Analysis of mid-twentieth century rainfall trends and variability over southwestern Uganda

F. N. W. Nsubuga* · J. M. Olwoch · C. J. deW. Rautenbach · O. J Botai

Abstract A methodology has been applied to investigate the spatial variability and trends existent in a mid-twentieth century climatic time series (for the period 1943–1977) recorded by 58 climatic stations in the Albert–Victoria water management area in Uganda. Data were subjected to quality checks before further processing. In the present work, temporal trends were analyzed using Mann–Kendall and linear regression methods. Heterogeneity of monthly rainfall was investigated using the precipitation concentration index (PCI). Results revealed that 53 % of stations have positive trends where 25 % are statistically significant and 45 % of stations have negative trends with 23 % being statistically significant. Very strong trends at 99 % significance level were revealed at 12 stations. Positive trends in January, February, and November at 40 stations were observed. The highest rainfall was recorded in April, while January, June, and July had the lowest rainfall. Spatial analysis results showed that stations close to Lake Victoria recorded high amounts of rainfall. Average annual coefficient of variability was 19 %, signifying low variability. Rainfall distribution is bimodal with maximums experienced in March–April–May and September–October–November seasons of the year. Analysis also revealed that PCI values showed a moderate to seasonal rainfall distribution. Spectral analysis of the time components reveals the existence of a major period around 3, 6, and 10 years. The 6- and 10-year period is a characteristic of September–October–November, March–April–May, and annual time series.

1 Introduction

The association between climate, natural resources, and socioeconomic activities has led to the demand for accurate information on the future of climate and the associated natural systems like the water cycle and its management (Ogallo 1993). This is paramount in water resource planning, agricultural planning, flood frequency monitoring, climate change impacts, environmental assessments, and ecology (Ngongondo et al. 2011; Michaelides et al. 2009; Ceballos et al. 2004). Such information is still scarce because of the few studies that have analyzed the relationship of climate patterns and water management among others especially in the East Africa region. For example, Kampata et al. (2008), New et al. (2006), Schreck and Semazzi (2004), Kruger and Shongwe (2004), Mahe et al.(2001), King'uyu et al. (2000), Nicholson (1996), Ogallo (1993), Beltrando (1990), Rodhe and Virji (1976), and Samson (1952) are among the most recent studies concerning long-term climatological trends that have fo-cused on surface air temperature and precipitation in Africa. From these and other studies, a range of potential climatic impacts on water management for various geo-graphic areas, flood prevention and control, drought man-agement, food and fiber production, etc. have been hypothesized. When it comes to reviewing germane studies in Uganda, a limited number appear to be available. For example, on the temporal distribution of rainfall in the Lake Victoria basin, Kizza et al. (2009) reported that the Lake Victoria basin experienced a predominantly positive trend

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over the twentieth century. Phillips and McIntyre (2000) investigated the subregional significance of El Niño–Southern Oscillation (ENSO) events in Uganda, distinguishing between unimodal and bimodal rainfall zones from 1931 to 1960 for 33 sites. They detected a significant correlation between ENSO events and rainfall seasons. Basalirwa (1995) applied principal component analysis on monthly records from 102 rain gauge stations for the years 1940–1975 to delineate Uganda into 14 homogeneous climatologi-cal zones aligned with the spatial pattern of the physical features.

Research focusing on national or regional analysis of climatic parameters has not been exhaustive that is why more studies using different methodologies are recommended (Ngongondo et al. 2011). The motivation for this study is to investigate further the temporal and spatial rainfall characteristics, including trends for Uganda at high spatial scales, in the Albert–Victoria water management area using old data records. This study fills in the gap for baseline data concerning trend analysis in Uganda, hence the period 1940 to 1977. Information on whether trends exist in Uganda's rainfall is useful for the Ugandan government to carry out effective water resource planning and management in the future. It will also serve to fill the gap in the map of rainfall trend analyses in the world. Uganda is a small country with a wealth of water resources that are also transboundary. Lack of information on the characteristics of these natural water resources may result in poor decisions on Uganda's economy and human health which are vulnerable to climatic anomalies. As demonstrated, a few studies (Samson 1952; Kizza et al. 2009) have been done to investigate trends and variability of rainfall in Uganda. For instance, Samson (1952) investigated trends of East Africa rainfall and used only 14 stations from Uganda to the year 1949. On the other hand, Kizza et al. (2009) used six stations found in the Victoria basin of Uganda to study the temporal variability in the Lake Victoria basin during the twentieth century. The main objectives of this paper are (1) to describe the spatial patterns of rainfall and concentration and the interannual variability of annual and monthly rainfall concentrations for the period 1943 to 1977 using 58 station locations in the Albert–Victoria water management area of Uganda and (2) to analyze the rainfall trends based on both monthly and annual series using parametric and non-parametric tests.

2 Data set and methodology

2.1 Study area

The Albert–Victoria water management area is located to the north and west of Lake Victoria in Uganda (Fig. 1). The area is traversed by the equator, has a number of water bodies, and has varying topography. It is also characterized by a dense network of rivers, which draw its water from the different water catchment areas into the main water bodies. For this particular study, the Albert–Victoria area comprises two water management zones: the Albert water management zone (hereafter Awmz) and the Victoria water management zone (hereafter Vwmz).

The Awmz covers an area of approximately 45,000 km^2, which falls into two distinct terrain systems. The northwest sloping peneplain found at 1,000–1,200 m above mean sea level (a.m.s.l.) contributes to the Kyoga catchment and the rift valley catchment which discharges into Lake Albert at a mean lake level of 615 m (a.m.s.l.). It receives relatively low mean annual rainfall with most parts receiving less than 875 mm. Rainfall averages increase towards the highlands, largely due to orographic influence. The Awmz extends to Butiaba in the north which lies at an altitude of 615 m (a.m.s.l.), with mean rainfall of 698 mm, and southwards to the Kabale meteorological station found at an altitude of 5,400 m (a.m.s.l.). This Awmz has potential for hydropower production on sites along the Nile River and geothermal power production sites. Population is estimated at about 4.5 million, with agriculture as the major industry albeit with significant fishing activities on Lake Albert and an oil development sector.

The Vwmz covers about 78,100 km^2 spread into two distinct terrain systems to the east and to the west direction, such as the gently sloping peneplain of the catchment discharging into Lake Victoria and the rift valley catchments which discharge into Lakes Edward and George. The furthest station in the east is Bugiri, elevated at 1,185 m (a.m.s.l.). The Vwmz is characterized by the abundant surface and groundwater resources. It has also the highest installed and potential hydropower production potential. Population in this zone is estimated at about 9 million, with agriculture as the major industry albeit with significant urbanization and moderately active industry and mining sectors.

The major climate parameter which has the highest space–time variation over Albert–Victoria water management zones (Fig. 1) is rainfall. Rainfall determines the spatial patterns of the natural resources and land use activities. Basalirwa (1995) outlined the major systems which control the space–time characteristics of rainfall in Uganda. These systems include the intertropical convergence zone (ITCZ), subtropical anticyclones, monsoonal winds, moist westerlies from Congo, regional features like the large water bodies, and complex topographic features. These features introduce significant modification in the general wind patterns over the region, coupled with convection processes that generate a climatic pattern, which is complex and changes rapidly over short distances (Nicholson 1996). These climatic processes result into a bimodal pattern of rainfall, with the primary rainy season occurring in March–

