Climatic Change
DOI 10.1007/s10584-008-9409-x

Falling Lake Victoria water levels: Is climate a contributing factor?

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Received: 19 May 2006 / Accepted: 6 November 2007

Abstract Recently, and perhaps most threatening, Lake Victoria water level has been receding at an alarming rate. A recent study suggested the possibility of the expanded hydroelectric power station in Uganda. However, since the lake receives 80% of its refill through direct rainfall and only 20% from the basin discharge, climatic contributions cannot be ignored, since the 80% water is directly dependant on it. It is therefore necessary to investigate climatic contribution to the declining Lake Victoria water level observed over a long period, i.e., 30 years. This contribution uses 30 years period anomalies for *rainfall*, *river discharge* and *lake level changes* of stations within Lake Victoria basin to analyse linear and cyclic trends of climate indicators in relation to Lake levels. Linear trend analysis using the Student's t test indicate a decreasing pattern in rainfall anomalies, with the slope being statistically similar to those of water levels at both Kisumu, Maziba and Jinja stations

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for the same period of time (1976–1999), thus showing a strong correlation. On the other hand, cyclic trend analysis using Discrete Fourier Transform (DFT) shows cyclic period of water level to coincide with those of droughts and rainfall. The strong relationship between climatic indicators of drought and rainfall on one-hand and lake levels on the other hand signifies the need to incorporate climate information in predicting, monitoring and managing lake level changes.

1 Introduction

Lake Victoria is a resource shared by the three East African countries: Kenya, Uganda and Tanzania and supports a livelihood of about 30 million people living around it. Its fish products, (i.e., Tilapia and Nile Perch) are exported the world over. Its role as an indicator of environmental and climate change on long-term scales together with its global significance are documented, e.g., in Nicholson et al. (2000, 2001) and Awange and Ong'ang'a (2006). Though the lake has continued to attract worldwide attention due to its significance and other environmental phenomenon such as water hyacinth, the recent recede of its waters (see, e.g., Fig. 1) has caused concern as to whether the lake is actually drying up as it happened in the pre-historic time (see, e.g., Awange and Ong'ang'a 2006). Since the 1960s, the lake level has exhibited fluctuations as pointed out by Nicholson (1998, 1999). The sharpest rise in the lake water level occurred during the El'Nino rains of early 60s and 1997/1998. Some reports, e.g., Aseto and Ong'ang'a (2003) suggest that the lake level rose by 2.5m following the 1960s floods. Kite (1981) attributed this rise to over-lake precipitation. In the last five years however, Lake Victoria water levels have dropped drastically (USDA 2005). According to Kull (2006), the lake levels have dropped more than 1.1 m below the 10-year average. Water levels have remained above average for more than 40 years, but current water levels are below normal and the lowest level since September 1961. The socio-economic impacts of this drastic fall in Lake Victoria water level have been reported in Awange et al. (2007a, b).

Previous interests in Lake Victoria water balance traces its roots back to the work of Brooks (1923). Other numerous subsequent works that evaluated the lake's water balance have been in the context of further understanding the hydrology of the Nile River. Nicholson et al. (2000) derived a water balance model for Lake Victoria that simulates lake

Fig. 1 Receding Lake Victoria waters leaves behind exposed wetlands being converted to farmland

level changes using only the over-lake rainfall as input. Linear regression was applied to model discharge based on rainfall and lake levels only. The model was used to calculate the end of year lake levels from 1931 to 1994, given an initial lake level value in the year 1930. This model indicated that the lake level fluctuated according to the over-lake rainfall with very high values for 1961–1964. This confirms that fluctuations of Lake Victoria and other East African Lakes are driven predominantly by rainfall (Yin and Nicholson 2002, Nicholson 1999). The lake typically recharges during the “short rains” and “long rain” seasons, but the amount of recharge dependents on seasonal rainfall amounts as well as water demand at the Uganda’s power utility.

Prior to 1910, rainfall measurements were made at few stations of Lake Victoria’s catchments, though historical information on the Lake’s levels extends back to the late eighteenth century (Yin and Nicholson 2002). Records of Nile flow permitted a rough estimation of the lake levels going back several centuries (Nicholson 1998). Though tidal gauge data exist in East Africa, they are inadequate to provide a critical analysis of the Lake water level. In an attempt to circumvent this shortfall, a recent study by Awange et al. (2007a) employed TRIMM (Tropical Rainfall Measuring Mission), GRACE (Gravity Recovery and Climate Experiment) and CHAMP (CHAllenging Minisatellite Payload) satellite data and revealed a reduction in the 20% basin discharge during the period 2001 to 2006, with little change in the basin rainfall over the same period. The study pointed a finger at the expanded Owen Falls hydropower complex, now consisting of the original Naluabaale Dam and the new Kiira Dam extension as a possible culprit in the decline in water over this period. Though Awange et al. (2007a) noted no significant change in rainfall over the 5-year period, EAC (2006) had pointed out that a long-term reduction in rainfall (i.e., climatic effects) could also be contributing to the fall in Lake Victoria water level. This is because 80% of the total catchments of Lake Victoria rely on direct rainfall while the remaining 20% comes from the river and underground discharges.

