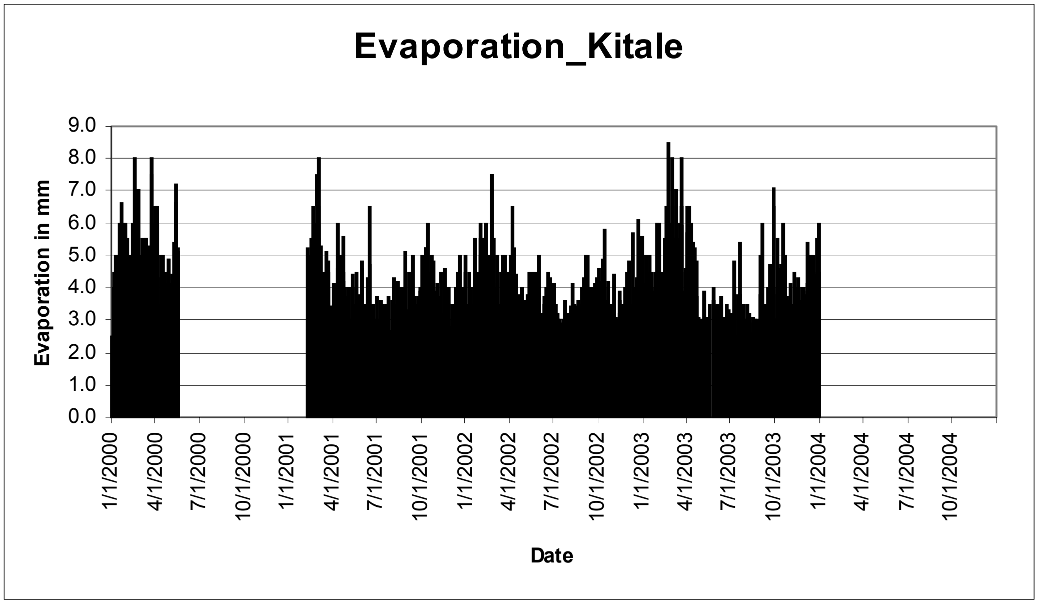


FIG. 7. Observed evaporation at Kitale with gaps.

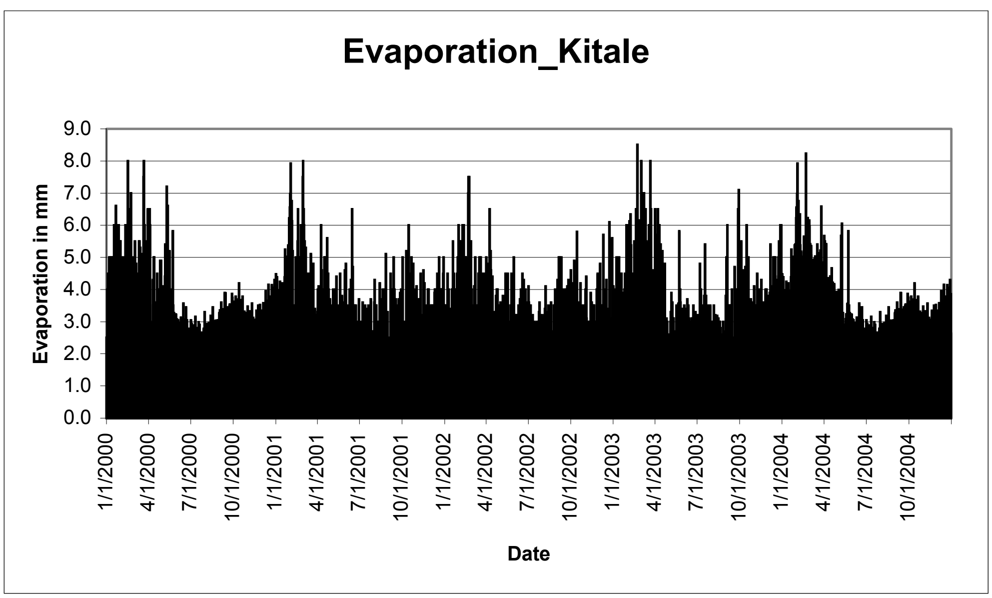


FIG. 8. Final evaporation for Kitale after gap filling by use of average daily evaporation observed over a period of 7 years.

River Discharges

Because the main interest of this study is to assess the discharge of water to the lake and to compute pollution loads, it is important to concentrate on the discharge at or near the river mouth. Rating equations have therefore been developed in a simple EXCEL MACRO using the standard formula:

$$Q = k(h - h_0)_x$$

Where,

Q = river discharge (in m^3s^{-1})
k = coefficient
h = gauge height (m)
h_0 = gauge height at zero flow (m)
x = exponent of rating curve

For quality control, a visual examination of a flow/level plot is considered sufficient to remove erroneous data. The river discharges have been computed by applying the rating equation to the daily gauge heights (see Fig. 9). Gaps in records are subsequently filled by the rainfall-runoff modeling.

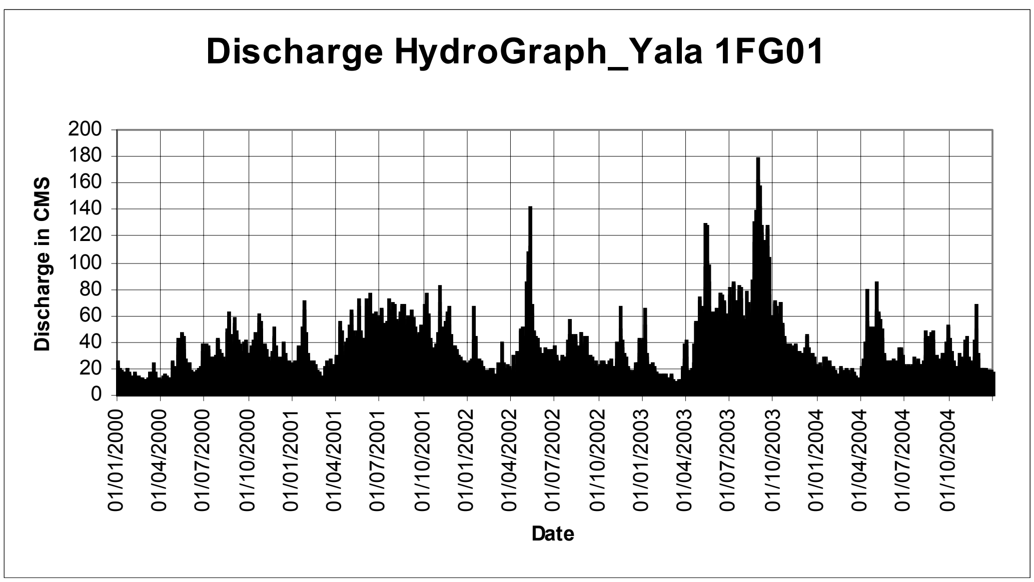


FIG. 9. Discharge hydrograph for River Yala after computation of discharges by applying the rating equation.

Rainfall Runoff Modeling

Modeling is used to fill gaps in discharge record and in this study; it has been applied in a few instances where gauge readings were not available either due to vandalism, damage or loss of gauge, lack of a reader or data logger failure. An example of discharge data gaps is shown in Fig. 10.

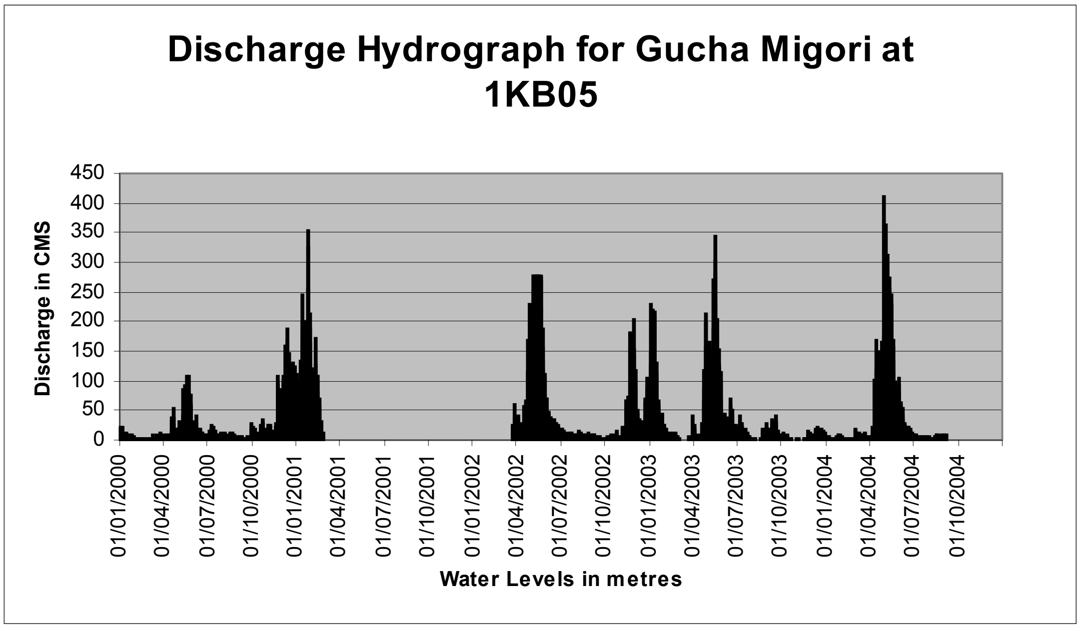


FIG. 10. Discharge hydrograph of Gucha River with gaps.