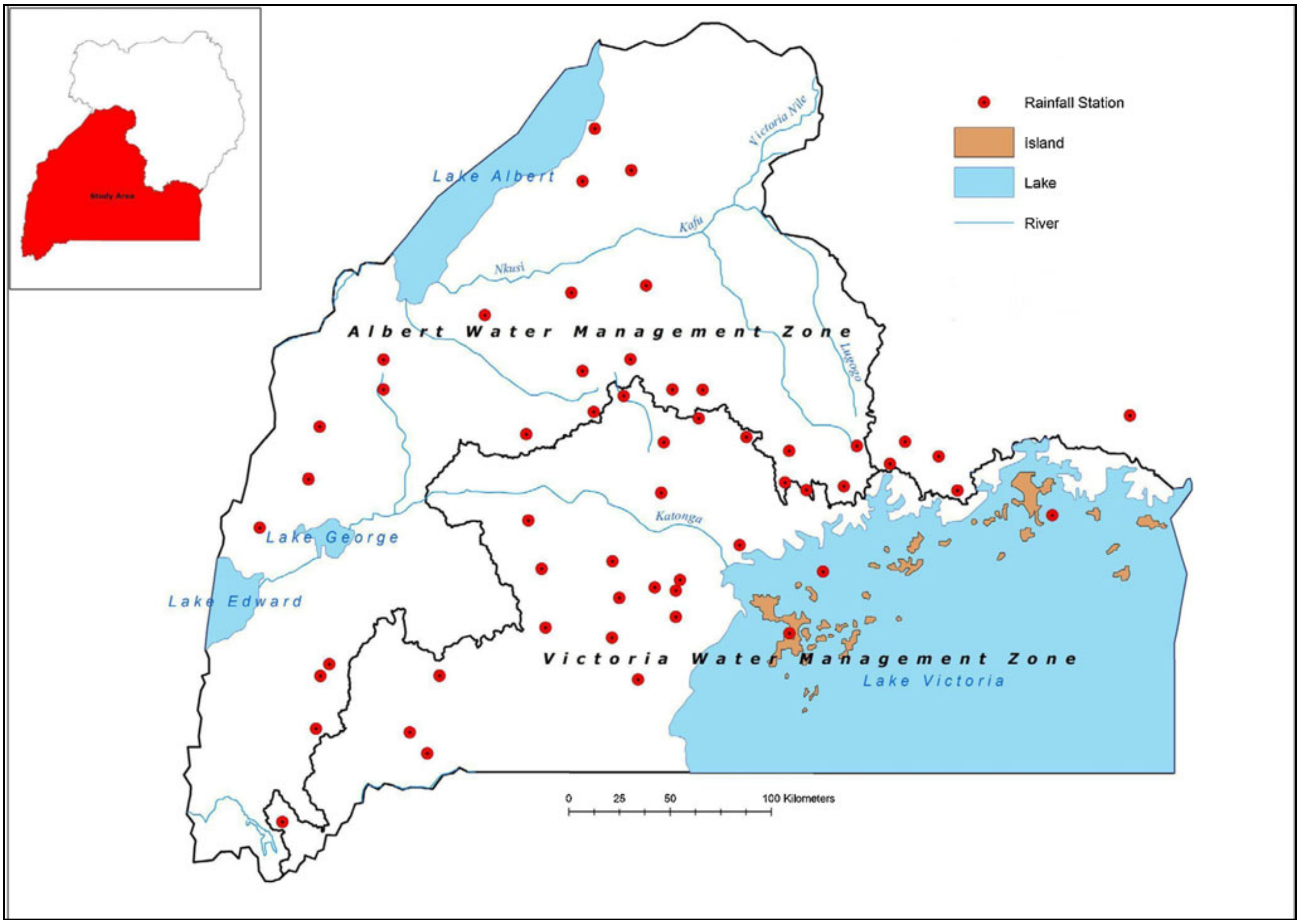


Fig. 1 Location of study area and stations in Albert–Victoria water management zones

May and a shorter secondary rainy season occurring in October–December (Phillips and McIntyre 2000).

2.2 Rainfall data

Monthly totals of rainfall data recorded at 58 stations by the Ugandan Department of Meteorology have been used. For both station-based and regional analyses, the study covers the period 1943–1977. Average record length of the stations is 33 years, with a record length varying from 28 to 35 years.

2.2.1 Missing value interpolation

Records of monthly rainfall totals have been examined in order to obtain homogeneous data and to ensure a good geographical representation where possible. First, a total of 150 stations have been selected for analysis. A preliminary examination of monthly totals showed that a number of monthly records had missing values. This is a challenge to which a number of studies (Türkeş 1996; Sahin and Cigizoglu 2010; Ngongondo et al. 2011) have applied different techniques to make rainfall data set complete. In this study, we applied the linear regression method. It is a method for estimating the value of a function between two known values. The method involves estimating a new value by connecting two adjacent known values with a straight line. A simple linear model can be defined as below:

$$y = \beta_0 + \beta_1 x \tag{1}$$

where β_0 is the intercept and β_1 is the slope. Let the difference between the observed value of y and the straight line ($\beta_0+\beta_1 x$) be the error ε. It is convenient to think of ε as a statistical error, that is, a random variable that accounts for the failure of the model to fit the data exactly.

$$y = \beta_0 + \beta_1 x + \varepsilon \tag{2}$$

Equation (2) is called a Linear Regression (LR) model. Customarily x is called the independent (regressor) variable, and y is called the dependent variable. Because Eq. (2) involves only one regressor variable, it is called a simple LR model (Sahin and Cigizoglu 2010).

2.2.2 Homogeneity testing

The literature suggests that a change, however minor it may be, in the station environment or observation methods can artificially alter the mean measurements and make the series suspect (Menne and Williams 2005) or not homogeneous. These in-homogeneities manifest themselves in two basic ways: as a gradual trend or as a discontinuity in the mean or variance (Easterling et al. 1996). Inhomogeneities in the statistical properties of climatological variables such as long-term means, trends, or standard deviations (Pandžić and Likso 2009) can be detected using absolute and relative homogeneity tests. Buishand (1982) and Peterson et al. (1998a, b) have discussed in detail the application of relative and absolute tests. Detailed mathematical development of the tests is also discussed in Wijngaard et al. (2003), while Ducré-Robitaille et al. (2003) provides a comparison between the techniques.

In this study, the homogeneity of the rainfall records has been analyzed by five tests, namely (1) the von Neumann ratio (V), (2 and 3) the cumulative deviations ($Q/n^{-0.5}$ and $R/n^{-0.5}$), and (4 and 5) the Bayesian procedures (U and A). Three of these tests have been used by Gemmer et al. (2004) to analyze precipitation records in China. The same tests have been highly recommended in the literature cited by Sahin and Cigizoglu (2010) to be superior when dealing with series with known physical parameters affecting homogeneity.

2.2.3 Test for randomness and persistence

Procedures used to detect trends and variability require that data should be random and persistence free. Autocorrelation was used to test for such randomness and independence (von Storch and Navarra 1995):

$$r_k = \frac{\sum_{i=1}^{N-k} (x_i - m)(x_{i+k} - m)}{\sum_{i=1}^{N} (x_i - m)^2} \tag{3}$$

where r_k is the lag-k autocorrelation coefficient, m is the mean value of a time series x_i, N is the number of observations, and k is the time lag.

If the calculated r_k is not significant at 5 % level, then the Mann–Kendall test is applied to the original values of the time series. Where the calculated r_k is significant, the data sets were smoothed using a 3-year moving average to reveal more persistent trends (Wheeler and Martin-Vide 1992). The smoothened time series may be obtained as follows:

$$\bar{y}_t = \frac{y_t + y_{t-1} + \ldots.. + y_{t-n-1}}{n} \tag{4}$$

where y is the variable (such as rainfall), t is the current time period (such as the current month), and n is the number of time periods in average.

2.2.4 Rainfall mean characteristics

In this study, annual and monthly mean rainfall data were used to calculate rainfall mean characteristics for the area and for each station. We also used the precipitation concentration index (PCI) to evaluate the varying weight of monthly rainfall to the total amount of rainfall (Li et al. 2010). By doing so, we will understand the monthly heterogeneity of rainfall amounts and its temporal trends. A modified version of PCI by Oliver (1980) in De Luis et al. (2000) was applied:

$$\mathrm{PCI} = 100 \times \frac{\sum_{\mathrm{i}=1}^{12} \mathrm{p}_\mathrm{i}^2}{\left(\sum_{\mathrm{i}=1}^{12} \mathrm{p}_\mathrm{i}\right)^2} \tag{5}$$

where p_i is the rainfall amount of the ith month, calculated for each of the stations and for each of the year (period) being considered. As described in the literature (Ceballos et al. 2004; Nel 2009; Ngongondo et al. 2011), PCI values below 10 indicate a uniform monthly rainfall distribution in the year, whereas values from 11 to 20 denote seasonality in rainfall distribution. Values above 20 correspond to climates with substantial monthly variability in rainfall amounts (Nel 2009 and references therein). A higher precipitation concentration index value also indicates that precipitation is more concentrated to a few rainy months during the year and vice versa (Li et al. 2010; Zhao et al. 2011).

Furthermore, the normalized precipitation anomaly series of annual rainfall (AR) and PCI are used to test for interannual rainfall variability. These were normalized using a procedure proposed by De Luis et al. (2000) and refer-ences therein. For a given station s, in a given year y, the ratio of each value to the mean for the reference period was defined as follows:

$$\begin{aligned}\mathrm{AR}_{\mathrm{sy}} &= \left(\mathrm{R}_{\mathrm{sy}} - \overline{\mathrm{R}}_\mathrm{s}\right)/\overline{\mathrm{R}}_\mathrm{s};\ \mathrm{APCI}_{\mathrm{sy}} \\ &= \left(\mathrm{PCI}_{\mathrm{sy}} - \overline{\mathrm{PCI}}_\mathrm{s}\right)/\overline{\mathrm{PCI}}_\mathrm{s}.\end{aligned} \tag{6}$$

The absolute values of the anomaly series (|AR| and |APCI|) will be used to detect changes in the amplitude of the interannual variability of the series.

2.2.5 Construction of the area-averaged rainfall series for regional trend analysis

This can be achieved by a simple addition or arithmetic averaging of local rainfall values. But for this study, the original monthly precipitation series were converted to standardized monthly series (M_{sy}) by subtracting the long-term mean $\left(\overline{R}_s\right)$ from the original monthly values

(R_{sy}) and then dividing by the standard deviation (σ_s) at each station. This process minimizes the problem of highly diverse means and variability and the randomness of the convective process reflected in the individual station totals (Nicholson 1986). The normalized monthly rainfall anomaly for a given station was computed as in Eq. (7):

$$M_{sy} = \left(R_{sy} - \overline{R}_s\right)/\sigma_s \tag{7}$$

The area-averaged (regional mean climatology) normalized monthly rainfall anomaly (M_{ry}) for a given region is defined as in Eq. (8):

$$M_{ry} = \left(1/N_j\right)\sum_{s=1}^{N_s} M_{sy} \tag{8}$$

where N_j is the number of regional stations operating in the year j. The use of regional average, in general, provides a time series that demonstrates large-scale climatic processes (Partal and Kahya 2006), making it easier to deal with one index series in a region.