The influence of climate change on water level was noticed, e.g., by Magadza (1996) who analysed the sensitivity of major rivers of the African continent. Magadza (1996) examined changes in Zimbabwe's main water storage facilities during the period of 1991–1992 drought cycles, and established that the storage had dwindled to less than 10% of its installed capacity. Jallow et al. (1996) and Li et al. (2008) have also studied the impact of climate change on water level. In their study of the flow of the Gambian river, Jallow et al., (1996) indicated that, with an estimated error of about 8%, the Gambia river flow was very sensitive to climate change. Based on the results of river flow responses and vulnerability analysis, climate variables alone were found to cause a 50% change in runoff in the Gambia river catchments (Jallow et al. 1996). Li et al. (2008) noted that primarily climate indicators of precipitation and temperature influenced the fluctuation of Lake Qinghai water levels. In general, Manneh (1997) points out that a 1% change in rainfall results in a 3% change in runoff which in-turn reduces the Lake’s recharge. While lake level fluctuations have been shown to track drought episodes (e.g., Beaudoin 2002), the concern here is the continual falling of the Lake Victoria levels, hence the authors acknowledge the need to investigate the contribution of climate change besides other environmental and man-made factors. Mistry and Conway (2003) investigated the climatological factors responsible for the rise in the lake level, and found out that there was a significant correlation between the Lake rainfall series and the Lake levels. They also pointed out that there was a time lag of 1 to 2 years between rainfall episodes and the water level peaks of the lake. Since the rainfall series are based on land-based observations, and the Lake itself is roughly one quarter of the whole basin, the lake level variability is partially explained by the over-lake rainfall.

The present study extends on the previous work of Awange et al. (2007a) which examined the possible causes of the fall in Lake Victoria within the period 2002 to 2006. The study contributes towards our knowledge of the hydrology of the lake by investigating the climatological contribution to the falling Lake Victoria water levels. This is achieved by relating the lake levels to climatic indicators, e.g., precipitation and drought. The study is organised as follows; in Section 2, data source is presented. Section 3 looks at the analysis approach. The results are discussed in Section 4 and the study concluded in Section 5.

2 Data source

The Lake Victoria Basin (LVB, e.g., Fig. 2), described elaborately in Awange and Ong'ang'a (2006), experiences a hot and humid equatorial climatic condition that is modified by the effects of altitude, relief and influence of the Lake (Kite 1981). Surface water temperatures range between 23.5°C and 29.0°C. The major rivers, namely; Sondu Miriu, Nyando, Nzoia and Yala, discharge into the Lake from the Kenyan side of the Lake while Kagera runs all the way from Rwanda and empties its waters in Uganda (see, Fig. 2). To analyse the contribution of climatic change on the Lake water level, the following data were used.

2.1 Rainfall data (1961–1999)

Kisumu station (latitude 0°6′ S, longitude 34°45′ E and 1m500 m above sea level) was selected because of its position vis-à-vis other stations in the region (see Fig. 2). There are a

Fig. 2 Lake Victoria basin (from Kayombo and Jorgensen, 2006)

number of other meteorological stations within the LVB, but all are found in the same (Lake Victoria) climatological zone with homogeneous anomalies. Past studies have shown significant homogeneity in the patterns of rainfall anomalies in East Africa including Lake Victoria basin, resulting into common use of single rain gauge location to represent large areas (Ogallo 1988, 1993; Basalirwa et al. 1993; Awange et al. 2007b). Several authors have also noted that large scale moisture transported by monsoonal winds enhance basin precipitation significantly. Thus lake Victoria does not generate its own climate through precipitation–evapotranspiration–reprecipitation recycling only (Anyah et al. 2006; Song et al. 2004). Based on this information, the rainfall anomalies of Kisumu station represented the entire region.

2.2 Lake level data

Lake level data from three stations within LVB were used. These were: Kibos in Kenya (1965–2000), Jinja in Uganda (1976–2005), and Maziba in Uganda (1956–2003).

2.3 River discharge

Stream flows are usually used as surrogates rather than rainfall (precipitation) in a climate change impact assessment, as it is easier to detect climate change in runoff than precipitation, since changes in precipitation are usually amplified in runoff (Chiew and McMahon 1996). Furthermore, stream flow data may be perceived as representing the integrated effects of the spatial variability of precipitation within the catchment. Therefore, the stream flow data may provide as much information as precipitation time series derived from several rainfall stations in the catchment (Chiew and McMahon 1996).

Discharge measurements from two rivers, i.e., rivers Yala and Nzoia from Kenya for the period (1962–1999) were considered. River Nzoia is the longest with the largest catchment basin in the region while river Yala is the second longest river (Kirugara and Nevejan 1996). To obtain the river discharge, the speed of river is multiplied by the cross sectional area and the units are given in m^3/s. Our attempt to obtain data for river Kagera were however futile. Such data will be incorporated in future studies as they become available.

3 Analysis approach

The daily records of data d_i (rainfall, water level and discharge) were averaged to get the monthly means $\overline{D_m}$ using

$$\overline{D_m} = \frac{1}{n}\sum_{i=1}^{n} d_i, \tag{1}$$

where *n,* denotes the number of days in a month. Seasonal means were then obtained by averaging the monthly means for the 3 months of a particular season, i.e.,

$$\overline{S_m} = \frac{1}{3}\sum_{m=1}^{3} D_m, \tag{2}$$

Table 1 Values of drought severity classified in percent of normal

Percentage (%)	Description of condition
>75	Wet
25–75	Near normal
<25	Drought

while for annual means, the average of the 12 monthly means in Eq. 1 were taken for a given year, i.e.,

$$\overline{A_m} = \frac{1}{12}\sum_{m=1}^{12} D_m. \tag{3}$$

In order to achieve comparison of the data, the rainfall, river discharge, and lake level data were normalized (standardized) using

$$Z = \frac{X_t - \overline{X_{30}}}{\sigma}, \tag{4}$$

where Z is the standardized value, X_t the observed value at a particular time (e.g., $\overline{S_m}$ *or* $\overline{A_m}$), $\overline{X}_{30}$ the 30 years' mean for a parameter given by

$$\overline{X_{30}} = \frac{1}{30}\sum_{m=1}^{30} \overline{A_m}, \tag{5}$$

and σ is the SD. The 30-years' mean was in accordance with World Meteorological Organization (WMO) requirement that this be the standard used to define the rainfall 'normal' of a region (Awange et al. 2007b). Using Eqs. 1–5, drought, linear and cyclic trend analysis were performed as discussed below.