The LVEMP Water Quality and Ecosystems Component in Kenya has adopted the NAM model, (a conceptual model) which originates from the Danish Technical University. In this model, the entire catchment is lumped and assumed to be a single unit with uniform characteristics, the flow of water through the system conceptualized into a number of reservoirs and the parameters partly reflect the physical properties of the catchment.

Model calibration (see LVEMP 2000) is done by use of at least 4 years of simultaneously measured rainfall, evaporation and discharge data. The model parameters are adjusted by trial and error until the best fit is observed between modeled and observed discharges in terms of accumulated runoff from the catchment, peak flows, recession curves and low flows (Fig. 11).

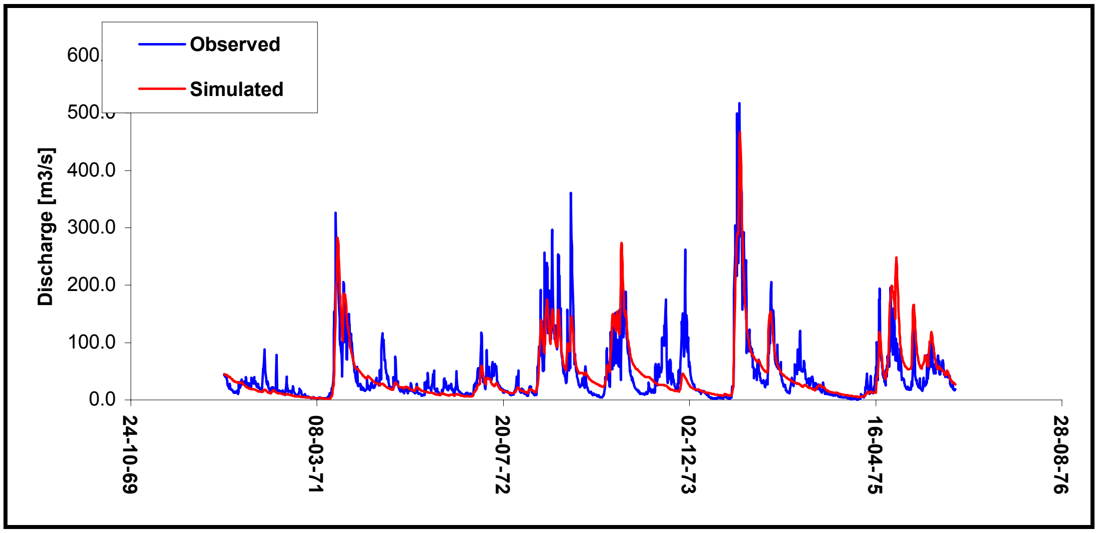


FIG. 11. Model and observed results for Gucha River from 1969-1976.

Model application is accomplished by applying the calibrated model to compute runoff at the station for the full period of 1950-2004 (Fig. 12). In this application, the final rainfall and evaporation generated for the full period is used for calculation of the water balance (Chapter 3 of Regional Report).

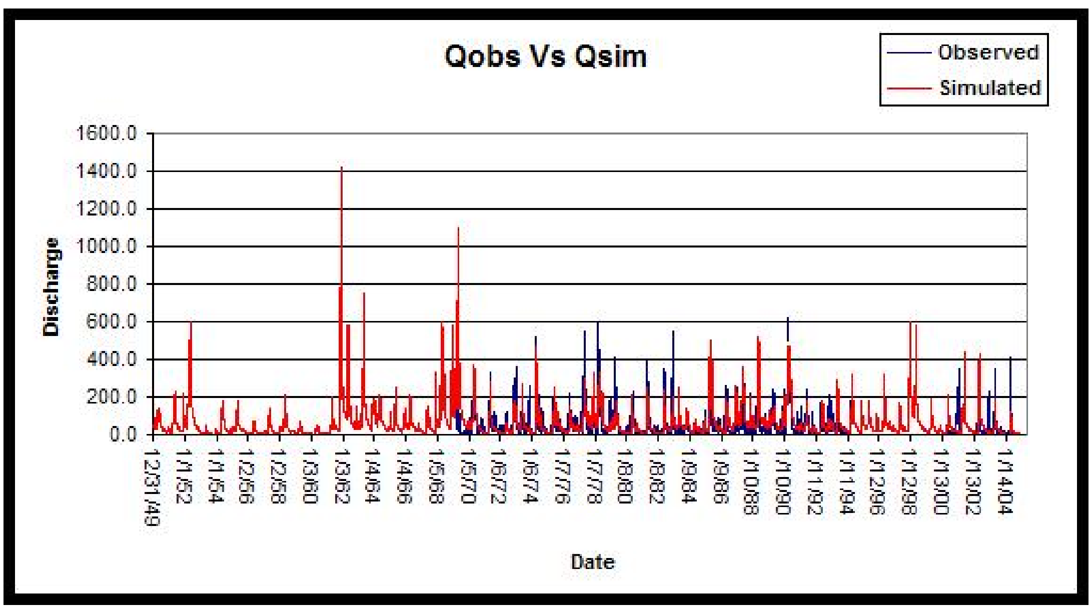


FIG. 13. Model application as accomplished by applying the calibrated model to compute runoff at a station for the full period of 1950-2004.

Some catchments and basins around the lake largely remained ungauged and have been lumped into composite basins consisting of small rivers and wetlands along the lakeshore for the purpose of estimating water inflows.

On the other hand, some of the rivers in these areas have been gauged but the data available neither sufficient nor representative of the whole basin area. In Kenya, there are two such areas namely the North Awach, which comprises of rivers Nyamasaria, Awach Seme, Kisian, Murgut, and other smaller ones and the South Awach comprising of River Awach Tende, Awach Kibwoun and other smaller ones.

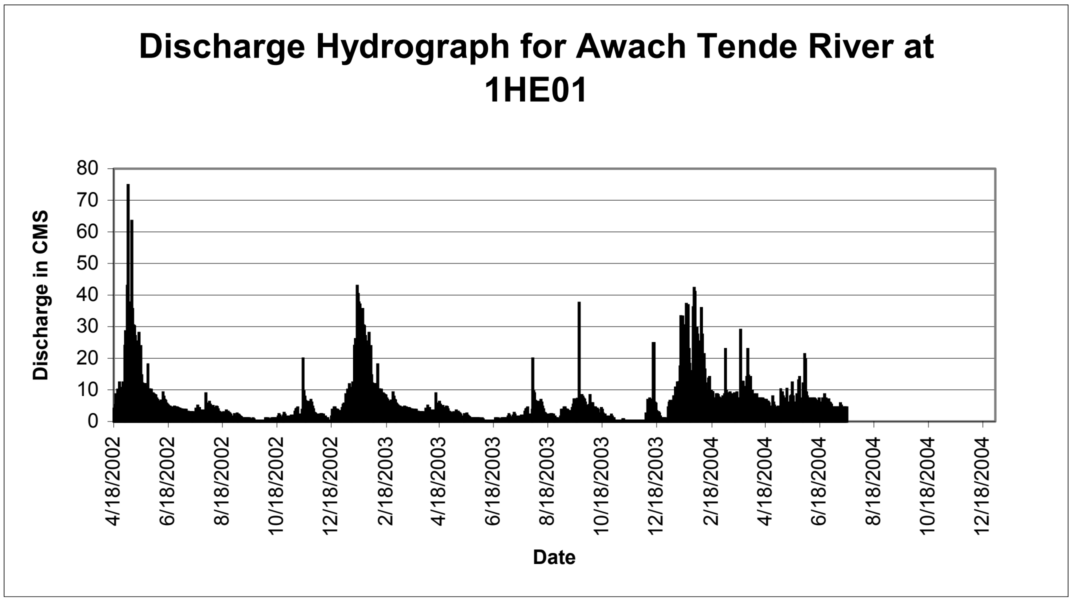


FIG. 14. Insufficiency of the data collected on one of the small rivers-Awach Tende.