Before using the (M_{ry}) series with confidence for the discussion and analysis of regional month-to-month and year-to-year fluctuations, it has to be demonstrated that it is indeed representative for the region (Kraus 1977; Nicholson 1986; Türkeş 1996). In other words, it has to be shown that spatial variations of (M_{sy}) are small, compared to the temporal variations of the region as represented by (M_{ry}). Kraus (1977) demonstrated that the variance in time can be estimated as follows:

$$v(\text{time}) = \frac{\sum N_j M_{ry}^2}{J-1} \tag{9}$$

where N is the number of regional stations in the year j and J is the number of years of record for the series (M_{ry}). The mean spatial variance between rainfall anomalies within the region is estimated as follows:

$$v(\text{area}) = \frac{n - \sum N_j M_{ry}^2}{n-J} \tag{10}$$

where n, the total number of stations years, is calculated as follows:

$$n = \sum_j N_j = \sum_i J_i \tag{11}$$

The statistical importance of variance estimates (variance in time/variance in area) is determined by the F test (Türkeş 1996).

2.3 Trend analysis

Approaches used for detecting trend in the time series can be either parametric or non-parametric. The most popularly used non-parametric test is the Mann–Kendall (MK) test (Mann 1945; Kendall 1955). It has been widely used for different climatic variables in various trend studies including those of Kampata et al. (2008), Kizza et al. (2009), Ngongondo et al. (2011), Rai et al. (2010), and Nsubuga et al. (2011). We applied the MK test at a significance level of 5 % to study the temporal trends of the following: (a) total annual rainfall and its coefficient of variability, (b) monthly total rainfall, and (c) seasonal total rainfall.

For the purpose of cross-verification, a linear regression test was also carried out to identify whether there is a linear trend by examining the relationship between time and the variable of interest. The complete mathematical description of these methods can be found in CRCCH (2005) and studies mentioned above.

The linear regression test assumes that the data are normally distributed and that the errors (deviations from the trend) are independent and follows the same normal distribution with zero mean. Data were tested for normality using a normal probability plot (Nsubuga et al. 2011). This is a graphical technique for assessing whether or not a data set is approximately normally distributed. Data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this line indicate departures from normality.

Rainfall is one of the main variables that define the climate of a region so its spatial characterization is highly relevant. Spatial patterns of rainfall means, variability, trends, and PCI across the area were investigated using ordinary kriging interpolation method (Ngongondo et al. 2011; De Luis et al. 2000). This method is robust in sparsely sampled regions (Ngongondo et al. 2011 and references therein), and the study area is such an ideal case for such a method. Normalized time series associated with September–October–November (SON), March–April–May (MAM), and annual data were spectrally analyzed using spectral power density embedded in MatLab software package at 95 % significance level.

3 Results and discussions

3.1 Quality control and homogeneity

Most of the stations used in the study had a certain percentage (5–15 %) of missing data. A threshold of not more than 10 % missing data was set for the first step which resulted in the selection of 70 meteorological stations for study. A linear regression method explained in Section 2.2 was then applied to make the series complete. Thereafter only 58 stations, including those with missing data of not more than 5 %, were used for further analysis.

Annual series of rainfall at these stations were tested for homogeneity to reveal the following results. Nine of the stations (Rwashamaire, Kigorobya, Bugoye, Kisomoro, Kyembogo, Kijura Tea Factory, Kyegegwa, Masindi, and Nalweyo Gombolola) were identified by four of the tests as being not homogeneous. Three of the stations (Bumagi, Kabasanda, and Kakumiro Variety T.C) were found to be inhomogeneous by three of the tests. Three stations (Kawanda, King's College Budo, and Nkozi Experimental Farm) were rejected by two of the tests, and only one station (Matete) was found to be inhomogeneous by one test at 5 % significance level. Results show that majority of the station annual series were homogeneous. Stations which were found not to be homogenous by three or more tests at 5 % significance were only analyzed for study at station level and excluded from regional analyses. This decision was based on reasons which can be found in the literature such as Easterling et al. (1996), Peterson et al. (1998a, b), Costa and Soares (2009), Domonkos (2011), and others. Therefore, for further analysis, the following station annual series were not used in generating a regional average rainfall series, namely Bumagi, Kabasanda, Kigorobya, Bugoye, Kisomoro, Kyembogo, Kijura, Masindi, Nalweyo, Kakumiro, Kyegegwa, and Rwashamaire (Table 1).

3.2 Serial correlation

Examination for autocorrelation was applied on annual, monthly, and seasonal series for each of the individual stations and tested for their significance at a 10 % significance level. The 10 % significance was given preference because real inhomogeneities might remain unrecognized at a lower significance level (Tu et al. 2005). Results showed that annual rainfall series data for 14 stations (shown in Table 3) did not come from a random process. The 14 annual series were then exposed to a smoothing process using Eq. (4) so that they can meet the independent identical distribution criteria and thus run the Mann–Kendall test directly.

3.3 Rainfall regimes of annual, seasonal, and monthly rainfall series

3.3.1 Annual rainfall series

The key statistics of the data set used in the study are shown in Table 3. Maximum mean annual rainfall (2,004 mm) was observed on Bumagi Ssese Islands located in Lake Victoria, while the least mean annual rainfall (698 mm) was reported at Butiaba H.M station found along Lake Albert (Fig. 4a). The highest recorded rainfall within the analysis domain occurred at Bumagi (2,636 mm), while the least was recorded at Madu (178 mm). In the 1960s, particularly 1961, at majority of the stations (not shown), above average rainfall was recorded. For example, the highest rainfall for 18 out of the 58 stations occurred before 1960. The lowest

Table 1 Stations that have been rejected by different homogeneity tests

Rainfall station	Test for randomness	von Neumann ratio	Cumulative deviations			Bayesian procedures	
	$r1$	V	$Q/n^{-0.5}$	Year Δ	$R/n^{-0.5}$	U	A
Bugoye	*0.68*	*0.6*	*2.0*	1964	*2.1*	*0.98*	*4.61*
Bumagi Ssese	0.18	1.5	*1.3*	1962	*1.6*	*0.54*	*3.28*
Kabale meteorological station	0.10	1.7	0.9	1956	1.1	*0.43*	*2.38*
Kabasanda	*0.27*	1.9	*1.4*	1964	*1.5*	*0.67*	*3.44*
Kakumiro Variety T.C	0.04	1.9	*1.4*	1968	1.4	*0.59*	*3.25*
Kawanda Research station	0.14	1.7	*1.3*	1960	*1.3*	*0.45*	2.37
Kigorobya	0.76	*0.7*	*1.4*	1961	*1.5*	*0.50*	2.31
Kijura Tea Factory	0.22	*1.2*	*1.4*	1961	1.4	*0.88*	*5.64*
King's College Budo	0.19	*1.4*	*1.1*	1973	*1.4*	0.38	*2.78*
Kisomoro	0.81	*0.2*	*2.1*	1964	*2.1*	*1.67*	*9.54*
Kyegegwa	0.18	*1.4*	*1.1*	1956	1.14	*0.52*	*3.26*
Kyembogo Farm	0.19	1.7	*1.6*	1967	*1.6*	*0.74*	*3.75*
Masindi meteorological station	*0.73*	*0.5*	*1.7*	1961	*1.8*	*0.63*	*3.01*
Matete Gombolola	0.15	*0.4*	1.0	1975	*1.3*	0.09	1.23
Nalweyo Gombolola	*0.88*	*0.2*	*2.4*	1961	*2.4*	*2.11*	*10.3*
Nkozi Experimental Farm	*0.24*	2.0	*1.5*	1960	*1.9*	0.53	2.56
Rwashamaire	*0.25*	1.9	*1.5*	1964	*2.2*	*0.55*	*3.29*

Italicized figures show results that are not homogeneous at 5 % significance level recorded values are more concentrated in the 1950s (16) and 1970s (21). This is in agreement with Nicholson (2000), finding below average rainfall in equatorial latitudes in the 1950s and 1970s and a reversed pattern in the 1960s.

3.3.2 Monthly rainfall series

Analysis shows that Bumagi Ssese station had the highest mean monthly rainfall in most of the months, followed by Nyabyeya and Kisomoro in the analysis domain (Table 2). On the other hand, Butiaba H.M meteorological station experienced the lowest mean monthly rainfall in the majority of the months. Much of this low rainfall is recorded in the months of September to February at Butiaba. January and February are the months in Butiaba having more than 100 % coefficient of variability, which signifies high variability in rainfall. A summary of mean monthly rainfall with the corresponding coefficients of variation and station is shown in Table 2. It is evident from the table that months with high mean rainfall have low coefficients of variations while months with low mean rainfall have high coefficients.

A close look at the series of the stations Bumagi and Butiaba reveals a contrasting distribution pattern despite the fact that both stations lie close to a lake. Comparison of mean annual rainfall at the two stations reveals that Butiaba recorded rainfall close to three times less than what was received at Bumagi station during the analysis period (Table 3). The distribution of rainfall recorded at Butiaba station show a fairly distributed rainfall pattern throughout the year (Fig. 2). On the other hand, the records for Bumagi Ssese show a distribution which brings out two seasons of high rainfall and also seasons of low rainfall distinctively (Fig. 2). Both stations recorded high peak rainfall in April and received a considerable amount of rainfall every month.