3.1 Determination of drought seasons and years

Using rainfall data computed from Eq. 3, the normal precipitation N- typically considered a 30-year mean is obtained from Eq. 5. The normal precipitation is then used to compute the *percentage of normal* P_n (quartile) using

$$P_n = \left[\frac{A_p}{N}\right] \times 100\%, \tag{6}$$

where Ap is the actual precipitation. Using the percentage of normal from Eq. 6, Drought Severity Index (DSI) is determined by considering all observations which are less than 25%

Table 2 Seasonal drought years

Seasons	Drought Years
DJF	1967, 1971, 1974, 1975, 1981, 1982, 1983, 1984, 1992, 1994, 1997, 1999.
MAM	1961, 1967, 1969, 1976, 1982, 1983, 1984, 1987, 1992, 1998.
JJA	1963, 1965, 1967, 1969, 1970, 1973, 1980, 1989, 1991, 1995, 1997, 1998.
SON	1963, 1966, 1970, 1973, 1975, 1977, 1980, 1981, 1985, 1990, 1993, 1997, 1998.

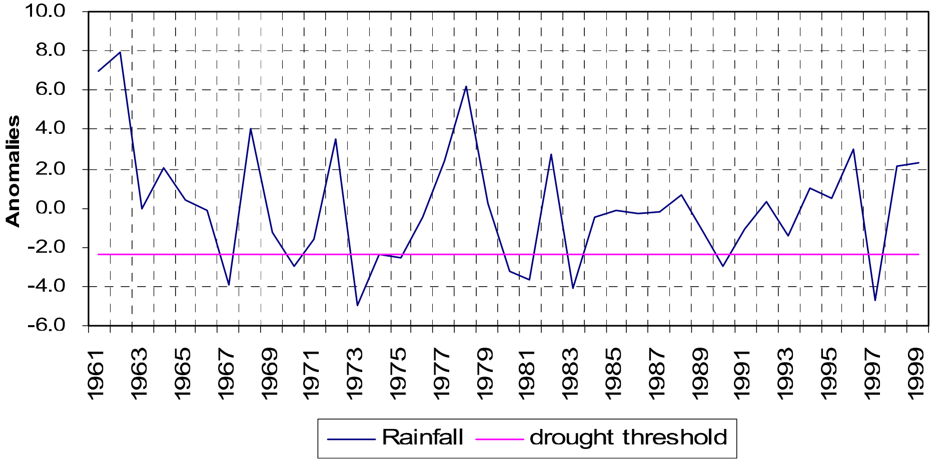

Fig. 3 Time series of annual rainfall anomalies for Lake Victoria

(first quartile) of the ranked historical records to be dry, while those which are more than 75% (third quartile) are considered wet (Table 1).

Four seasons common in the region are December–January–February (DJF), March–April–May (MAM), June–July–August (JJA) and September–October–November (SON).

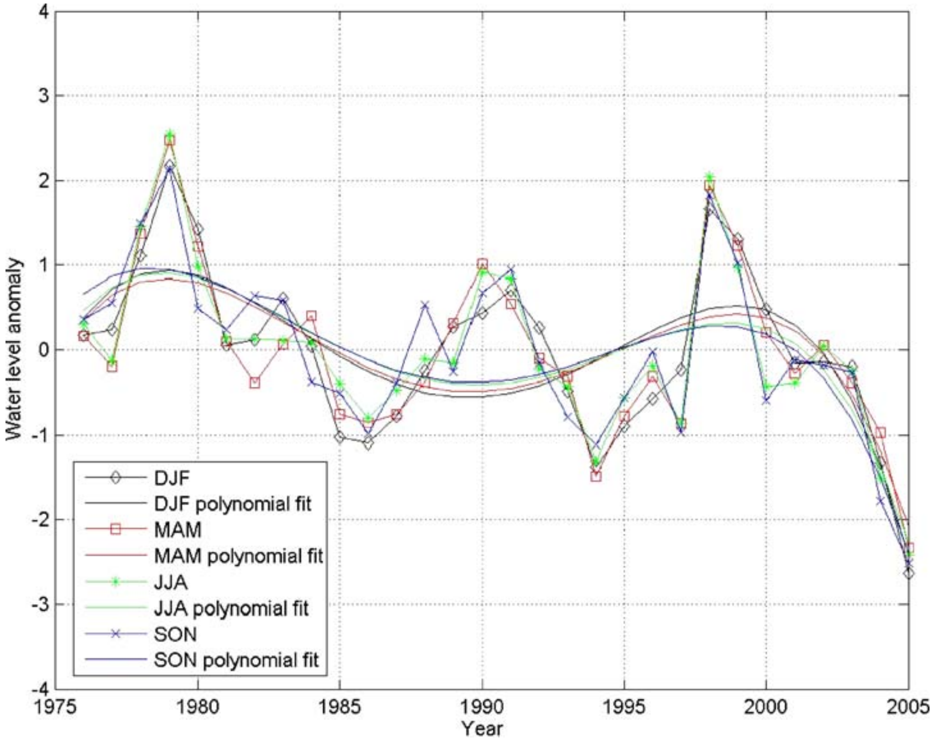

Fig. 4 Seasonal anomalies of Jinja water level from 1976 to 2005 and their fourth order polynomial fits

MAM is the 'long-rains' season and SON the 'short-rains' season in the region. Drought seasons and years were identified by observing the years and seasons in which the anomalies were below the drought threshold line (i.e., DSI). These drought years are then used in the analysis process to compare those times of drought in the region and the Lake Victoria levels.