In this case therefore an empirical model was applied to simulate monthly flows using parameter values from an adjacent similar catchment. The model is an application of the rational formula mentioned above.This has been tested with monthly rainfall and discharge data in Nzoia, Sondu, Kibuon and Sio River basins and a good fit was obtained.

RESULTS

Rainfall

In this case, a rainfall record for 1950-2004 at each station was generated. Fig. 15 gives an example of such a rainfall record for the Kericho station. Since a time series of rainfall data representative for a river basin is required for use in the rainfall-runoff models, it is generated as a weighted mean of the selected station in the basin. Weighting of each station is dependent on the proportional area assigned to the station and on the rainfall characteristics.

In Kenya, two prevalent zones are considered i.e. the low flat area near the lake and the high altitude area with irregular topography in upper reaches of catchments. The weighting therefore takes into account the different physiographic characteristics of these areas.

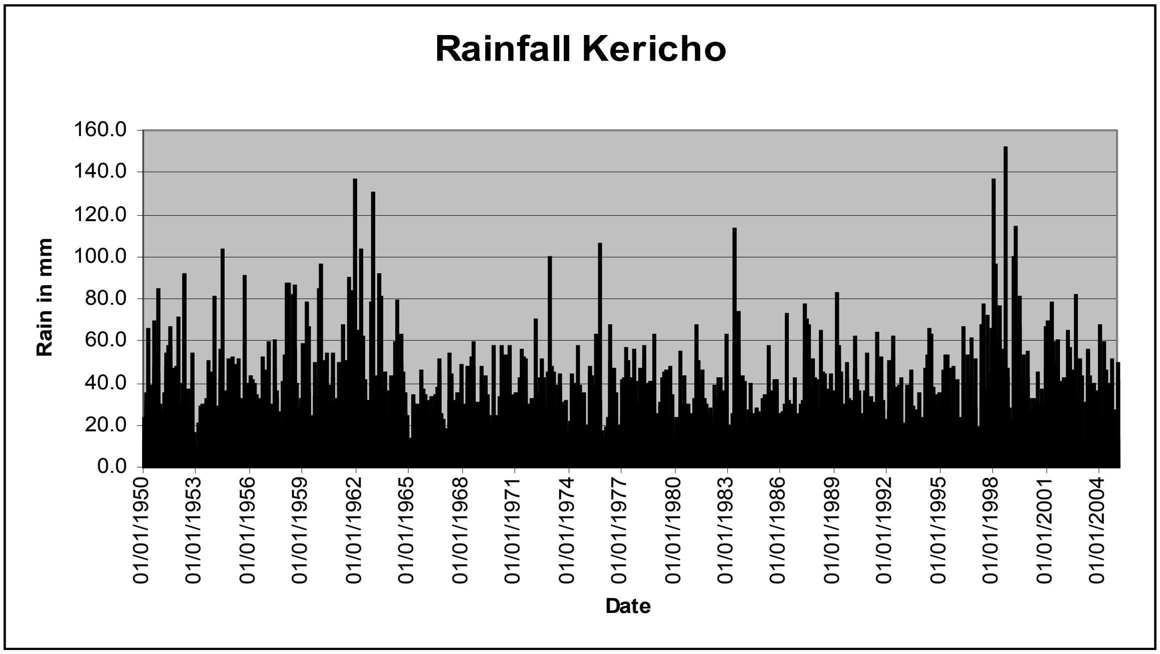


FIG. 15. Time series of rainfall data for Kericho for the period 1950-2004.

Meteorology trends in Lake Victoria basin

This study established wet and dry seasons to occur in March to May and October to November respectively (Fig. 16). Mean monthly rainfall maxima are recorded in April (213 mm) and November (345 mm). The driest months are observable during January and December. Fig. 17 shows rainfall totals over the years 1950-2004; it indicates that the driest years were 1953 (1180 mm), 1959 (1183 mm) and 1984 (1230 mm). Conversely, the wettest years were recoded in 1961 (1749 mm), 1968 (1761 mm) and 1977 (1775 mm). An autocorrelation function was produced to detect the repeat cycles of dry or wet years; however, this did not show any significant correlation at 95% confidence intervals.

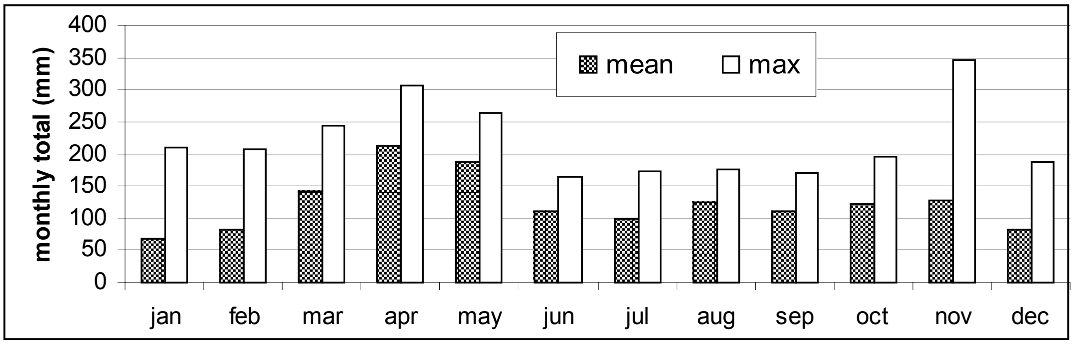


FIG. 16. Mean and maximum monthly totals of rain in Lake Victoria.

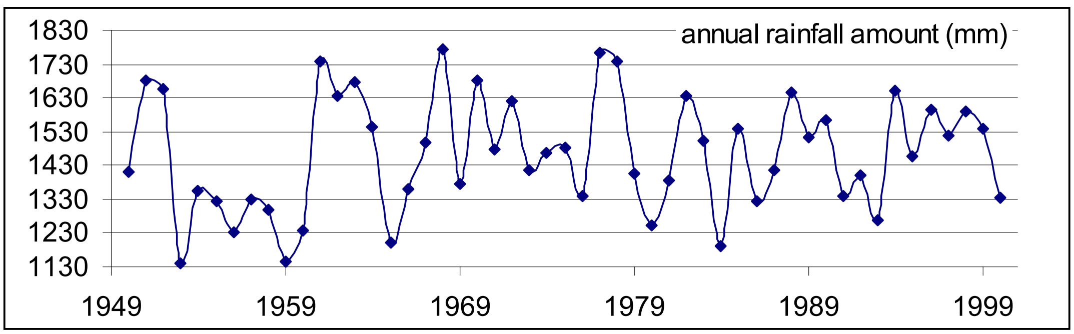


FIG. 17. Yearly total of rain in Kenya catchments of Lake Victoria.

Spatially, less rain falls near the lakeshore than upstream of the catchment (Fig. 18.). Over the years of record, it can be seen that the highest amounts have been recorded consistently in Alupe, Kisii and Kericho area. Alupe lies on the southern foothills of Mt. Elgon, while Kisii and Kericho lie on the peak of Manga hills and Mau ranges (at altitudes greater than 2000 m a.s.l) respectively.