3.3.3 Seasonal rainfall series

Seasonality of rainfall has been described through the monthly rainfall total as a percentage of the total annual rainfall (Nel and Sumner 2006; Nel 2009). Results indicate that annual rainfall in the Albert–Victoria area is seasonal, with 39 and 37 % of the annual rainfall occurring in MAM and SON seasons, respectively. On average the MAM and SON totals accounted for 76 % of the mean rainfall in the water management area. Evidence of this seasonality was also reported by Ogallo (1984), Basalirwa (1995), and Nicholson (1996) and later used by Phillips and McIntyre (2000) to delineate Uganda into sites of uni- and bimodal rainfall distribution patterns. Beltrando (1990) attributed this distribution pattern to the seasonal movements of the ITCZ. The area experienced a bimodal seasonal distribution of rainfall, with maxima occurring 1 month after the two transitional seasons (Fig. 3) marked with two (long and short) rainy seasons (Beltrando 1990).

Our analysis revealed that April recorded the highest percentage of rainfall (15 %), followed by October and November with 13 and 12 %, respectively, towards the annual rainfall amount for the region (Fig. 3). The months

Table 2 Summary of mean monthly maximum and minimum rainfall with their corresponding coefficient of variation at a station

Variable	Mean maximum rainfall	Coefficient of variation (%)	Station	Mean minimum rainfall	Coefficient of variation (%)	Station
January	117	50	Bumagi	16	111	Butiaba
February	127	59	Bumagi	22	106	Butiaba
March	206	39	Bumagi	61	64	Butiaba
April	322	28	Bumagi	57	47	Kyegegwa
May	308	34	Bumagi	56	89	Lyantonde
June	149	45	Bumagi	16	125	Rwoho
July	118	49	Nyabyeya	17	102	Kiteredde
August	163	39	Nyabyeya	37	74	Katera
September	188	34	Nyabyeya	67	54	Butiaba
October	222	45	Kisomoro	77	58	Butiaba
November	196	52	Bumagi	72	82	Butiaba
December	164	55	Bumagi	7	68	Bakijulula
Annual	167	18	Bumagi	58	22	Butiaba
DJF	139	33	Bumagi	22	80	Butiaba
MAM	278	24	Bumagi	57	42	Butiaba
JJA	169	20	Kakumiro	25	69	Lwengo
SON	186	29	Kisomoro	58	22	Butiaba

Table 3 Spatial distribution, mean rainfall, rainfall variability, and basic statistical characteristics of selected rainfall stations in the Albert–Victoria water management area in Uganda

Rainfall station	Mean annual rainfall	Highest rainfall (mm)	Lowest rainfall (mm)	Slope	*t*	PCI	CV (%) Rainfall	CV (%) PCI	Rainfall (*Z*)	PCI (*Z*)
Bakijulula	1,207	1,622	946	3.8	1.15	10	14	8	1.21	0.03
Bale Gombolola	1,295	2,348	802	14.9	*3.7*	10	21	11	*4.39*	−1.28
Bugaya	1,324	2,010	995	1.9	0.53	10	16	10	0.89	−0.21
Bugiri	1,388	2,252	765	−1.9	−0.24	10	26	8	−0.02	−0.47
Bugoye	1,035	1,401	676	−10.2	−3.00	10	20	30	*−2.03*	0.69
Bukuya	1,047	1,517	112	−1.9	−0.42	10	26	32	0.31	1.16
Bumagi Ssese	2,004	2,636	1,293	11.2	1.88	10	18	10	*2.78*	−0.51
Bushenyi	1,278	1,854	934	1.3	0.26	10	17	9	0.84	0.54
Buta	1,094	1,863	544	−16.8	*−3.17*	10	29	12	*−4.2*	0.15
Butemba	1,113	1,436	395	−0.12	−0.04	10	19	13	0.51	−0.19
Butenga	999	1,772	620	2.19	0.44	10	27	12	0.67	−1.32
Butiaba H.M	698	1,077	400	3.50	1.36	10	22	15	1.08	0.82
Buvuma Island	1,596	2,132	1,077	8.81	1.97	10	17	13	*1.69*	*−2.30*
Entebbe Veterinary Lab	1,602	2,324	1,097	−1.15	0.22	10	17	11	0.6	*−2.12*
Kabale meteorological station	1,017	1,313	768	5.66	2.10	10	15	11	*1.72*	−1.18
Kabasanda	1,323	1,947	953	−11.5	*−2.76*	9	20	4	*−2.16*	*−4.71*
Kakumiro Variety T.C	1,315	1,780	926	8.44	2.58	10	15	11	*2.15*	−1.63
Kalagala	1,174	1,488	761	−3.08	−0.98	9	13	22	−0.58	1.22
Kalungu	1,049	1,597	743	−8.01	*−2.46*	10	19	19	*−3.72*	0.77
Kasagama	734	1,109	328	−1.51	−0.56	10	22	32	−0.48	−0.37
Kassanda	851	1,087	561	−4.5	−1.68	10	19	13	−0.62	−1.36
Katera Sango Bay	1,184	1,530	873	1.15	0.34	11	15	10	0.31	*−1.74*
Katigondo WFM	1,080	1,486	844	−1.48	−0.47	10	16	10	−0.57	*−1.81*
Kawanda Research station	1,256	1,737	820	8.73	2.02	9	20	9	*2.09*	*−1.84*
Kawungera	922	1,688	423	15.9	*4.13*	10	30	16	*4.06*	−1.08
Kigorobya	1,145	1,550	530	7.78	1.78	10	21	11	*1.83*	−0.78
Kijura Tea Factory	1,487	2,024	520	14.5	3.64	10	18	19	*3.52*	−1.19
King's College Budo	1,225	1,656	497	−5.83	−1.54	9	18	16	−0.86	0.45
Kisomoro	1,444	1,843	822	−18.9	−4.01	10	17	15	*−4.36*	1.39
Kitabi Seminary	1,341	1,788	1,113	2.89	0.98	9	13	5	1.47	−0.47
Kitalya Prison Farm	1,137	1,465	844	−3.74	−1.11	10	15	8	−0.85	−0.82
Kiteredde Mission	1,029	1,600	572	−3.38	−0.83	11	22	17	−0.95	1.19
Kyegegwa	1,303	1,647	198	−9.32	−2.78	10	27	24	*−2.4*	*1.76*
Kyembogo Farm	1,303	1,923	963	−9.32	−2.78	10	17	15	*−2.77*	1.39
Lwemiyaga	914	1,622	669	4.04	1.00	10	24	13	0.62	*2.65*
Lwengo Gombolola Headquarters	895	1,253	314	−5.83	−1.54	11	22	25	−1.27	−0.48
Lyantonde Dispensary	793	1,287	529	−11.8	*−4.45*	10	24	11	*−2.79*	1.09
Madu	888	1,239	178	−3.07	−0.82	10	21	16	0.34	0.14
Masaka Forest station	1,159	1,691	900	10.6	*3.12*	10	18	13	*2.68*	−1.38
Masindi meteorological station	1,315	1,584	1,097	5.03	2.39	10	10	9	*1.95*	*−1.71*
Matete Gombolola	861	1,576	568	1.82	0.51	10	21	11	−1.29	*1.96*
Mbarara meteorological station	955	1,522	696	3.61	1.19	10	18	9	*1.69*	−0.95
Moniko Estate	1,494	1,972	1,103	5.45	1.52	9	15	8	1.45	−0.99
Mpigi Agricultural Station	1,258	1,712	925	−2.66	−0.71	9	16	10	−0.85	0.98
Mubende second order station	1,224	1,647	766	−5.69	−1.80	10	15	10	*−1.95*	−0.48
Mugalike W.F.M	1,281	1,651	701	10.6	*3.43*	10	17	14	*3.09*	−0.99

Table 3 (continued)

Rainfall station	Mean annual rainfall	Highest rainfall (mm)	Lowest rainfall (mm)	Slope	*t*	PCI	CV (%) Rainfall	CV (%) PCI	Rainfall (*Z*)	PCI (*Z*)
Mukono Agricultural Station	1,384	2,098	912	−10.5	−1.49	9	25	9	−1.39	−1.36
Nakabango	1,223	1,888	785	−2.15	−0.56	10	18	11	0	−0.39
Nalweyo Gombolola	1,219	1,661	951	13.1	6.60	10	15	12	*4.35*	−0.65
Namanve	1,348	2,220	944	3.64	0.84	9	19	9	0.99	0.19
Namungo	1,170	1,564	749	1.71	0.63	10	13	11	0.42	−1.78
Ngongwe Coffee Nursery	1,501	2,027	940	−1.97	−0.39	9	16	23	−0.24	0.85
Nkozi Experimental Farm	1,086	1,503	728	4.16	1.42	10	16	11	1.57	−1.33
Nyabirongo	1,135	1,422	410	2.58	0.75	10	17	17	0.09	0.74
Nyabyeya	1,518	2,145	1,125	−4.34	−1.03	10	15	12	−0.95	−1.44
Rwashamaire	1,010	1,228	709	*−3.02*	−1.32	9	12	13	*−1.74*	1.12
Rwoho Forest station	1,059	1,606	669	1.13	0.23	10	21	9	0.69	*2.64*
Sembabule	810	1,159	501	−2.43	−0.91	11	19	11	−0.74	1.04

Italicized figures indicate significant values at 5 % level. Italicized names show station data which have serial correlation

of June and July recorded the lowest percentages of rainfall (5 %), while January recorded the second lowest of 6 % in the Albert–Victoria region. However, at the level of a water management zone, June and July's monthly percentage of total rainfall is 5 and 4 %, respectively (Fig. 3). The rainfall of the wettest month (April) is three times the rainfall received in January, June, and July (Fig. 3). As observed by Martin-Vide (2004), the occurrence or not of one of these high amounts can change the character (dry or rainy) of any given month, season, or year. This can lead to considerable uncertainty in the average pluviometric contributions, which in turn has environmental and social repercussions.

