Asian Journal of Advanced Research and Reports

16(5): 33-61, 2022; Article no.AJARR.86458
ISSN: 2582-3248

Effect of Rainfall and Temperature Variability on Streamflow in Nzoia River Basin, Kenya

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJARR/2022/v16i530473

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/86458

Original Research Article

Received 04 March 2022
Accepted 08 May 2022
Published 19 May 2022

ABSTRACT

Nzoia River Basin is one of the regions in Kenya that is highly vulnerable to climate change making its hydrological regimes highly sensitive to rainfall and temperature variability. The aim of this study is to assess the effect of rainfall and temperature variability on streamflow using long-term observational data from nine meteorological stations and two hydrological stations. Trends are indicators to climatic variability and have been analysed using the parametric test of Linear regression and the non-parametric test of Mann–Kendall. Mann-Kendall statistical test was used to identify statistically significant trends in streamflow, rainfall and temperature. Rainfall and temperature exhibit both increasing and decreasing trends in the basin. Streamflow in Nzoia river regions upstream at Webuye (IDA02) and downstream at Rwambwa (IEFO1) has been slowly rising. There is a positive correlation between streamflow and rainfall indicating that streamflow changes in accordance with rainfall. On the other hand, streamflow is negatively related to temperature. This is understandable given that rainfall is the controlling factor for runoff generation; and higher temperatures are a second order effect usually leading to increased evaporation and transpiration. The results of this study will be useful to policy makers in the development of adaptation plans for effective water resources management in the basin.

Keywords: Nzoia river basin; rainfall; temperature; streamflow; trend analysis.

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1. INTRODUCTION

Global climate change is projected to modify the global hydrologic cycle, impacting streamflow and water availability, and potentially disrupting river discharge regimes [1, 2, 3]. In recent decades, there has been a growing interest in the relationship of climatic variability to hydrological processes and water resources across various temporal and spatial scales to give additional evidence for warming-induced hydrological cycle intensification [4,5,6,7]. Many simulation findings have shown a global rise in streamflow, which is closely related to climate change [8,9,6,7]. Climate variability's feedback on the hydrological cycle, on the other hand, is highly nonlinear, extremely complicated, and less predictable, and it varies significantly within and among hydrometeorological regions [8,7]. In various parts of the world, historical records have revealed considerable declines in streamflow as well as no discernible patterns indicated by hydroclimate models [8,10,11]. Because there is still a lot of uncertainty about regional streamflow trends [10], further research on regional patterns of climate-induced streamflow changes is needed to better understand the multiscale climate–streamflow cascade.

Currie [12] and Probst & Tardy [13], studied mean annual discharge fluctuation of fifty major rivers distributed around the World, showing that the river flow in North America and Europe fluctuated with opposite trends, while it presented a synchronous fluctuation in South America; Williams [14], investigated the nature and causes of cyclical changes in hydrological data of the World, and he detected a correlation between water discharge and sunspots with varying success. Whitfield [15] looked at temperature, precipitation, and streamflow in British Columbia and the Yukon and discovered that streamflow increased throughout the year in the northern part of the research area. Woodhouse [16], and Gedalof et al.[17] employed tree rings to reconstruct historical hydrological data in the Middle Boulder Creek watershed (Colorado, USA) and Columbia river (Washington, USA), and then pinpointed drought years across interannual, decadal, and interdecadal flow regimes. Absalon and Matysik [18] investigated runoff variation in the Upper Oder River basin (Poland) and found that runoffs were decreasing in all cases from 1970 to 2000, but these trends were not significant when using the Student t test; however, runoffs increased with statistical significance from 1991 to 2000. Sen [19] studied riverflow variability in England and Wales by looking at monthly discharge time series from 15 catchments from 1865 to 2002, and discovered that discharges had a strong annual cycle.