3.2 Trend analysis

Under trend analysis, linear trends of the anomalies with respect to the common epochs of the data were plotted and the slope of the line computed using *polyfit* function of Matlab software. The slopes of linear trends from rainfall, water level and discharge data for the common period 1976–1999 were then tested for statistical significance using the Student's *t*-test. Assuming that each data follows the normal distribution with sampled mean and standard deviation, let a_1 and a_2 be the estimated slopes from the first order least squares method and σ_{a1} and σ_{a2} the standard deviations of a_1 and a_2, respectively. The unbiased combined (pooled sampled) standard deviation of two datasets is given, e.g., by Johnson and Wichern (2002) as

$$S = \sqrt{\frac{\sigma_{a_1}^2 + \sigma_{a_2}^2}{n}}, \tag{7}$$

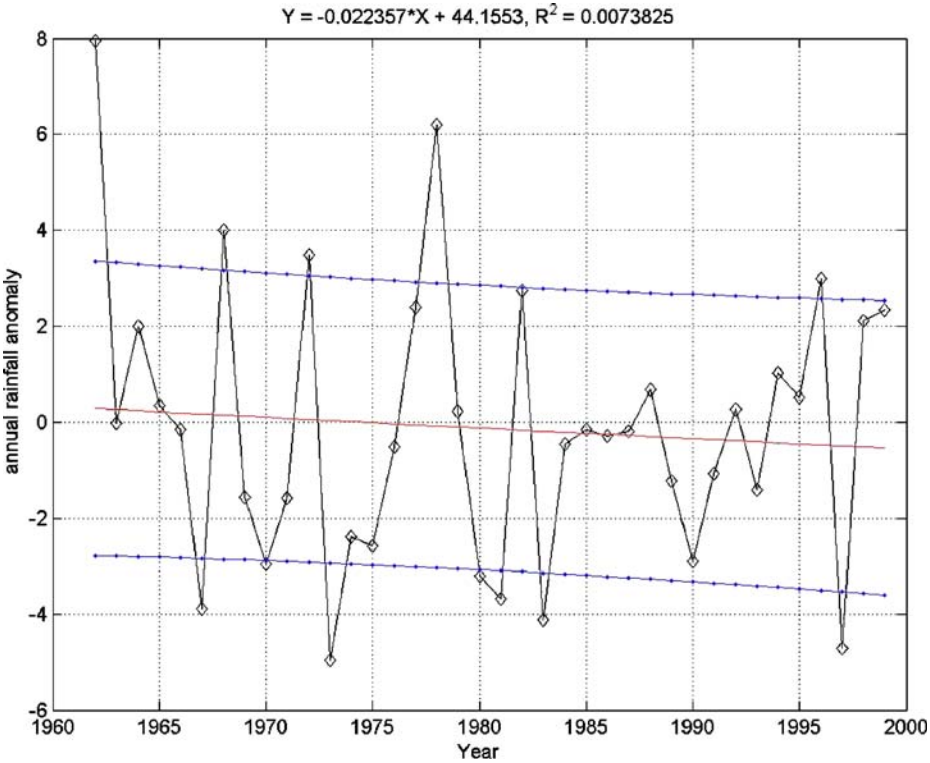

Fig. 5 Annual rainfall anomaly in Kisumu station from 1962 to 1999. The first order line fit results and R^2 values are presented in the top of each plot

where n is the number of samples with the degree of freedom of $n-1$. If the samples have different sizes, the combined standard deviation of the datasets is given as

$$S = \sqrt{\frac{(n_1-1)\sigma_{a_1}^2 + (n_2-1)\sigma_{a_2}^2}{(n_1+n_2-2)}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}, \tag{8}$$

where n_1 and n_2 are the numbers of each samples with the degree of freedom of n_1+n_2-2. The null and alternative hypotheses are then formulated as:

$$H_0 : a_1 = a_2$$
$$H_1 : a_1 \neq a_2,$$

and H_0 is the null hypothesis that the slope of a_1 equals that of a_2, while H_1 is the alternate hypothesis. Using Student's *t*-distribution, and S from either Eq. 7 or 8 depending on the sample sizes, we express the test value as

$$t = \frac{|a_1 - a_2|}{S}, \tag{9}$$

and test it against the test criterion (tc) at 99% confidence level. The null hypothesis is accepted if t<tc or rejected otherwise. In case the Null hypothesis is accepted, i.e., the slopes a_1 and a_2 statistically equal, then the occurrences are said to be related.

Annual anomalies are too general and cannot give a clear impression of drought on seasonal basis. It is possible to experience drought in one season in a year, which can result