3.3.4 Annual rainfall variability

Measures of variability about the mean are of critical importance to water resources. According to Nel and Sumner (2006), the greater the variability of annual rainfall, the more difficult and expensive management of water resources

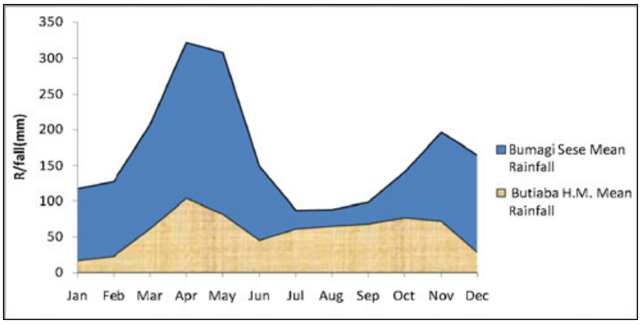


Fig. 2 Distribution of mean monthly rainfall (mm) for Butiaba H.M station and Bumagi Ssese station 1943–1977

becomes. In this study, interannual variability of each station was established using the mean coefficient of variation (CV). The coefficient of variation for the annual rainfall series for the stations is in a range of 12 and 30 % for Rwashamaire and Kawungera stations, respectively (Table 3). The average CV is 19 %, indicating that rainfall does not vary greatly from one year to another. Further still, CV is low for high-rainfall stations and high for low-rainfall stations (Fig. 4b) which, according to Rodhe and Virji (1976), indicates high reliability and low reliability at those stations, respectively.

In the studies of De Luis et al. (2000) and Türkeş (1996), it is noted that areas with coefficients of variation higher than 30 % are likely to have more frequent and severe droughts and floods. Records available do not reveal occasional flooding in this part of Uganda. A closer study of Fig. 4 reveals that a significant decrease in rainfall associated with an increase in interannual variability was detected in the areas commonly referred to as the "dry corridor" of Uganda. This is one of the most densely cattle-populated areas in the country, which demands high quantities of water and grass. Increase in interannual variability poses a threat to the pastoral activity. Rainfall variation is also a threat to Uganda's water resources. The combination of low (high) rainfall and abstraction results in low (high) flow of rivers, low (high) groundwater, and the drying of wetlands. This in turn has detrimental impacts on freshwater ecosystems and water quality. Scarcity of regular water sources will encourage the use of alternative sources like rainwater harvesting to supply drinking water, water for industrial purposes, animal, and wildlife. If such rainfall characteristics are maintained in the future, it may adversely affect the availability of water resources and associated economic activities.

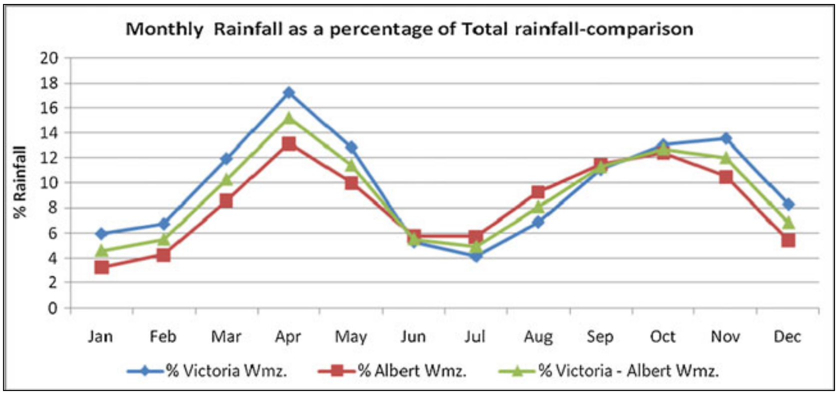


Fig. 3 Seasonality through monthly rainfall totals as a percentage of the total annual rainfall

3.3.5 PCI and coefficient of variation of PCI series

Interannual distribution of rainfall amounts in space and time (Fig. 5) shows that stations in the study area have concentrations values between 9 and 11, which denote a moderate to seasonal rainfall distribution. There are 11 stations located in Vwmz with a stable monthly rainfall regime where the mean PCI<10 (Table 3). The study does not reveal any evidence of stations with high concentration in the regime, i.e., mean PCI>20. There is a close relationship between amounts of rainfall and concentration of indices. For instance, stations with higher mean rainfall had relatively lower concentrations indices and vice versa. Ngongondo et al. (2011) also revealed this characteristic in Malawi, which could partly be explained by the climatic systems such as the ITCZ that are experienced near the equator.

The interannual variability in the distribution of rainfall is low to moderate (Table 3). The coefficients of variation of PCI ranged from a minimum of 4 % at Kabasanda to a maximum of 32 % at Bukuya and Kasagama stations. Rainfall concentration is an important factor affecting erosivity and desertification (De Luis et al. 2000 and references therein) in that it may promote sediment yield transport and thus affect the sustainability of ecosystems like that of Lake Victoria and Lake Albert. A detailed study on trends in the seasonal distribution of rainfall is much needed to assess fully the potential effects of changes in rainfall pattern on ecosystem dynamics. This is important because literature from organizations like WMO, UNEP, and IUCN have found that severe drought can degrade and destroy wetland ecosystem through changes in water availability which causes deteriora-tion in habitats (Enete and Ezenwanji 2011).

Since the precipitation concentration index, like other statistical indices, does not reveal the actual month or season of maximum rainfall, the examination of the station data set is necessary to identify the period (season) of the year with maximum rainfall, if there is any (Michiels et al. 1992). Mean monthly rainfall over a period of 35 years for the stations in the two zones is shown in Fig. 6. This figure demonstrates that there was no single month without rainfall, which is in agreement with the uniform to moderate seasonal distribution derived from the PCI value (Table 3 and Fig. 5). Variability in the region is owed to topography and the presence of Lake Victoria, which exert a great influence to the extent of not having a real dry month (Beltrando 1990). Furthermore, shapes of mean monthly rainfall data for the two zones (Fig. 6) show a bimodal rainfall distribution (depicting the expected seasonality), with a period of maximum rainfall in MAM and SON.

4 Trend in rainfall elements

4.1 Monthly PCI trends

We observe that majority of the stations (34 (59 %)) experienced negative PCI trends, of which 11 (32 %) were significant. Positive trends were recorded at 23 (40 %) stations, of which 4 (17 %) are statistically significant (Table 3). A calculation of the correlation of coefficient (−0.4) revealed that there is a relationship between rainfall trends and PCI trends. For example, PCI values are high in places where rainfall trends are decreasing and variability is increasing (Fig. 7a).

4.2 Annual rainfall trends

Mixed results are detected in the rainfall trends of the stations under the analysis domain. For example, 31 stations have positive trends, of which 8 are statistically significant at 5 % level. Negative trends were found at 26 of the stations and only 6 stations were statistically significant at 5 % level. Furthermore, our analysis shows that annual rainfall at Nakabango station had no trend (see Table 3). The stations Bale Gombolala, Bugoye, Bumagi, Buta, Kalungu, Kawungera, Lyantonde, Masaka Forest station, Kisomoro, Kyembogo, Kijura Tea Factory, and Nalweyo Gombolola had very strong rainfall trends at a 99 % significance level (Fig. 7b).