Linear regression analysis and Mann Kendall test Statistic (S) were used to analyse streamflow at Nzoia river upstream (Webuye, IDD01) and Nzoia river downstream (Rwambwa, IEFO1) at 5% significance level. Changes in rainfall volume, intensity, and frequency will affect not only the volume of streamflow but also the intensity and frequency of extreme events like floods and droughts. This might have a big impact on how we manage our water resources. Changes in streamflow as a result of changing climatic circumstances will have significant ramifications for water management structure design and regulation. In recent years, assessing the potential impact of climate change on hydrological regimes has become critical for assuring proper water management strategies and building appropriate adaptation plans that take climate-related risks into account during the planning process. Variations in rainfall and temperature affect streamflow (climate change). The Nzoia River Basin has experienced serious water issues such as flooding, droughts, and water scarcity, as well as uncoordinated water regulation, pollution, and aquatic ecology degradation, all of which have had a negative impact on socioeconomic development; however, streamflow research in the Nzoia River Basin is rarely reported. Based on long-term observational data from nine meteorological stations and two hydrological stations in the Nzoia River Basin between 1970 and 2016, this research seeks to analyze the effect of rainfall and temperature on streamflow and the relationships between these variables.

2. MATERIALS AND METHODS

2.1 Study Area

The Nzoia River is Kenya's second largest river, with a discharge of aproximately 118 m3/s or 3,721 million cubic meters per year and a length of 334 kilometers. Between longitude 34° E–36° E and latitude 00° 00′ N–1015′ N the river basin covers 12,959 km2 (Fig. 1).

The population of the basin is estimated to be around 3.7 million people [20]. The basin is separated into three physiographic regions:

highlands, which include the Cherengani hills and Mount Elgon; upper plateau, which includes Eldoret and Kitale; and lowlands, which include the Budalang floodplains of Busia. At an altitude of approximately 4,300 m a.m.s.l. (above mean sea level) the main river originates in the Cherengani hills and Mount Elgon highgrounds. The climate of the basin is tropical humid, however it differs per county due to the basin's varied landscapes and elevations. Each year, there are four rainfall seasons: two rainy seasons and two dry seasons. Between March and May, there are long rains, while between October and December, there are short rains. Temperatures in the highground areas of Cheranganyi and Mt. Elgon range from (4 °C -16 °C) and the semi-arid lowlands of Bunyala (16 °C -28 °C). The geology of the basin is characterized by metamorphic basement rocks, volcanic rocks and quaternary sedimentary rocks. Clay soils make up 77%, loams 9% and sandy soils14% of the basin as described by Odwori [21].

2.2 Data Sources

Streamflow data used in this study were high quality records of mean daily discharge from 2 gauging stations; Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1) as shown in Table 1.