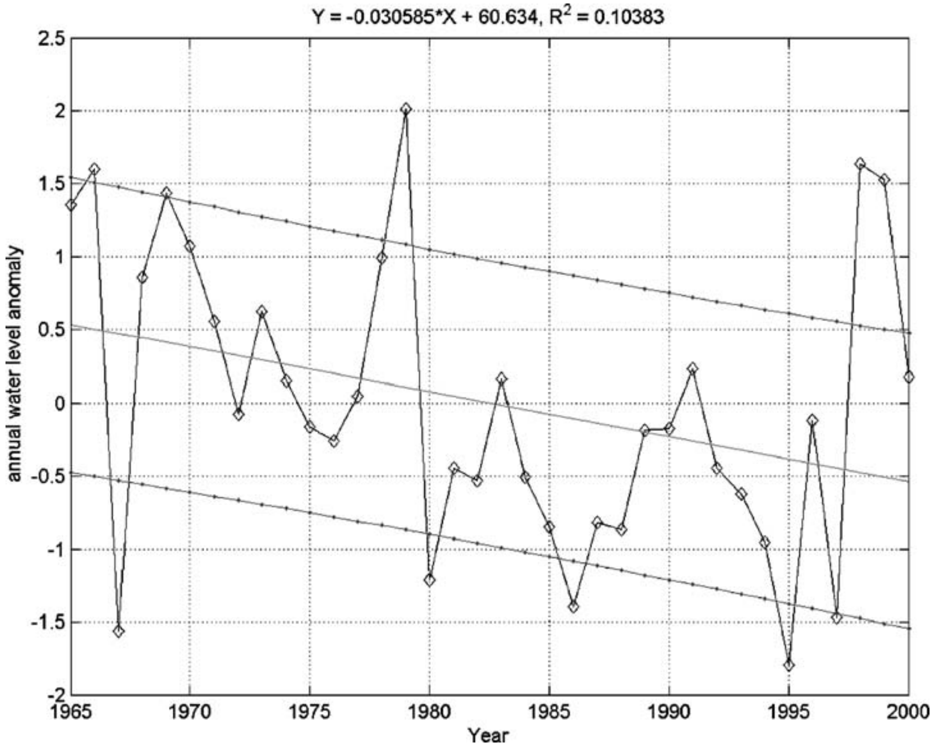

Fig. 6 Annual water level anomaly in Kibos station from 1965 to 2000

to severe impacts. This cannot be reflected if annual anomalies are used in case there was much rainfall in another season of the same year since the rainy season would compensate for the drought season. Because of this, it is important to analyse drought on seasonal basis along with annually anomaly analysis. Cyclic analysis, i.e., periods of year-to-year recurrences of droughts, were investigated using Discrete Fourier Transform (DFT; see, e.g., Kaiser 1994; Torrence and Compo 1998; Torrence and Webster 1999 for alternate wavelet analysis approach). Discrete Fourier Transform of the N seasonal data, (*dj*), are expressed as

$$\begin{aligned} X(k) &= \sum_{j=0}^{N-1} d(j) e^{-\left(\frac{2\pi jk}{N}\right)i} \\ &= \sum_{j=0}^{N-1} d(j)\left[\cos\left(\frac{2\pi jk}{N}\right) + i\sin\left(\frac{2\pi jk}{N}\right)\right] \end{aligned}, \tag{10}$$

where k=0…(N−1) (Bracewell 1965; Press et al. 1989). Its power spectrum, P, is given as the mean of the absolute values of $X(k)$ and the maximum frequency that can be recovered without aliasing, i.e. the Nyquist frequency (f_c), is given as

$$f_c = \frac{1}{2\Delta} \tag{11}$$

where Δ is the sampling interval. In our cases, the Nyquist frequency is 0.5 and this means that the minimum cyclic trend can be found with the seasonal data of 2 year.

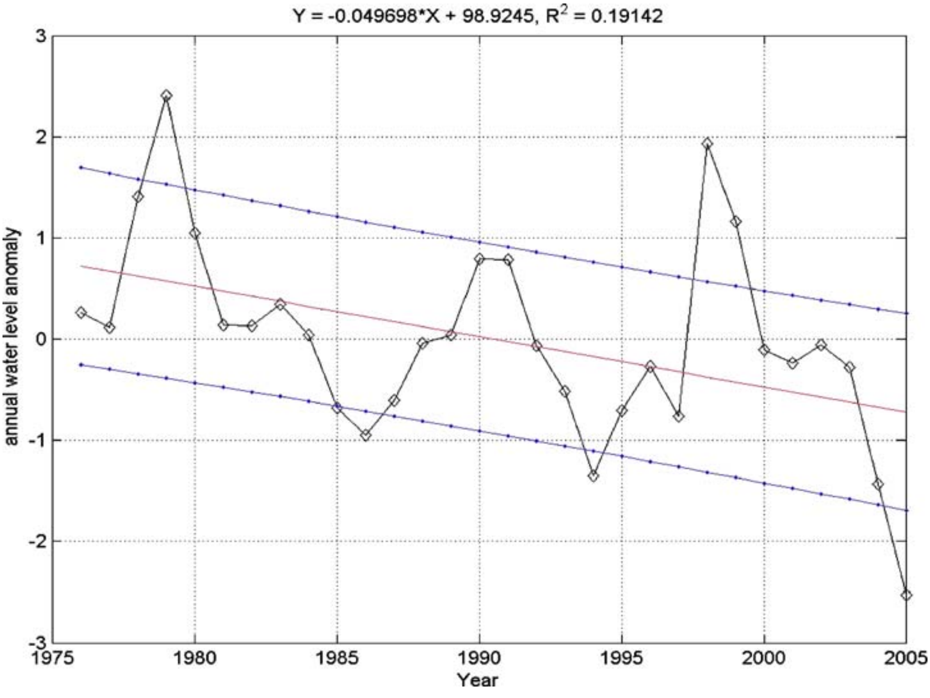

Fig. 7 Annual water level anomaly in a station in Uganda from 1976 to 2005

4 Results and discussion

4.1 Drought years from the rainfall anomalies

In Table 2 and Fig. 3, drought years from annual rainfall anomalies of the region are identified. It was noted that floods are also recurrent within the lake basin. Some of the extreme drought and floods have been linked to El Niño/southern oscillation (ENSO), Indian Ocean Dipole, and many other large-scale climate systems (Ogallo 1988). Prominent cycles that have been detected in rainfall over eastern Africa including lake Victoria basin are 2.0–2.5 years, 2.7–3.3 years with less prominent cycles at 3.5–4.4 years, 5.0 years 6.0–6.5 years, 7–8 years and 10–11 years (Ogallo 1984 and 1993). Because of the El Niño rains of 1998, the 1990s were not particularly dry, but significant droughts did occur in 1990 and in 1997 (Fig. 3).