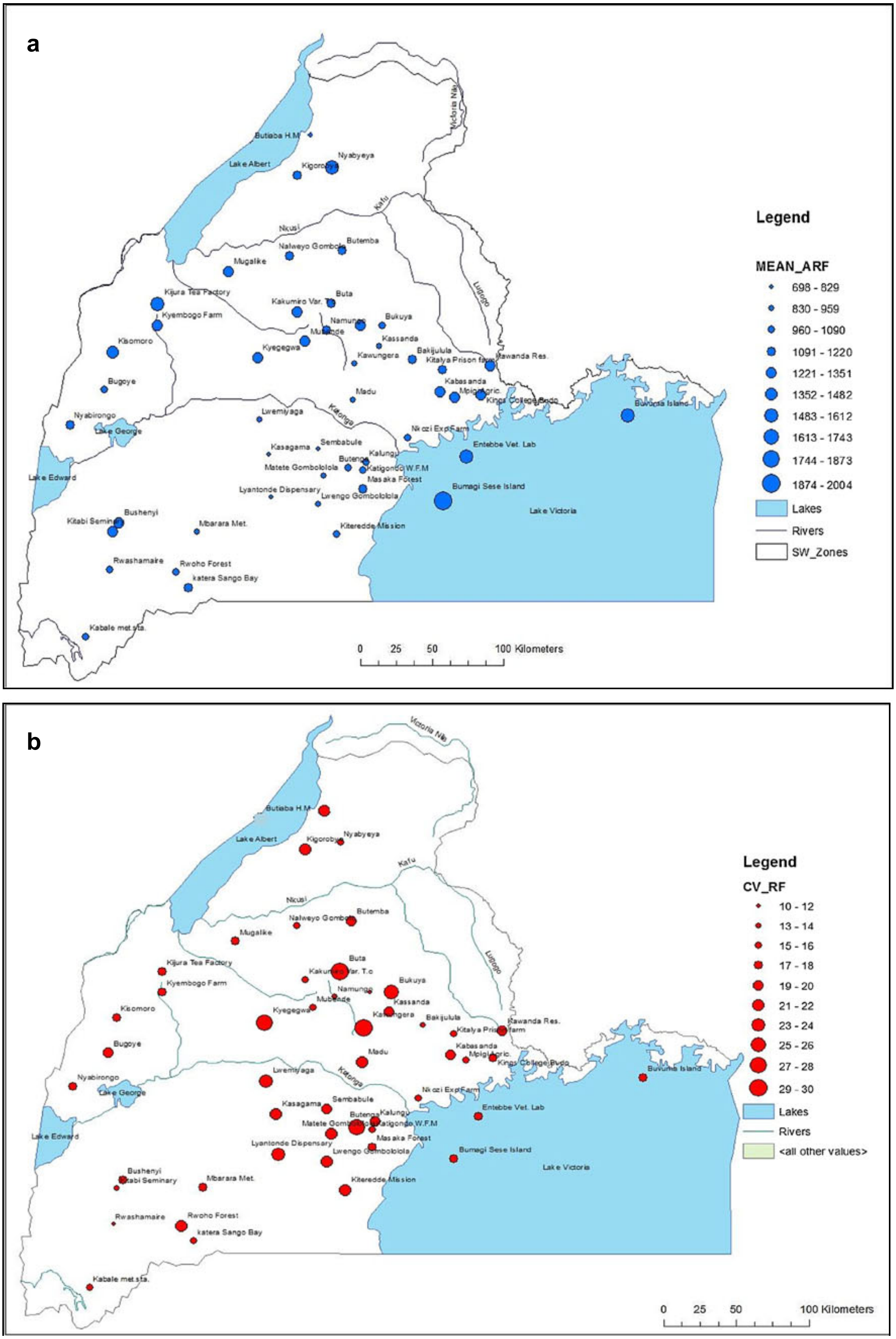


Fig. 4 Annual rainfall of Albert–Victoria water management area (1943–1977). **a** Mean annual rainfall. **b** Spatial distribution of interannual variability of annual rainfall

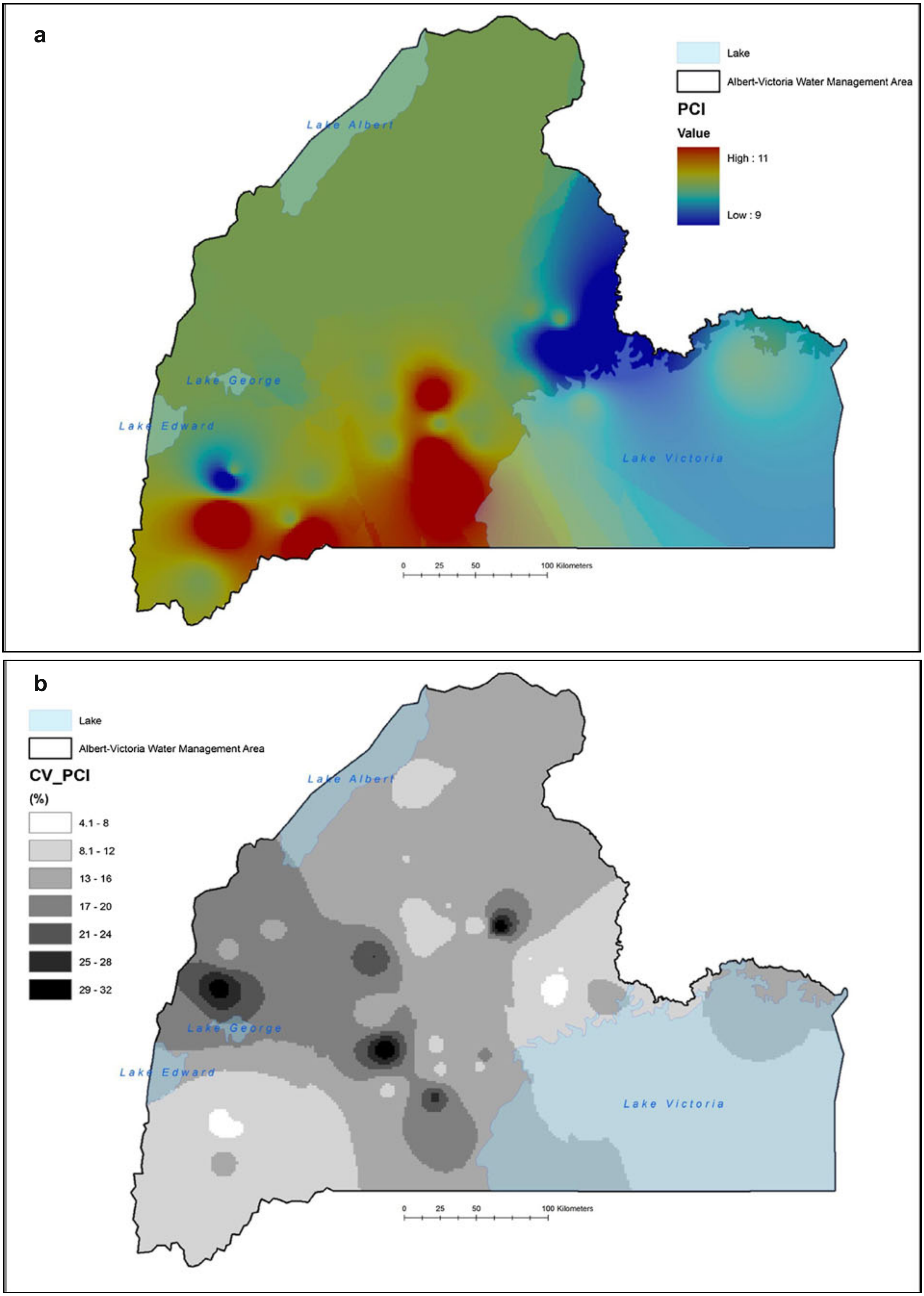


Fig. 5 Annual PCI in the Albert–Victoria region (1943–1977). **a** Mean annual PCI. **b** Spatial distribution of interannual variability of PCI

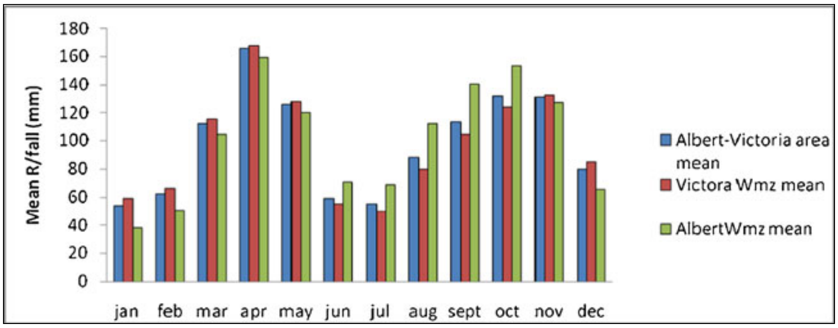


Fig. 6 Distribution of mean rainfall in Albert–Victoria area and Albert and Victoria water management zones in Uganda

4.3 Monthly rainfall trends

Monthly rainfall trends were calculated for January to December. Negative trends (which were not significant at $\alpha=0.05$) were dominant for most of the months. The percentage of trends for the respective months and seasons recorded at the 58 stations is shown in Table 4. The study reveals that August has the highest number of stations (46), which recorded a negative trend, and 9 % of these were statistically significant, followed by September with 40 stations. In January, February, and November, over 40 stations recorded positive trends, of which 20.7 % were significant at 5 % level. The highest percentage of significant (positive and negative) trends for monthly rainfall is in April, May, and August with 15.5 % at the stations. Trends recorded in July in the analysis domain are substantial but not significant. January and February have the least number of stations experiencing significant trends, accounting for only 5.2 %. Results also show that 38 stations experienced negative trends in the MAM season, while 41 stations recorded a positive trend during the SON season (Table 4). The MAM season has 20.7 % of trends recorded as significant, while eight stations exhibit positive significant trends in the SON season. The distribution of December–January–February (DJF), MAM, June–July–August (JJA), and SON trends for the studied stations is shown in Table 4. Trend analysis results of monthly and annual data for the Albert–Victoria water management area are presented in Table 4.

4.4 Regional trend

Based on the procedure described in the construction of the area-averaged series section, 12 monthly series onto which a trend analysis was performed were generated to discover a possible regional behavior. Before using the regional mean normalized series for trend and spectral analyses, variance analysis has been applied to the regional data in order to assess whether regional monthly series adequately represents the region as a whole. Using the ration of the variance estimates in time to the variance estimates in the area, it is apparent that majority of the area-averaged monthly anomalies tend to vary in a statistically coherent manner over the rainfall regions. Tests on the series showed that the geographical variations (v(area)) between different places within the region are small, compared to the temporal variations of the whole region as represented by v(time). Results for the F test for February, July, October, and November are not statistically significant at 5 % level.