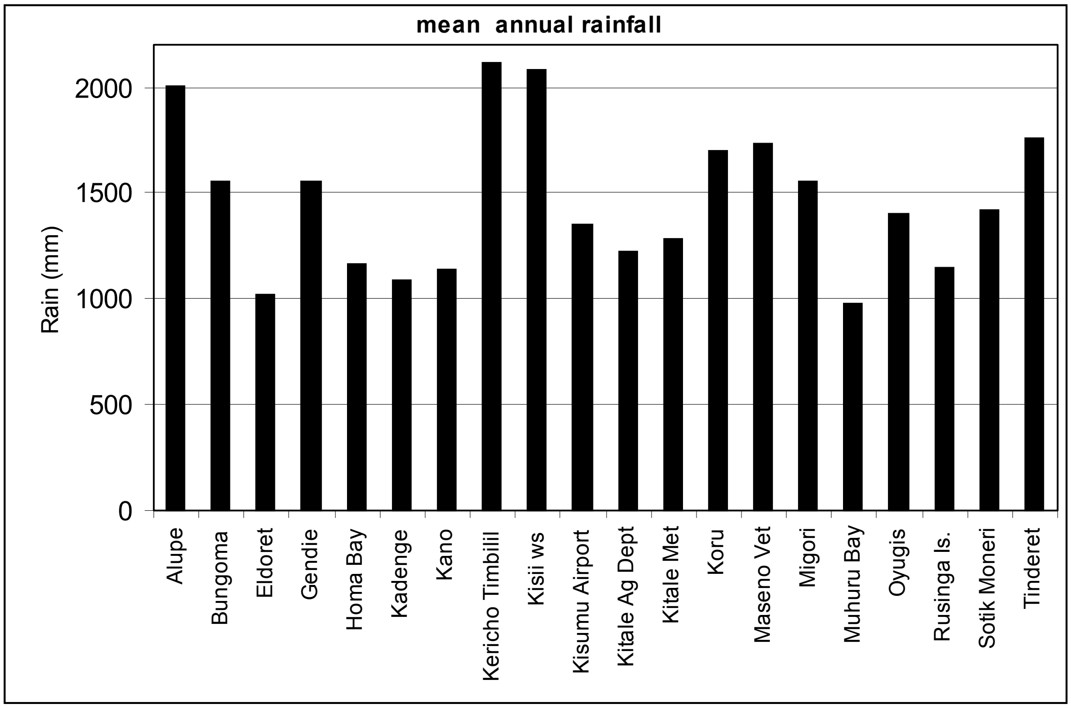


FIG. 18. Mean annual rainfall for stations in Kenyan Lake Victoria basin.

LVEMP period compared to 50-year record

By plotting on the same axis the first 60 monthly totals of each decade, the LVEMP period of record was compared to 50-year record to determine how representative it was of the longer period. Criteria for choosing the first sixty months were based on the fact that, this is the length of the period LVEMP has been collecting data. Fig. 19 and Fig. 20 shows there is no significant difference between decades in both upcountry (Kisii) and lakeshore (Kisumu) rainfall. Wet and dry months seem to occur at the same time as in every other decade. Rainfall totals for the months in the different decades do not seem different either. It was further shown that autocorrelation coefficient function for different decades have not changed significantly (Table 1 for Kisii station) which shows within decade autocorrelation coefficient as being strongest in the decade of the nineties and that of 60s which respectively gave a recurrence of 2 and 6 months period. H.M. Njuguna (pers. commun.) has found that rainfall of the 1960s and late 1970s was highest over the last half century. This is well reflected in the long term records of lake levels discussed later in this chapter.

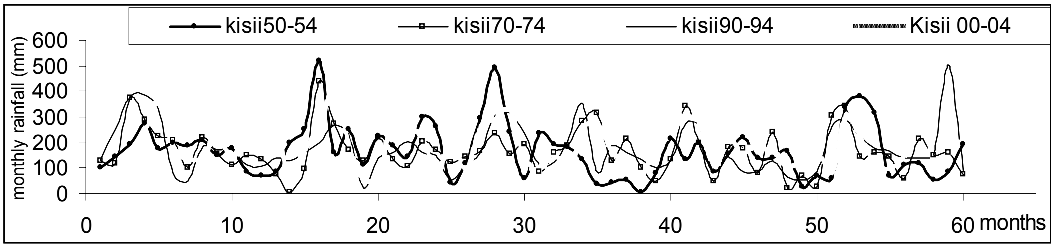


FIG. 19. Kisii station first sixty months of each decade monthly rainfall.

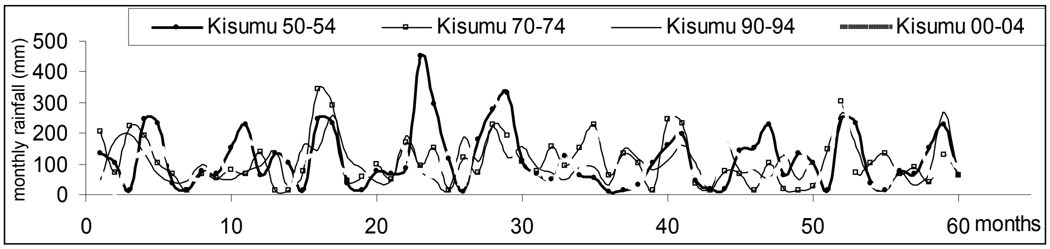


FIG. 20. Kisumu station first sixty months of each decade monthly rainfall.

Flow occurrence between decades

Total monthly flow for each decade was plotted for two rivers; Nzoia and Nyando (Figs. 21 and 22). This was done to assess whether wet and dry events occur at the same months and whether there is any significant difference in their magnitude. Nzoia depicts a regular recurrence of wet and dry seasons among the three decades though the nineties' wet season seems to have a longer duration than those of previous decades (Fig. 21). Nyando River also seems not to have had any significant difference in the frequency of wet and dry months occurrence, though the magnitude of the fifties appear smaller than the rest (Fig. 22). To assess which months among decades had close association, a cross partial correlation coefficient was computed. It can be deduced that for Nzoia River, the sixties and nineties were found to be significant after every 8, 10 and 14 months (95% confidence interval). Inter-decades analysis showed that a weak but nevertheless significant autocorrelation was present in the seventies after every 8 months, while the other two did not show any.

Nyando within decade autocorrelation was found significant after every 3 months for fifties, 4 months for sixties, none for seventies, 3 months for eighties and 8 months for nineties. Cross correlations between decades were found significant for month of fifties and sixties after every 5, 7 9 and 12 months and between eighties and fifties were strongest after every 6 months. Nineties and seventies and nineties and fifties were significant at 11 and 7 months respectively.

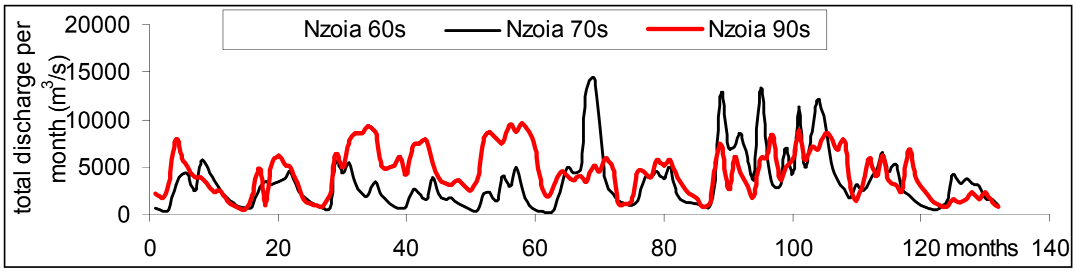


FIG. 21. Monthly Nzoia discharge compared for different decades.

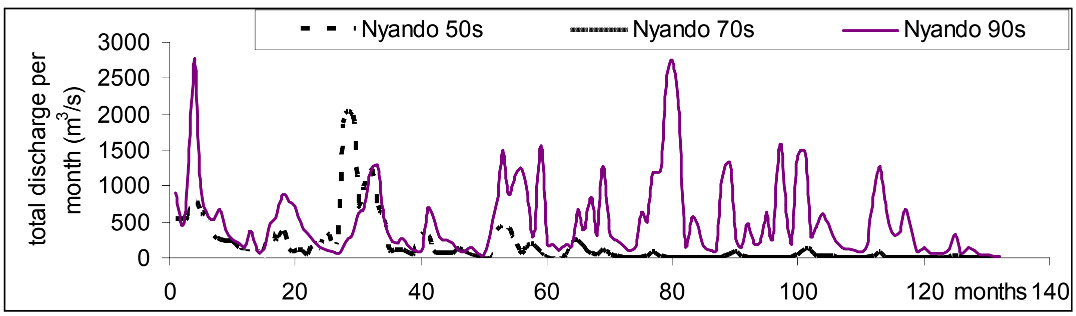


FIG. 22. Monthly Nyando discharge compared for different decades.