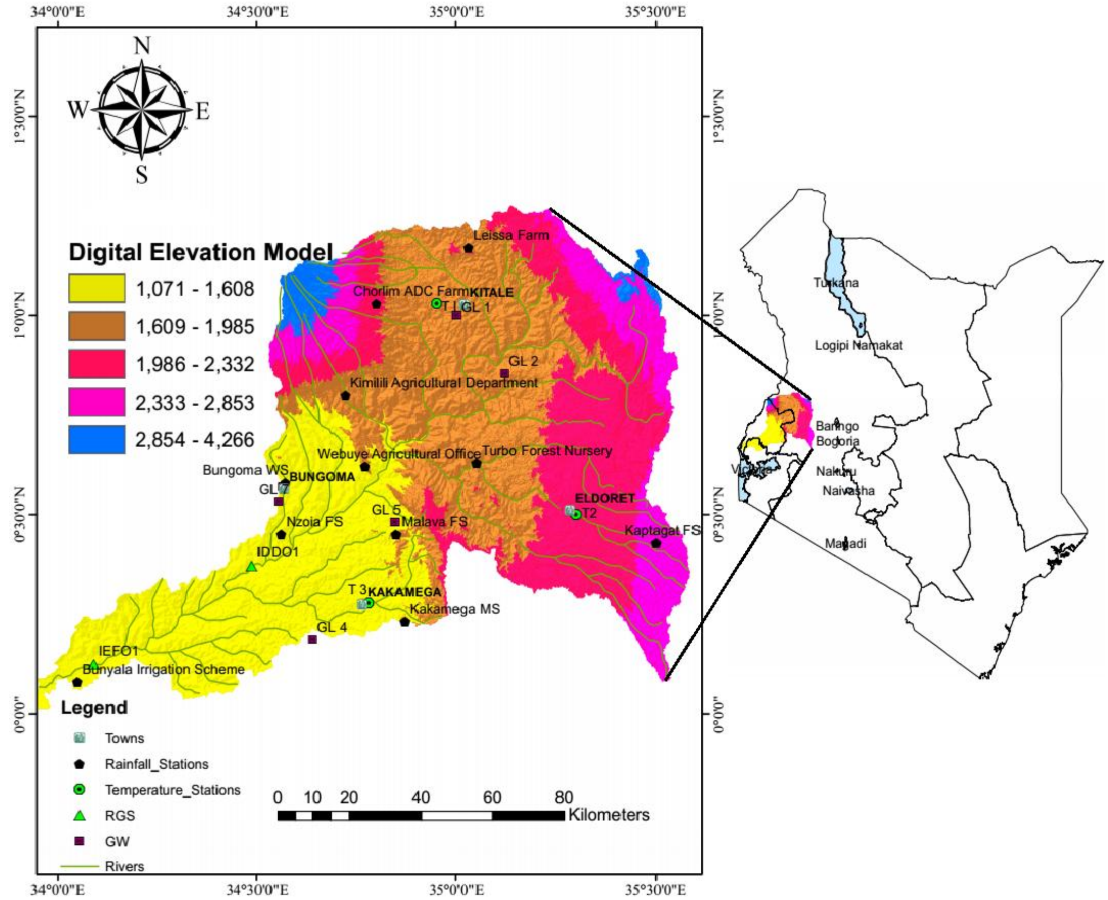


Fig. 1. Map of Nzoia River Basin, Kenya

Table 1. Streamflow regular gauging stations selected for study in Nzoia River Basin, Kenya

Station ID (in Fig.1)	Station Wrma Code	Station name	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (a.m.s.l)
STMF I	IDDO1	Nzoia river upstream at Webuye	0.617	34.767	1494
STMF 2	IEFO1.	Nzoia river downstream at Rwambwa	0.127	34.071	1120

The three main criteria for station selection [22] were: (a) no substantial influence by water withdrawals for hydropower or other water-use purposes; (b) spatial independence between station records; and (c) at least 30 years of continuous and complete observations. The data was analyzed for the period 1974 to 2017, covering a period of 43 years. The streamflow gauging stations are all operated by the Water Resources Management Agency (WRMA). Monthly rainfall and temperature data were obtained from the Kenya Meteorological Department (KMD), Nairobi, Kenya [23].

Monthly rainfall data were collected for six stations; Leissa Farm Kitale, Kaptagat Forest Station, Kakamega Meteorological Station, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp with data covering 31 years period from 1970 to 2001 from the Kenya Meteorological Department (KMD), Nairobi, Kenya as shown in Table.2. The rainfall data are expressed in millimetre (mm). Monthly maximum and minimum temperature data was collected for three stations; Kitale and Kakamega meteorological stations with data covering 35 years period from 1979 to 2014 and Eldoret international airport, 15 years period from 1999 to 2014 from the Kenya Meteorological Department (KMD), Nairobi, Kenya as shown in Table.3. Temperature data are expressed in degree Celsius (^{0}C).

Weather station selection was made according to their quality, length and period covered and ensuring they possess simultaneous records of meteorological data. Daily values were averaged in order to obtain monthly temperatures for each of the stations. Mean annual temperatures were obtained by averaging the monthly values for each year. Further information regarding the measurement uncertainty is given in Roman et al. [24]. Some necessary data quality control tests were performed before data were used. All the variables were checked against empirical upper and lower limits, systematic errors, which resulted from different sources (e.g., archiving, transcription and digitalization). This can include non-existent dates, etc. Further details about these tests can be seen in El Kenawy et al. [25]; Bilbao et al. [26]; Miguel et al. [27] and Roman et al.[24]. Instrumentation and alteration of surrounding land cover might create non-homogeneity and/or inconsistencies in meteorological data recordings [28].