The anomalies computed from Eq. 4 indicate years that received below and above normal rainfall. The DSI in Fig. 4 shows the seasonal rainfall anomalies for all the four seasons for the Lake Victoria basin region. For the same year, the Figure indicates that one season can receive too much rainfall than the others. A good indication of this is in 1997, which has been highlighted as a drought year. This resulted from the below 'normal' rains that were received in the first three seasons of the year. In the last month of 1997, which is part of the 1998 DJF season, the El'Nino rains were experienced in the region. The year 1997 is ranked as a drought year since the El'Nino rains started in the last month of that year.

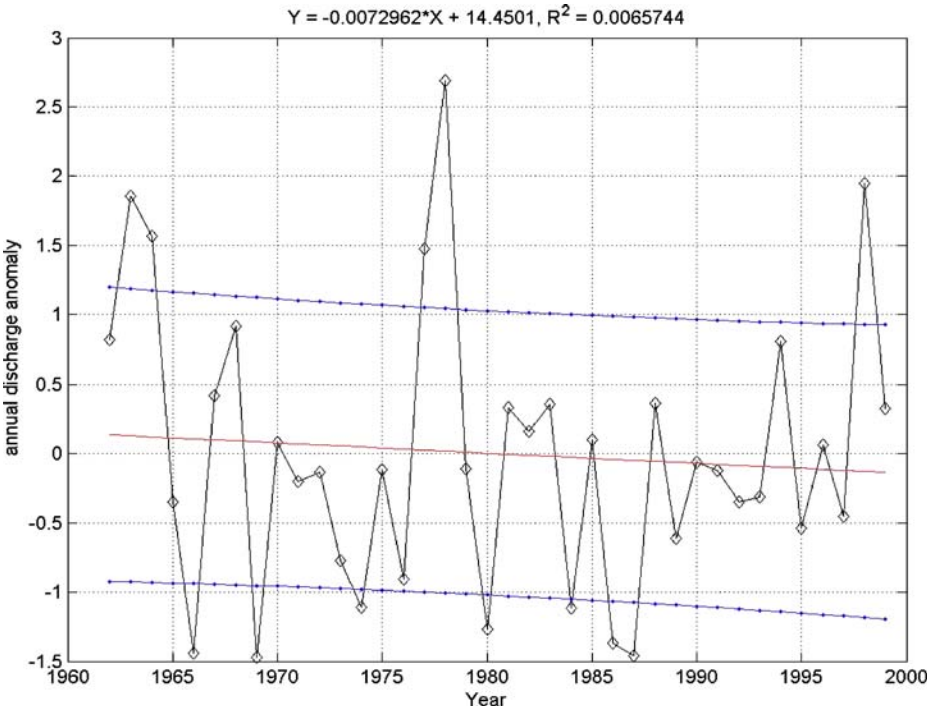

Fig. 8 Annual discharge anomaly in river Nzoia station from 1962 to 1999

Table 3 Estimated slopes and their SD of rainfall, water level and discharge data from four stations in Kenya and Uganda from 1976–1999

Item	Kibos (water level)	Jinja (water level)	Kisumu (rainfall)	Nzoia (discharge)	Maziba (water level)
Slope a_i	−0.0081	−0.0296	−0.0046	−0.0012	−0.0351
Std_ a_i	0.0301	0.0270	0.0766	0.0302	0.0326
Number of data	24	24	24	24	16

General patterns of drought identified for the Lake Victoria seasons, e.g., in Awange et al. (2007b) were:

- During the hot dry season (DJF), severe drought can be expected approximately every 7 to 8 years.
- During the long rainy wet season (MAM), severe drought can be expected every 5 to 8 years.
- During the dry season (JJA) there is no clear cycle of drought events.
- During the short rainy wet season (SON), severe drought can be expected every 3 to 4 years.

4.2 Linear trend analysis

Annual rainfall anomalies' linear trend is plotted in Fig. 5, while those of lake levels are plotted in Figs. 6 and 7 for Kibos and Jinja stations. Figures 5, 6, and 7 for rainfall and lake levels show annual declining linear trends. Figure 8 presents a linear trend for Nzoia river. The linear trends are tested according to Eqs. 7 and 9 at 99% confidence level. Table 3 presents the slope data, standard deviations of the slopes and the sample sizes for water level, rainfall and discharge data types for Kibos, Jinja, Kisumu, Nzoia and Maziba stations. Tables 4 and 5 show the results of the statistical analyses. From the analysis, it is noted that the null hypothesis is accepted in the entire test, indicating that the slopes were significantly the same. The results indicate the acceptance of the null hypothesis and imply that the decline in rainfall contributes to the fall in water level. A plot of the rainfall anomalies together with the drought threshold (DSI) in Fig. 3 indicate a general declining trend in the lake water levels since 1965 after it had attained a rise as a result of much El'Nino rain that were received in the region during the period between 1961 to 1964. Some years, which recorded large annual lake levels fall, e.g., 1967, 1980 and 1983 (Figs. 6 and 7) coincide with the annual drought year periods (Fig. 3), where the rainfall anomalies were below drought thresholds.

Table 4 Student's *t*-test results of the estimated slopes of water level and discharge data from Kibos, Jinja and river Nzoia

Item	Kibos vs Jinja (water level)	Kibos vs Nzoia (discharge)	Kibos vs Maziba (water level)
Test value (t)	2.6049	0.7928	2.6890
critical value (tc)	3.7676	2.8073	2.7116
Accept or reject H_0	Accept	Accept	Accept

Table 5 Student's *t*-test results of the estimated slopes of rainfall, water level and discharge data from Kisumu, Kibos, Jinja and river Nzoia

Parameter	Kisumu (R) vs Kibos (WL)	Kisumu (R) vs Jinja (WL)	Kisumu (R) vs Nzoia (D)	Kisumu (R) vs Maziba (WL)
Test value (t)	0.2083	1.5079	0.2023	1.4996
critical value (tc)	2.8073	3.7676	2.8073	2.7116
Accept or reject H_0	Accept	Accept	Accept	Accept