Lake level fluctuation

The mean lake level variability is dominated by a decreasing trend as reflected by Fig. 23, in which a high stand of 2.9 m has fallen to a low of 1.8 m (above datum); reflecting a fall of 1.1 m. Consistenct with rainfall records, water level peak is observed every May after that of peak rainfall in April, and a slight increase recurs in December. The lowest levels are measured in October and are usually about 18 cm above mean annual lake level. The months of May, June, July, January and December were found to be above mean annual lake level that has been computed as 2.45 m over the period of record. On a daily basis, highest water levels are observed at 1800 hours (6:00 p.m.) while the lowest are at 0200 and 0400 hours in the morning. Despite the seasonal rains experienced in the region, it has not been possible to restore the lake to year 1999 levels experienced after the El Nino events of 1997-1998. This means that 1997-1998 were exceptional years.

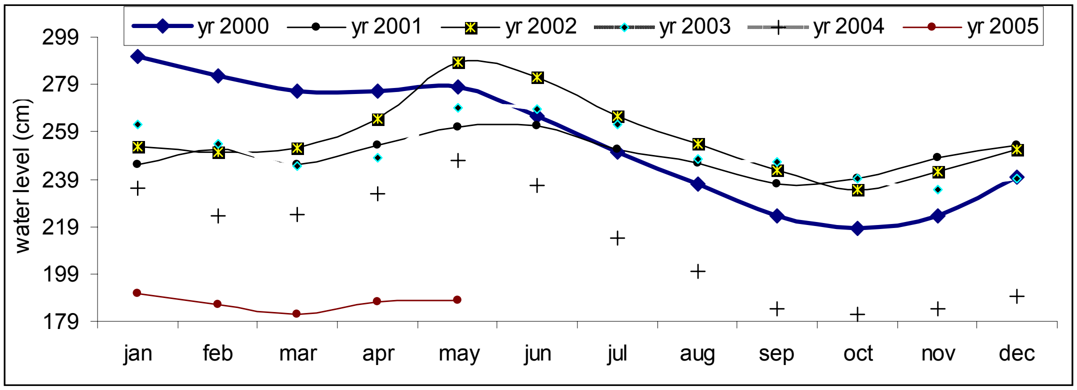


FIG. 23. Mean monthly lake level during LVEMP period.

At the level gauging site, water temperature has been on a rising trend since the year 2000 (Fig. 24). The highest rate of temperature increase occurs in the months of September and October while the rest of the months show a steady increase of 0.1 ^{o}C. The lake temperatures measured are apparently too high, probably because the level recording site is in protected and shallow water.

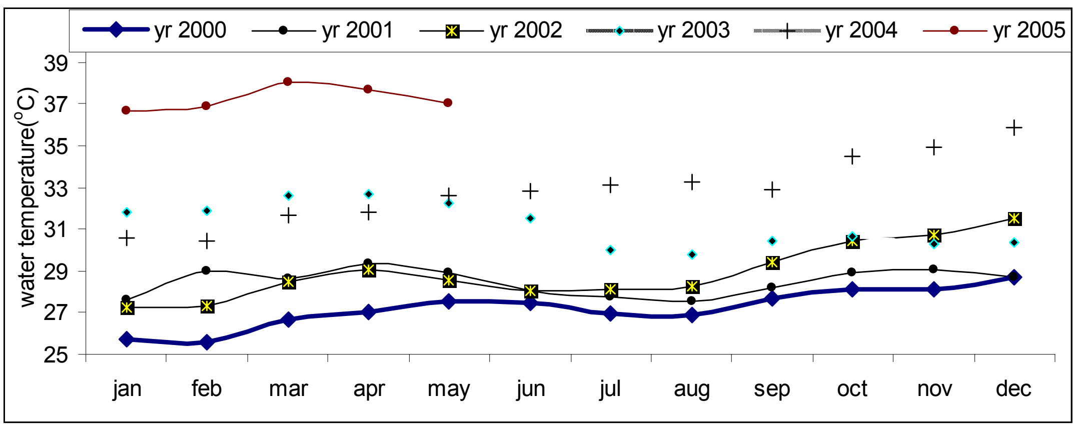
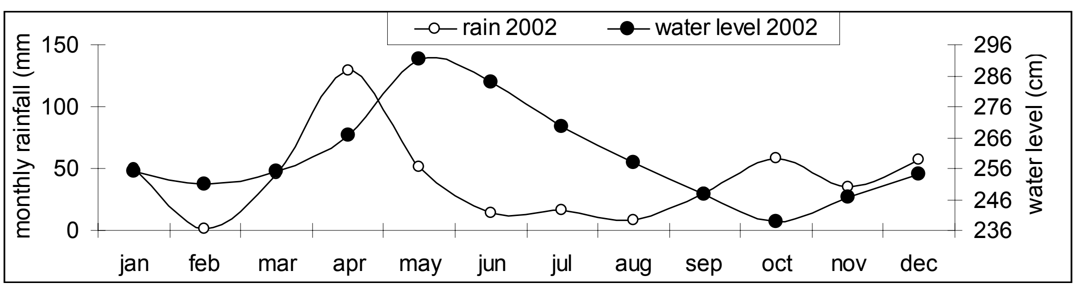


FIG. 24. Mean monthly water temperature at level gauging station.

Lake level and rainfall relationship

Reformat below

It has been acknowledged that rainfall over the lake as well as in its watershed are the fundamental causes for the accumulation of water in the lake (EAMD, 1974) and it is therefore expected that variations in the component rainfalls should be reflected in the lake level fluctuations. Peak rainfall and lake level are observed in April and May respectively. This was examined by cross-spectral analysis between the lake level and the rainfall series. Lake level lags the rain signal by a mean of 42 days emphasizing the peak occurrence of rain in April and that of the lake in May. An unusual phenomenon may have occurred b in May 2004 in which a sudden profound fall in lake level is observable in Fig?. Data of Yala swamp (where is this figure/data)show the rain signal to be dominated by a non-seasonal decaying exponential trend in which rain decreased from 1.47 to 0.695 mm per day (length of record October 2001 to December 2004). Fig ? shows the falling trend of the rain to be accompanied with reduced variability of the rain in subsequent years compared to initial years when the automatic Meteorological Station was installed. On a decadal scale, Fig current 11??? suggests a ten-year cyclic fluctuation. Others are 5.25 and 13.7 in decreased order of variance contribution. The results further show the lake level to have decreased from 2.97 in 1964 to 2.47 in 2004 a decrease of 0.5 m. EAMD (1974) observe that the highest peak was recorded in May 1964 and that level has not been recorded since the beginning of the century and monitoring records. The Lake level was lowest during May 1922 to April 1923 Compared to the 41 year record of 1923 to 1964 in which the lake experienced a rise of 2.57 m, and 2 m during 1961 to 1964 alone, the fall of 0.5 m over 40 years (1964 to 2004) is insignificant and therefore the lake is yet to resort back to previous low levels recorded prior to 1923. Kisumu's rainfall record at its airport from 1950 to year 2000shows the main component is low frequency additive season with no trend that has cyclic rain events lasting 17 years. The floods of 1997-1998 (1375 mm) were severer than those of 1961-1964 (1364 mm what are these data ? elevation change' rainfall? This section is hard to follow but important; please review for clarity) and those of 1978 -1979 (1347 mm). High frequency cyclic rain events were observed every 3.4, 8.5 and 5.1 years in that order of strength.



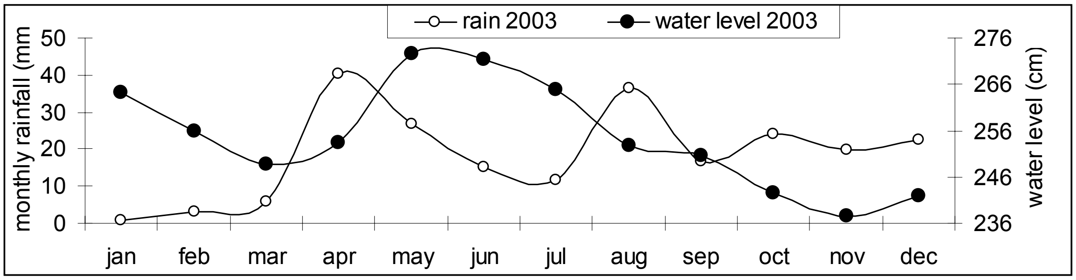


Figure ?? water level and rain signal co variation reflecting the one month lag between them

Rainfall / Run off relation

Rainfall is expected to generate run off that is reflected in the river discharge. Fig ?? shows a plot of the partial autocorrelation function of the series Kisumu rain and Nyando discharge for year 1990-1994 taken to represent this scenario. This section is very important yet it seems incomplete in presentation and is not mentioned in the Discussion below!! Is it possible to compare moden annual catchment rainfall and annual discharge (with appropriate lags if necessary) for Kenya catchments with historic data. It is often observed that land clearance for agriculture changes the rainfall-runoff relation and this in itself can cause increased sediment and pollution record. We need to examine this closely. It also can explain tendency to more severe flooding. Please comment on the stability of the rainfall-runoff relation over time or say that the data are inadequate to do such an analysis which would be unfortunate.