Trend analysis results of monthly and annual data for the Albert–Victoria water management area are presented in Table 5. An overall inspection of the table indicates that the regional MK statistic was significant in February and December (shown in italics). The indication from the linear regression test statistic also validates the outcomes of the Mann–Kendall test in the same region.

The yearly fluctuation in total rainfall for the Albert–Victoria water management area is shown in Fig. 8a–e using normalized annual series. A close scrutiny of Fig. 8e shows that a pattern of rainfall recorded was below the regional annual mean for most of the years. The period from 1951 to 1959 was the longest to have recorded rainfall below the annual mean. Nicholson (2000) found out that during the 1950s, the equatorial latitudes of Africa experienced drier conditions contrary to the subtropical latitudes. It is evident from the figure that 1961 to 1964 recorded heavy rainfall, the maximum being recorded in 1962. Reoccurrence of extreme rainfall events like those of the 1960s can result into storm water discharges from combined sewer and surface water overflows, and fluid erosion leading to mobilization of stored runoff of agricultural fertilizers and pesticides, animal wastes, and manure. Heavy rains can also lead to the weakening or failure of dams (Enete and Ezenwanji 2011).

Years of anomalously high rainfall can be identified in all plots such as total annual rainfall for 1947, 1951, 1961, 1962, 1963, and 1972 in Fig. 8. For the MAM rainfall, the years that have high rainfall include 1951, 1952, 1957, 1961, 1963, and 1964, while for the SON rainfall, the years are 1944, 1945, 1951, 1954, 1961, 1962, 1972, and 1975. Despite the few differences in studying rainfall trends, Kizza et al. (2009) also found out that 1951 and 1963 of the MAM season and 1951, 1961, and 1972 of the SON season received anomalously high rainfall. In line with future projections of changes in total annual precipitation in the tropics (IPCC 2007), increased precipitation levels and

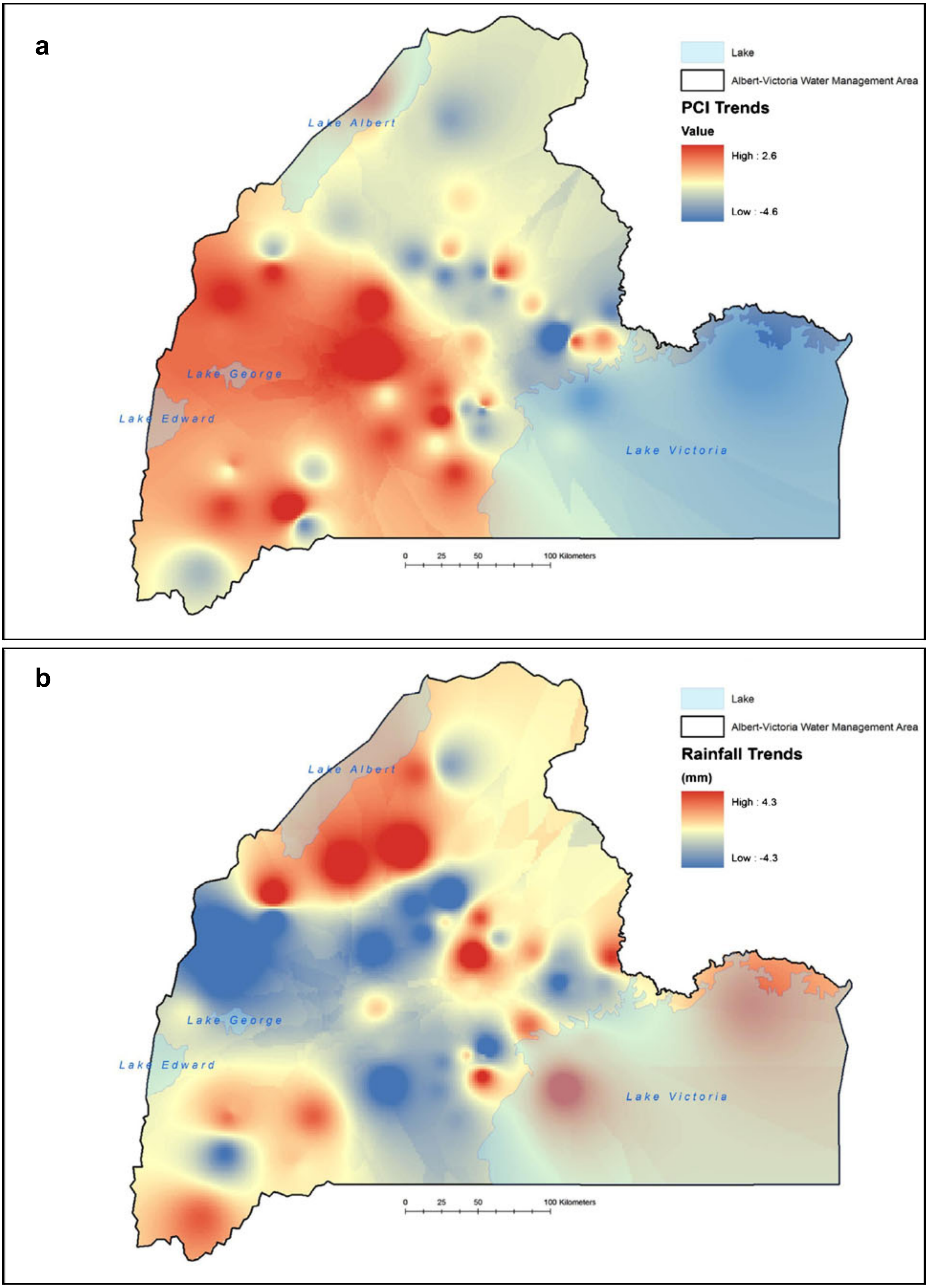


Fig. 7 Observed trends in **a** annual PCI and **b** annual rainfall for the period 1943–1977 in the Albert–Victoria wmz

Table 4 Summary of trend test results for monthly rainfall in Albert–Victoria water management area in Uganda (number of stations=58)

Variable/trend	Number of stations with negative trends	Significant negative $\alpha=0.05$ level	Number of stations with positive trends	Significant positive $\alpha=0.05$ level	Significant trends (%)
January	14	0	41	3	5.2
February	12	0	45	3	5.2
March	25	0	31	5	8.6
April	35	5	22	4	15.5
May	34	6	33	3	15.5
June	25	0	32	4	6.8
July	32	0	24	0	0
August	46	4	11	5	15.5
September	40	4	17	1	8.6
October	30	0	27	6	10.3
November	8	0	49	6	10.3
December	43	2	14	0	3.4
DJF	23	1	34	3	6.8
MAM	38	9	19	3	20.7
JJA	32	2	24	1	5.2
SON	16	2	41	8	17.2
Annual	26	6	31	8	24

extreme variation may cause damage (flooding, soil erosion, mass movement) in highland areas. JJA is the season in Uganda expected to have low amounts of rainfall. However, the plots show that 1943, 1947, 1948, 1958, 1972, 1973, 1974, 1975, 1976, received rainfall far above the average in the JJA period of analysis. A closer exami-nation of the DJF plot shows that for about 18 years, there was less than average rainfall recorded in the first part of the analysis period (before 1962), and thereafter, rainfall records showed mixed fluctuations every year of below and above the mean rainfall (Fig. 8).

The long-term productivity and competitiveness of the Albert–Victoria water management area's economic activity (agriculture) is at risk if increased variability aggravates water availability especially in the central lowlands of the study area. The variability in rainfall could reduce the yields of major staple food such as cereals. A Significant rainfall trend may require shifts to new varieties that are more tolerant to rainfall changes. Interannual or interseasonal rainfall variability represents a major challenge to the rain-dependent agricultural producers and the water managers. This may disrupt the growing conditions and results in crop failures with serious implications for food security, water availability, and agricultural productivity. Rainfall variability also influences the manner in which the factories plan input production and affects both inputs and outputs (Molua 2006).

Spectral analysis using fast Fourier transform shows that the total annual series has peaks at 0.5, 2.6, 6.5, and 10 years. The MAM series has peaks at 3.5, 6.3, and 10.8 years, while the SON series has peaks at 3.8, 6.7, and 10.5 years. Generally the spectral analysis of the time variations asso-ciated with these components (Fig. 9) reveals a major peri-odicity around 3, 6, and 10 years. Other studies have shown that 5–6 years is a major periodicity over East Africa (Beltrando 1990 and references therein; Kizza et al. 2009). This time period has been associated with the ENSO phe-nomenon explained by Nicholson (1996) in Kizza et al.(2009).

5 Conclusions

This study investigated the spatial and temporal characteristics of various rainfall variables at 58 stations in Uganda's Albert–Victoria water management area. We highlight the following key points from the results of the study after basic data quality control and analysis. Most of the stations that were available from the Department of Meteorology had a certain percentage of missing data. We applied quality control steps that enabled us to end up with 58 station series of rainfall. Serial correlation for annual series was high for 14 stations. These series were smoothed so that they can meet the distribution criteria and enable the running of the Mann–Kendal test directly. Majority of the station series were homogeneous; stations which were inhomogeneous were not used in the analysis of the area-averaged (regional) series.