R Rainfall, *D* discharge and *WL* water level

4.3 Cyclic trend analysis

Though the analysis of annual rainfall anomalies and annual lake level averages gives some general relationship overview, seasonal anomalies are also examined for periodic cyclic trends. Seasonal lake levels time series are plotted and smoothed using the Polyfit function of Matlab software and is presented in Fig. (4) for Jinja station, which shows a cyclic trend for the seasons DJF, MAM, JJA and SOD. Figure 4 shows seasonal variation of rainfall anomalies for all the four seasons for Lake Victoria region (Table 6). The seasons with very low lake levels are; JJA(1967), SON(1972), SON(1980), DJF(1986), SON(1995) and JJA (1997), some of which were identified as drought years in Fig. 3. Lake level rose in all seasons from 1961, reaching its peak in 1964. This is attributed to the above-normal rainfall in the region from 1961–1964, which caused the Lake to rise with an unexpected 2.5 m (USDA 2005).

From Figs. 4, 6, and 7, a general trend in declining lake level is evident. As in the first 20 years 1961–1979, in most of the seasons, the lake levels were above the threshold line and yet from 1980–2000, most of the seasons had below 'normal' lake levels. For the same years, the figure indicates that one season can receive too much rainfall compared to the others. A good indication of this is in 1997, which has been highlighted as a drought year. This resulted from the below 'normal' rains that were received in the first three seasons of the year. In the last month of 1997, which is part of the 1998 DJF season, the El'Nino rains were experienced in the region. The year 1997 is ranked as a drought year yet El'Nino rains started in the last month of that year. This cyclic pattern is analysed using Discrete Fourier Transformation, which shows the dominant peaks in the signals and provides the cyclic period (Figs. 9 and 10). The periods of these peaks for rainfall and water level at Jinja are compared to the drought periods of Awange et al. (2007b, Table 7). The results of Table 7, which compares the drought cycles from Awange et al. (2007b) and those obtained from Fourier Transformation of rainfall and water level data, are interesting. The results indicate closeness in the periods of drought cycles and those of less rainfall and drop in water level. Climate change, indicated by variation in rainfall and drought therefore contribute to the fall in water level in the long term.

Table 6 Seasonal mean and SD for Lake Victoria water levels

Seasons	Mean (X)	SD (σ)
DJF	1,224.3	28.8
MAM	1,235.9	34.5
JJA	1,225.7	54.7
SON	1,209.2	40.8

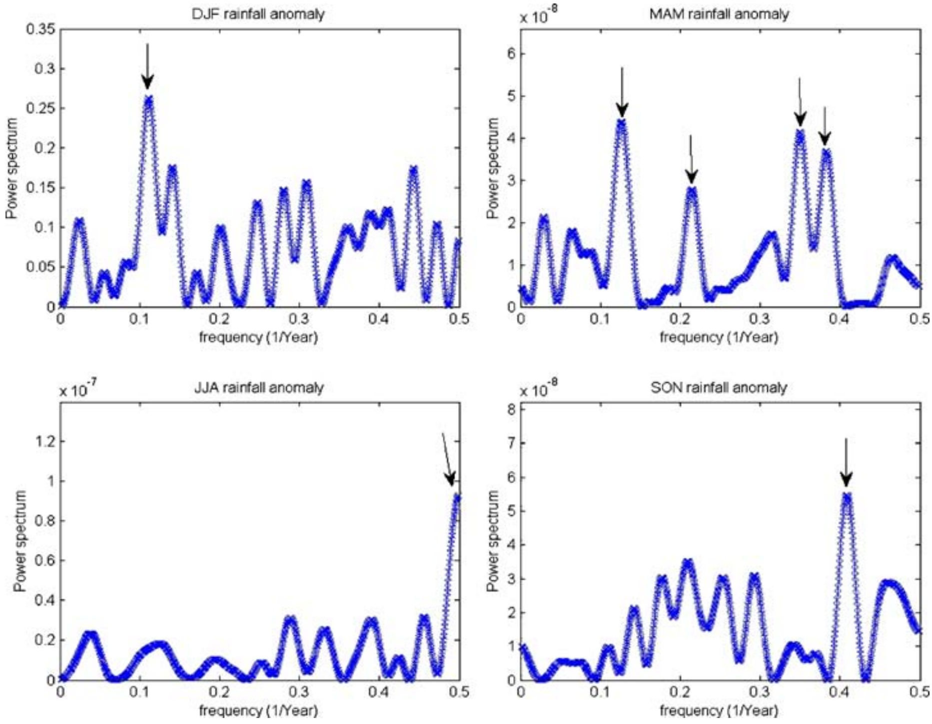

Fig. 9 Seasonal anomaly of Kisumu rainfall from 1962 to 1999 and its power spectrum. The strong modes are indicated by an arrow

Lake levels anomalies calculated using Eq. 5, plotted in Figs. 4, 6, and 7 shows the fluctuations, and identify seasons and years when the Lake recorded very low levels. The figures indicate a general falling linear trend of the lake levels since 1965 after it had attained a rise because of much rain in the region during 1961 to 1964. Though the Lake levels show a general falling trend, there are very significant falls in certain years like in 1967, 1980–1981, 1986, 1997, 2000 and 2005 for Jinja station. Drought in the region would also have an impact on the river flows in the lake basin. Therefore, for evidence of drought impact on the lake levels, the stream flows of rivers in the basin are considered.