Rain over Lake Victoria

This represents the largest inflow of water to the lake. Just like in the earlier COWI/LVEMP study there still exists an insufficient number of rainfall stations over the lake area. With knowledge on the wind patterns, it follows that rainfall is highest along the West Coast followed by the North and lowest on the South. This has enabled estimates based on the few rainfall observation along the shore and on the islands. COWI REPORT make sure this is referenced (Pg. 69) Figure shows the rainfall stations in the lake basin used to estimate over-lake rainfall with their mean annual rainfall based on measurements above, their corresponding isohyets and divisions of the lake into a number of boxes that form the basins of estimating total rainfall over the lake. Each rainfall "box" has a reference rainfall station. Where mean rainfall is estimated on the basins of isohyetal curves respectively.

The daily rainfall in each box is calculated sing $R\ box = R\ ref * MAR_{box}/MAR\ ref$

Where R_{box} = Daily rainfall in the box

R_{ref} = Daily rainfall in the box

MAR_{box} = Mean annual rainfall in box

MAR_{ref} = Mean Annual rainfall at Ref. Station.

The average daily rainfall for the lake is therefore calculated as the sum of the area weighted means of the daily box rainfall (R_{box})

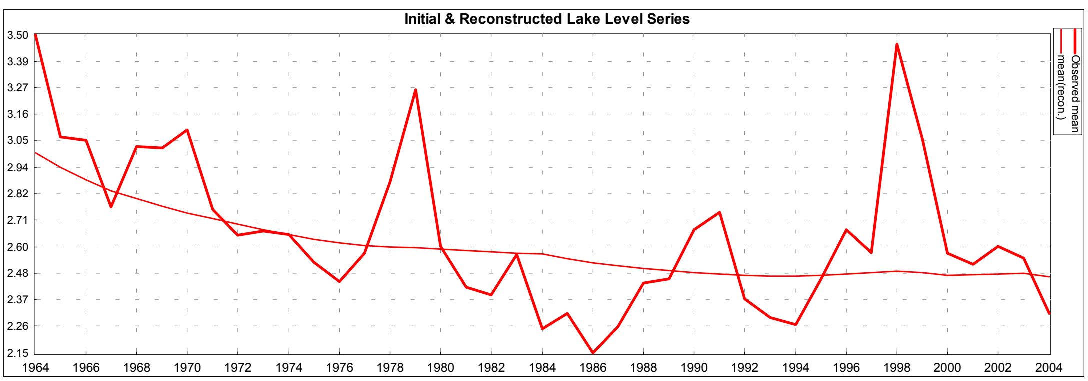
See table ??
Lake Rain = Σ (R_{box} weight)

Table:?? Shows rainfall figures for 2000-2004 in relation to the low term figures for 1950-2000

Rainfall over Lake Victoria (Kenya Side)

Box No.	Name	Wt	MAR_{box} mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean Annual Lake rain for each box
1	Muhuru	0.074				
15	ICIPE Rusinga	0.076				
16	Homa Bay	0.006				
17	Kisumu	0.01				

Table ?? shows rainfall figures for 2000-2004 in relation to the long-term figures for 1950-2000 for catchment rainfall.



Figure?. Long term lake level observed at Kisumu pier This is an important figure make sure the scales are legible

Evaporation

Evaporation data is essentially prepared and analyzed in the same way as rainfall. The only difference is that there are fewer evaporation stations with large distances between them hence it is inappropriate make correlations to extend records. Pan evaporation can vary significantly or a vary only a little on any given day. There is hardly any relationship between evaporation and the occurrence of wet and dry rainfall years. Therefore it was decided to use daily average evaporation to fill gaps in record eg the average of all records on January 1 is used to fill all gaps on January 1 evaporation figures for 2000-2004 in relation to the long term figures (1950-2000) and the boxes used for calculating average evaporation over the lake. In this table, the Muhuru Meteorological Station no longer exists. Because there is no met. station nearby, the average daily evaporation is used to fill the record.

Figure Final Evaporation For Bungoma

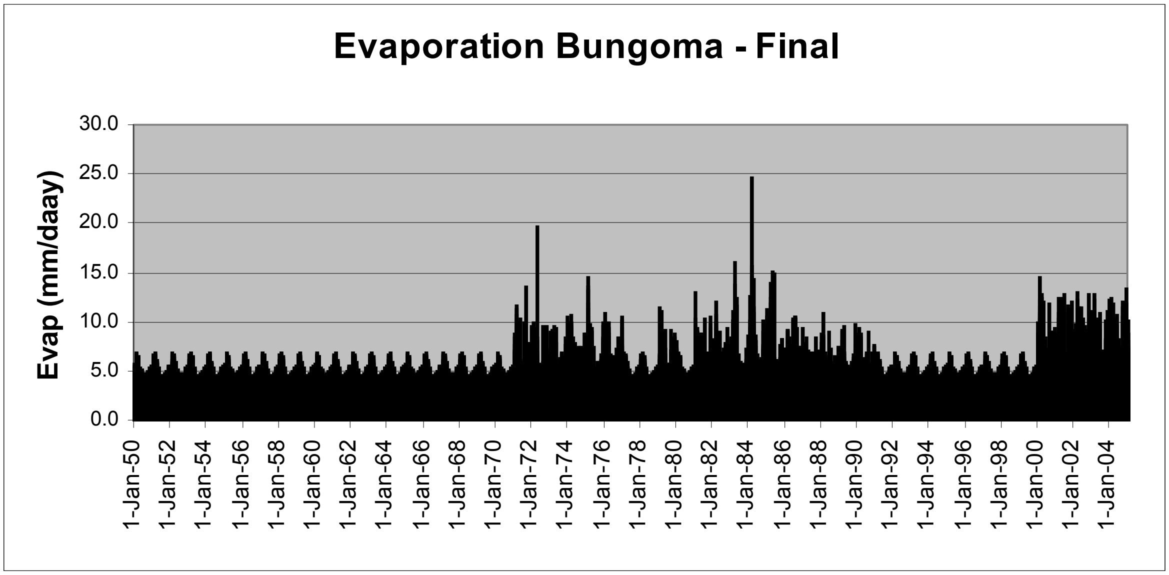


Table: Shows the evaporation boxes over Lake Victoria (Kenyan Side)

Box No.	Name	Wt	MAR_{box} mean annual raw for box (mm)	MAR ref. Mean R/F for stations (mm)	R ref. MAR 1950-2004	Mean + Lke rain for each box
1	Muhuru	0.041				
10	Rusinga (ICIPE)	0.124				
11	Kisumu	0.012				

Wind speed and direction

Wind was found to have a mean speed of 1.34 m/s and is greatest in February and March and again in September. July and November months have comparable speeds and represents lowest speeds for the series. Wind directions are represented by wind roses plotted (Fig 18) for the months of February, May and November by virtue of the other processes that occur during this time. Overall, the directions are dominated by flows from the south especially during the first six months.