Table 5 Results of regional trend analysis: *t* is the linear regression test statistic and *z* is the Mann–Kendall test statistic

	January	February	March	April	May	June	July	August	September	October	November	December	Annual	DJF	MAM	JJA	SON
Year of max. rainfall	1947	1964	1951	1964	1946	1973	1973	1975	1945	1947	1962	1961	1962	1963	1951	1975	1961
Year of min. rainfall	1965	1946	1943	1976	1966	1971	1971	1973	1968	1957	1943	1943	1956	1946	1943	1960	1957
Slope	0.01	0.01	0.01	−0.0	−0.0	0.0	0.0	0.0	−0.0	−0.0	0.0	0.0	0.0	0.0	−0.0	0.0	−0.0
t	0.85	*2.1*	1.5	−0.8	−1.3	0.9	0.9	0.2	−1.9	−1.8	1.8	*2.4*	1.9	*2.8*	−0.1	0.9	−0.9
z	0.13	*0.2*	0.2	−0.1	−0.1	0.1	0.1	−0.1	0.2	−0.2	0.2	*0.2*	*0.2*	*0.3*	−0.0	0.1	−0.1

Italicized figures indicate significant values at 5 % significance level

Different homogeneity adjustment techniques naturally produce different results, which makes the decision on what technique to use rather difficult (Peterson et al. 1998a, b). However, two different adjustment versions can lead to similar results and improve the reliability of the data for many uses. We found evaluating the breaks detected as well as the attempt to correct the series from artificial steps to be poor because of the lack of metadata support. A homogeneity-adjusted time series is not the same as a pristine time series that is homogeneous without needing adjustments. Many approaches can make average adjustments since one may not be able to de-termine the level of bias a change introduces at a particular station given its site and microclimate (Peterson et al. 1998a, b).

Results show that stations close to Lake Victoria recorded high amounts of rainfall. The rainfall distribution is bimodal, with maximums experienced in the MAM and SON seasons of the year. Annual rainfall is seasonal in that 39 and 37 % occur in the MAM and SON seasons, respectively. Spectral analysis of the time component reveals year periods around 6 and 10 years which is a characteristic of the annual, MAM, and SON series. April recorded the highest rainfall, while January, June, and July recorded the lowest rainfall. Average CV is 19 %, which signifies low variability in the analysis domain. The coefficient of variation is low for high-rainfall stations and vice versa. Interannual variability of rainfall distribution is low to moderate. Analysis also reveals that PCI values lie between 9 and 11 which denote moderate to seasonal rainfall distribution. The coefficient of variation for PCI rainfall series was in the range of 4 to 32 %. Furthermore, 63 % of the stations experienced negative trends and only 32 % were significant. Also noted was the close relationship between rainfall trends and PCI trends. It has also been demonstrated through mean monthly rainfall that there was no single month without rainfall. Results also revealed that 12 stations had very strong trends at 99 % significance level. Non-significant negative trends at 95 % were dominant in various months and seasons recorded in the region.

At a regional scale, positive and non-significant trends of monthly rainfall occurred in the analysis domain, whereas negative trends are noted for the months presumed to be of high rains (Table 5). The increases in rainfall totals for some months (February and December) are also reflected in the DJF significant trends for the area (Table 5). The Albert–Victoria region generally did not reveal significant trends in the mid-twentieth century at 5 % significance level. Empirical studies do not provide information on the causal factors of detected trends. The authors are aware that a 30-year period is not enough to encompass fully any climatic variability signal. Therefore, the observed changes should be considered with caution.

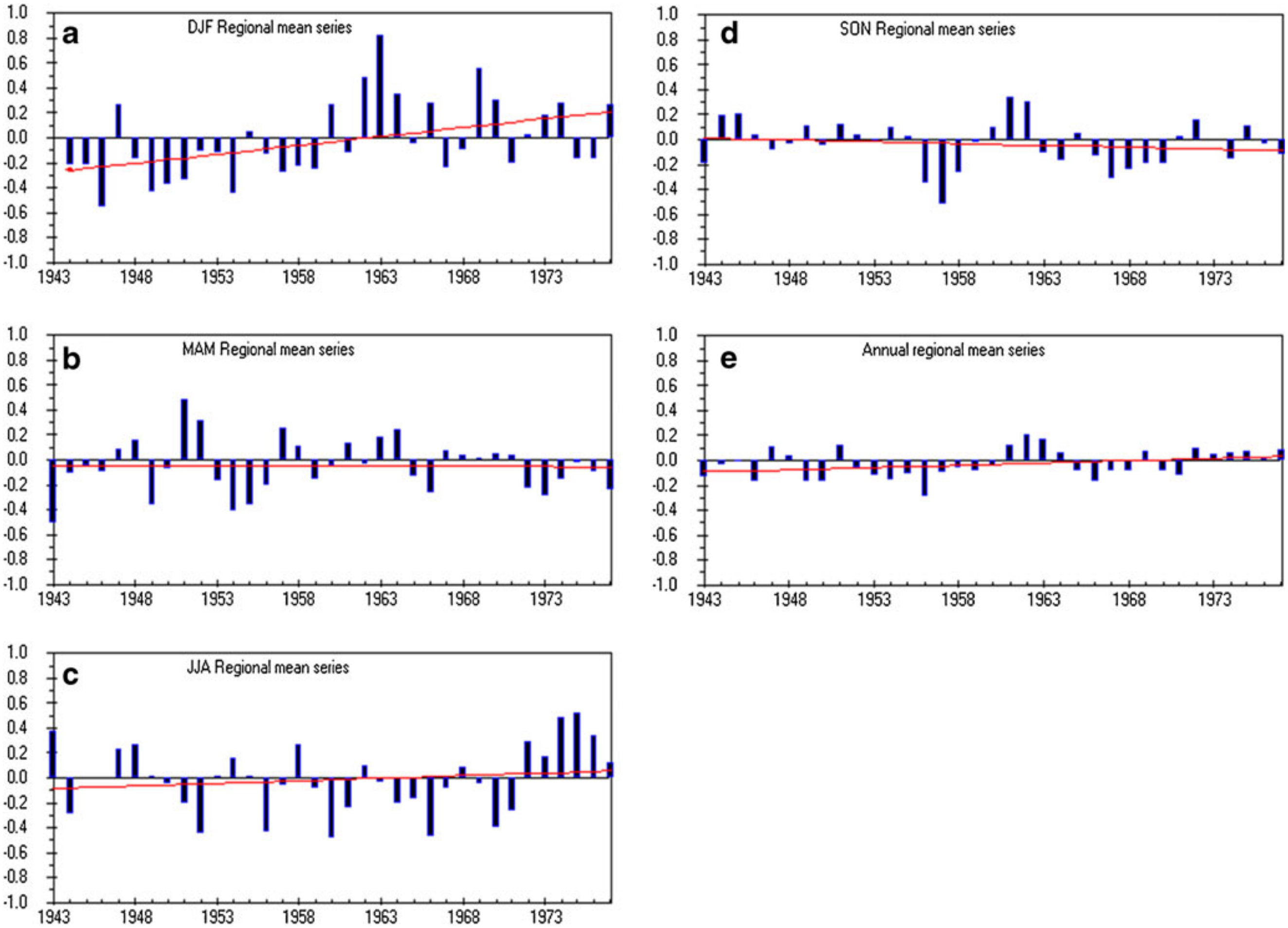
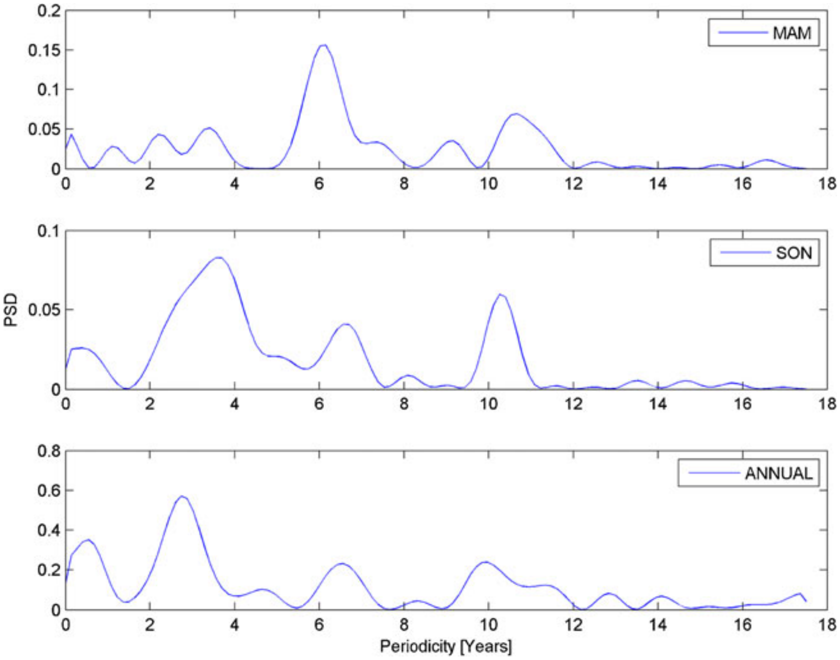


Fig. 8 **a**–**e** The climatology and seasonal mean trend pattern for the Albert–Victoria water management area from 1943 to 1977

Fig. 9 Power density of the normalized regional time series associated with the components for MAM, SON, and annual series



Acknowledgments We would like to extend our gratitude to Caroline Nakalyango (DWD), M. Kizza (MUK), and Adebayo (UP) for the input and contribution to this work. We are also grateful to one anonymous reviewer for the comments that clarified the paper.

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