Statistical analyses (Tables 4 and 5) indicate the impact of drought on the Lake water level. This is also evidenced by the declining trend (Fig. 8) of the discharge of river Nzoia which contributes to the 20% refill of the Lake. The explanation for the years when the Lake level was increasing and the flow of the river decreasing as in 1968/1969 (Figs. 6 and 8) could be due to the rainfall falling directly on the lake. The years when the river flow was increasing and the lake level falling as in 1994 could be due to rains on the catchment and not over the Lake or the rate of lake water withdrawal could have been faster than the expected input from both the over-lake rainfall and the river flows (see also Fig. 7 for Jinja station). Since the flow of a river is sensitive to the rainfall of the region, similarities in the trend patterns of the river and lake levels indicate that rainfall in the basin have greater impact on the lake levels. Any reduction in the river contributes to the general reduction of the 20% lake recharge from the basin. For the droughts of the late 1960s and early 1980s, both the lake levels and the river discharge show a declining trend. They both show a rise as a result of the 1961/1962 rains and the 1997/1998 El'Nino rains.

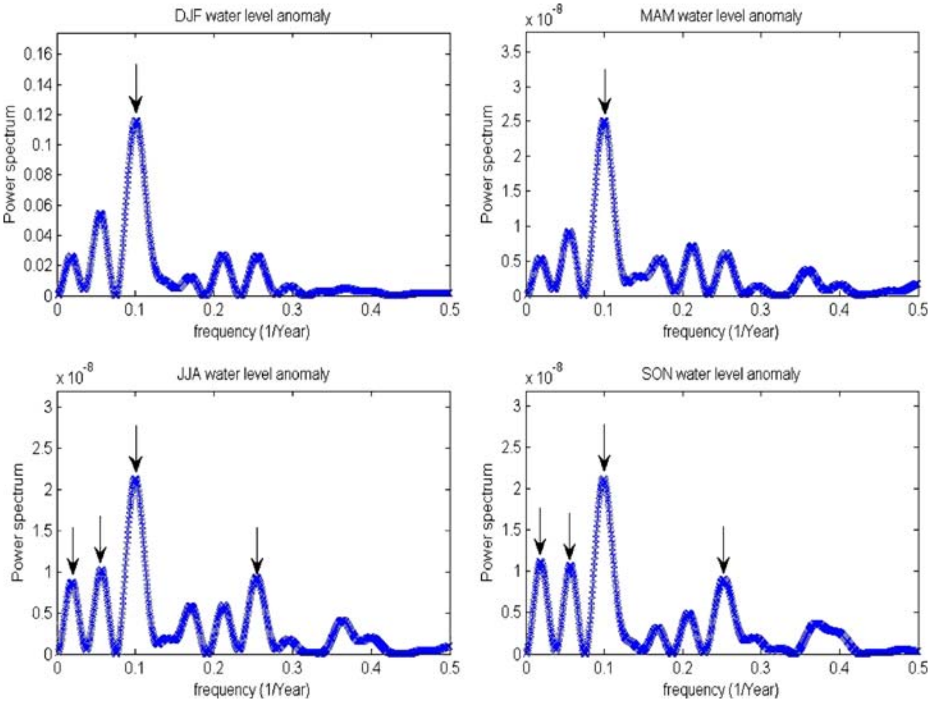

Fig. 10 Seasonal anomaly of Jinja water level from 1976 to 2005 and its power spectrum. The strong modes are indicated by an arrow

Drought in the Lake Victoria basin, therefore, contributes to sharp drops of the lake levels. The magnitude of the impact of drought on the lake levels is determined by the period of the drought. Prolonged droughts in the region have long-term impacts on the water levels of the Lake, while short droughts have short-lived impacts on the lake levels since the lake regain its water level when rains resume. Though it has been noticed that drought in the lake region contributes to the sharp drops of the lake levels, it can also be noticed that the lake levels indicate a reducing trend in its levels since 1965 and this is not only as a result of drought in the region.

5 Conclusions

The study has demonstrated that the lake levels fluctuate annually and seasonally with significant drops during drought seasons and rapid rise during periods of above average

Table 7 Cyclic trends of rainfall (Kisumu, 1962–1999) and water level (Jinja, 1976–2005) found by both Awange et al. (2007) (C_{Awange}) and the method by the Fourier analysis ($C_{Fourier\_rainfall}$, $C_{Fourier\_waterlevel}$)

Item	C_{Awange} (year) Kisumu	$C_{Fourier\_rainfall}$ (year) Kisumu	$C_{Fourier\_waterlevel}$ (year) Jinja
DJF	7~8	~8.3	~10.0
MAM	5~8	~2.9, ~2.6, ~4.8, ~8.3,	~10.0
JJA		~2.0	~4.0, ~10.0, ~16.7, ~50.0
SON	3~4	~2.4	~4.0, ~10.0, ~16.7, ~50.0

rainfall in the region. Lake Victoria water levels are very sensitive to climatic factors and as such, any long-term analysis should incorporate climate parameters. During the short period between 2001 and 2006, studies with satellite datasets (Awange et al. 2007a) revealed no major influence of precipitation on the falling water level. In case of long-term fluctuation of the Lake Victoria water level, however, climatic factors play a significant role. Further analysis incorporating more data, e.g., rainfall and discharges from river Kagera, which could not be obtained during the preparation of this contribution needs to be incorporated to enhance the conclusion.

Acknowledgement The authors are grateful to IGAD Climate Prediction and Applications Centre (ICPAC) for granting the facilities and data used in the study. Special thanks to Dr. Gilbert Ouma at University of Nairobi who was instrumental in obtaining data, climatic products and other information that were used in this research. JLA acknowledges the financial support of Curtin Research Fellowship and the Applied Training Project (PMU). KHB would like to thank the Cooperative Research Centre for Spatial Information (CRC-SI) for a research fellowship. Further, the authors are indebted to Prof. CHD Magadza, Dr. VS Muhandiki and the Editor Prof. S. Schneider for reviewing the article and providing valuable comments that enriched the manuscript. This is The Institute for Geoscience Research (TIGeR) publication number 98.

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