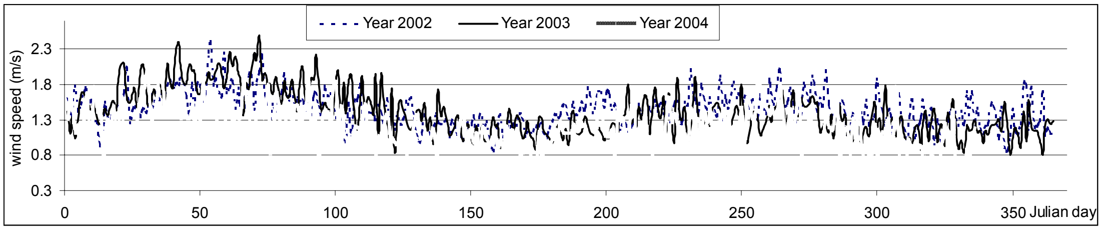
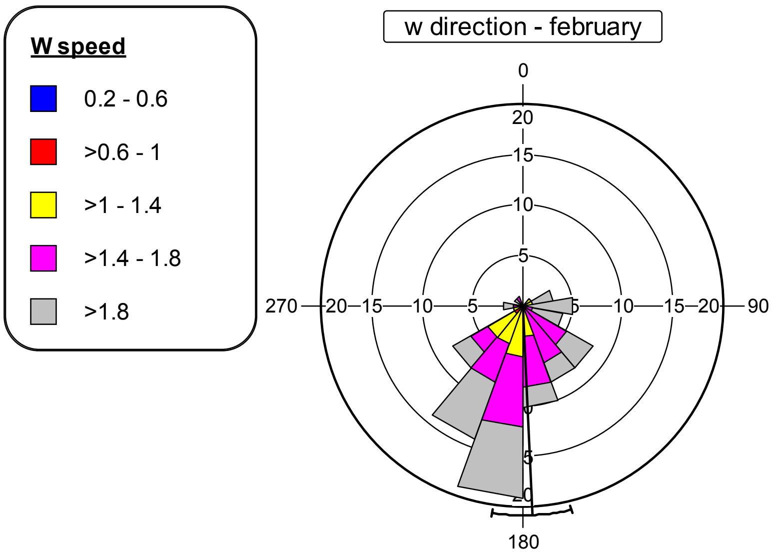
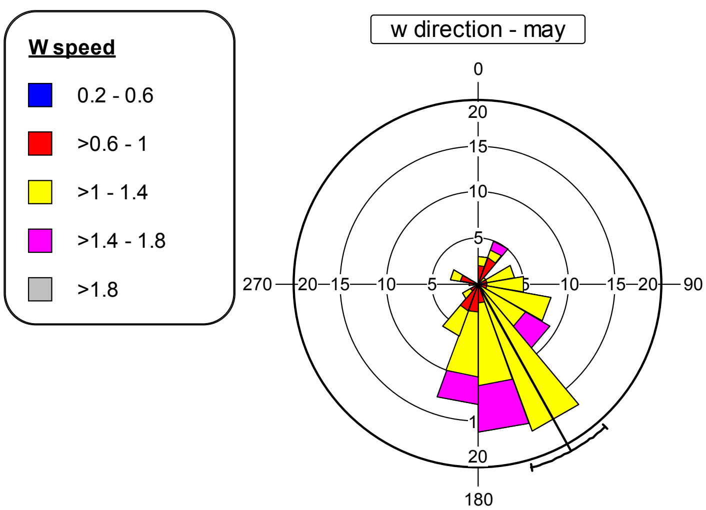
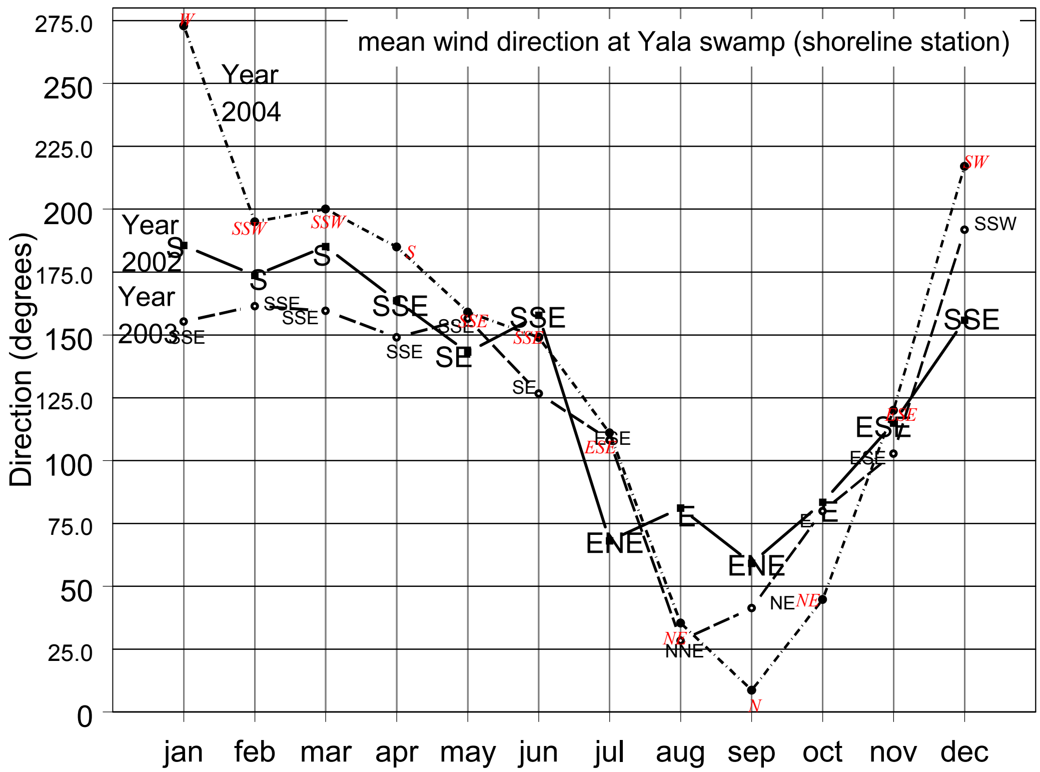


Figure ?? Mean monthly wind speed at Yala swamp





Figure??. Wind rose for the months of February and May. Constructed from 3 year wind series



Figure??. Mean wind direction measured at Yala swamp, shoreline station

Discussion

This study has presented and examined time series of river flows and lake levels, rainfall and wind as measured from the Kenyan catchment of Lake Victoria. This was done with an aim of elucidating trends and periods of meteorology and hydrology from which some plausible explanation on the variability in time of the eutrophication of Lake Victoria can be offered based on meteorology and hydrology processes.

Please comment on trends in rainfall, discharge, rainfall-runoff relationships for different basins (are they all similar or different?) You have done a lot of analysis but this discussion section is where you help the reader understand why you did all these analyses. What were you looking for; what did you find, do any trends or changes have significance to the lake. You do not want leave the reader wondering why all this was done. Discuss the data you have presented above to provide meaning to the reader.

Wind direction has been found to be south to southeasterly dominated during all the months except the period between July and November when the winds from the east. Low-level southeasterlies play an important role in the process of convection/rainfall formation by joining the over-lake convergence and by displacing the convergent center to the northwest of the lake (Nicholson and Yin, 2000).

An important finding concerning evaporation and solar radiation is the strong linear correlation coefficient during the months of April, June and July. This does not compare with the finding of Nicholson and Yin, (2000) who found evaporation to be high in the December-March season and around August, during which time the cloud cover is very low. During the three years the series used in this study was generated, evaporation was found to be high commencing November to March during which time ??? incomplete sentence

River Discharges

Gauging stations close to the mouth are chosen for this study. Table shows the list and location of gauging stations.

This whole section was presented above i.e. your methods Since the gauging stations are not placed exactly at the river mouth, the discharge is not representative of the entire basin area hence the need to calculate the discharge from the entire basin. For example is the un-gauged area represents 2% of the total basin area, then discharges are increased by a factor 1.02.

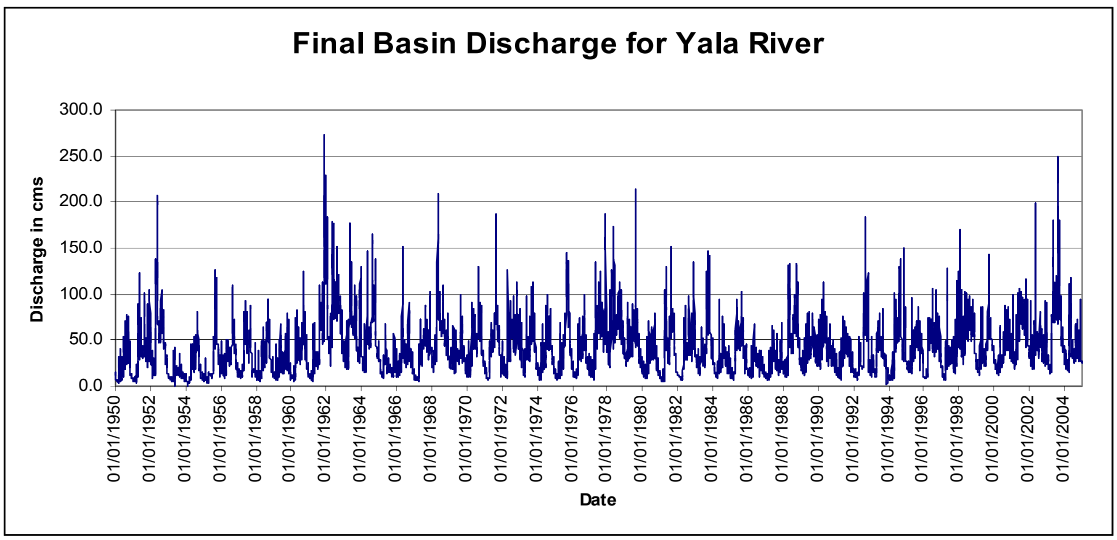


Figure ??…. Yala Basin Final Discharge increased by 1.40
Table …??…… shows the long-term average daily discharge from rivers **(M^3/s)**.

RIVER BASIN	**MEAN DAILY DISCHARGE 2000 – 2004 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2000 (M^3/s)**	**MEAN DAILY DISCHARGE 1950 – 2004 (M^3/s)**
SIO	9.1	11.4	11.5
NZOIA	112.5	115.3	118.7
YALA	47.8	37.6	39.3

N. AWACH	4.0	3.7	3.8
NYANDO	41.8	18.0	20.8
SONDU	41.8	42.2	43.3
S.AWACH	5.7	5.9	6.0
GUCHA MIGORI	38.8	58.0	57.9

Table ……

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sio	4.3	3.1	4.2	16.1	28.2	18.6	10.5	9.3	9.8	11.7	13.7	8.1
Nzoia	62.0	45.8	47.4	100.3	171.5	139.5	148.4	186.4	165.8	134.8	125.5	92.1
Yala	22.4	18.2	19.1	36.0	53.2	43.0	44.4	60.3	59.2	45.3	39.1	30.1
N. Awach	2.0	1.9	3.2	7.8	9.5	6.2	3.0	1.7	1.8	2.0	3.4	3.2
S. Awach	4.6	3.9	4.3	9.3	11.7	11.4	8.0	4.1	2.5	2.7	4.6	4.9
Nyando	15.1	9.3	9.9	32.8	46.8	22.8	21.3	25.9	21.1	12.7	17.4	13.3
Sondu	21.6	15.2	19.8	56.1	88.1	58.7	47.1	51.5	54.2	35.4	38.1	32.6
Gucha Migori	41.5	31.9	46.6	109.7	152.0	77.7	40.4	27.8	26.7	25.2	50.4	63.3

Figure ….shows mean monthly discharges for the Kenyan Basin ???

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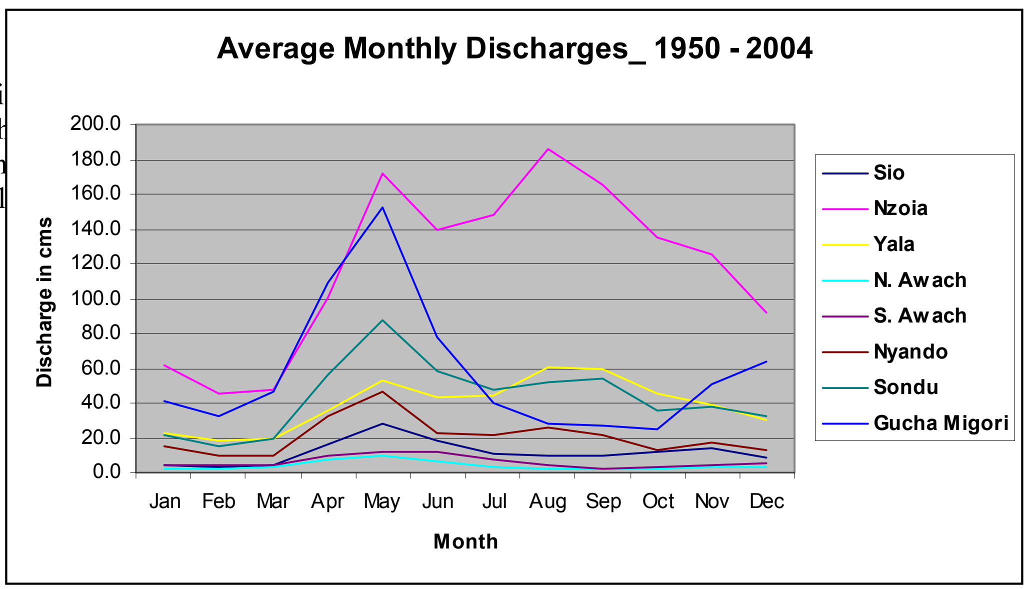
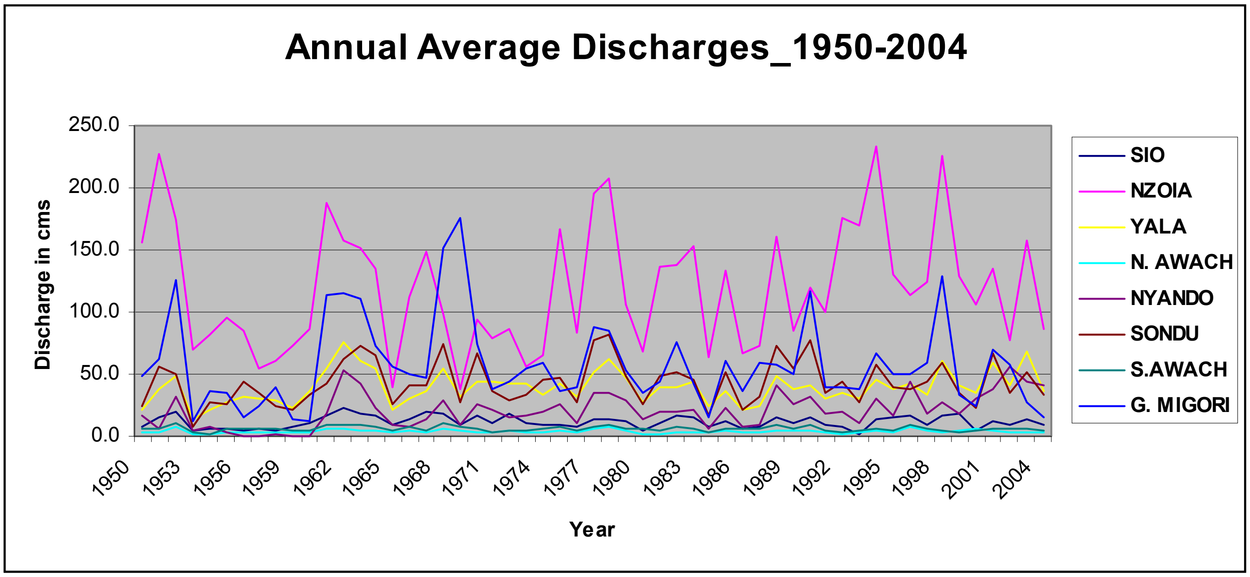


Figure …… Mean Annual Discharges ???

Also present data on runoff coefficient for each catchment i.e. discharge per unit area and discuss why they may be different in terms of the catchment characteristics. Also please comment on possibility that these runoff coefficients might have changed over time refer to Hecky et al in the special issue of the Journal of Great Lakes Research for possible discussion issues.



Conclusions and recommendations:

Conclusions (see comments above on topics to be covered in conclusion esp. concerning evidence of lack of evidence for trends in meteorology and hydrology).

- The method developed for generating discharge data is successful and quite ideal for use in such a study.
- Data gap filling techniques used have proved to be quite successful too.

  - Extension of rainfall and evaporation records by correlation to adjacent station
  - Insertion of typical evaporation data to fill gaps
  - Rainfall runoff modeling to extend discharge records.
- The time series of discharges rainfall and evaporation generated provides an important basis for water quality studies especially in assessment of pollution loads.

- The database so far generated in EXCEL spreadsheets is simple to understand and use in analytical work

- It is noteworthy and commendable that most of the currently operational meteorological stations are owned and run by agricultural based industries that have so far made a major contribution as a source of data to this study.

Recommendations:

- The institutional capacity of regional offices should be strengthened so as to continue filling data gaps with observed data and extending the studies.

- Capacity should also be increased so that more real/observed data is generated for the un-gauged catchment.

- There is need for further cooperation with private and quasi Government sector in data collection and dissemination.

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