Both published literature and primary data collected from different sources and field observations have been used in this study to assess the eefect of rainfall and temperature variability on streamflow based on long-term observational data from nine meteorological stations and 2 hydrological stations between 1970 and 2016.

Table 2. Rainfall Stations with 31 years data covering the period 1970 to 2001 selected for study in Nzoia River Basin, Kenya

Station ID (in Fig.1)	Station Wmo Code	Station name	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (a.m.s.l)	Mean Annual Rainfall (mm/year)
		Upper Catchment				
R I	8835039	Leissa Farm Kitale	1.17	35.03	1968	995
R 2	8935010	Kaptagat Forest Station	0.43	35.50	2624	1212
		Middle Catchment				
R 3	8934028	Kakamega Meteorological Station	0.23	34.87	1804	1982
R 4	8934119	Webuye Agricultural Office	0.62	34.77	1681	1532
		Lower Catchment				
R 5	8934139	Bunyala Irrigation Scheme	0.08	34.05	1232	1099
R 6	8934140	Kadenge Yala Swamp	0.03	34.18	1256	1095

Table 3. Temperature Stations selected for study within Nzoia River Basin, Kenya

Station ID (in Fig.1)	Station Wmo Code	Station name	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (a.m.s.l)
T I	8834098	Kitale Meterological Station	1.03	34.95	1825
T2	8935115	Eldoret International Airport	0.50	35.30	2120
T 3	8934096	Kakamega Meteorological Station	0.28	34.78	1501

2.3 Methodology

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. For trend detection, different researchers have employed various techniques. Change detection approaches for hydrologic data are described by [29]. In general, the magnitude of a time series' trend is determined using either Regression analysis (parametric test) or Mann–Kendall test and Sen's slope method (non-parametric test).

2.3.1 Linear regression analysis

A parametric model, linear regression analysis is one of the most often used approaches for detecting a trend in a data series. By fitting a linear equation to the observed data, this model builds a link between two variables (dependent and independent). First, the data is examined to see if there is a link between the variables of interest. This can be accomplished with the use of a scatter plot. Linear regression models will not be beneficial if there appears to be no relationship between the two variables. The correlation coefficient, which runs from -1 to +1, is a numerical measure of the relationship between the variables. A perfect match is indicated by a correlation coefficient of ± 1. A value around 0 indicates that the two variables have a random, non-linear connection. The following equation describes the linear regression model in general:

$$Y = mX + C$$

Where, Y is the dependent variable, X is the independent variable, m is the slope of the line and C is the intercept constant. The coefficients (m and C) of the model are determined using the Least-Squares method, which is the most commonly used method, t-test is used to determine whether the linear trends are significantly different from zero at the 5% significance level.

2.3.2 Mann-Kendall test and sen's slope method

Mann–Kendall test [30,31] is a non-parametric test for randomness against time for correlation and has, in the last half decade, become useful in water resources research for examining significance in trends within river basins [32-36]. The Non-Parametric Mann–Kendall (MK) test [30,31] and rank correlation method [36] were used to study the trend analysis because of their powerful nature over other methods in hydrological analysis [37]. The MK test is commonly applied to detect significant trends in hydro-meteorological time series and is highly recommended by the World Meteorological Organization (WMO) [38-41]. The MK test is based on the null hypothesis (H0), which states that there is no trend, the data are independent and randomly ordered, and is checked against the alternative hypothesis (Ha), which claims that there is a trend [42]. Sen's slope (SS) estimator was used to predict the genuine slope (change per unit time) [43]. The Mann-Kendall statistics (S) are calculated using the formula [36,30,43].

2.3.3 Pearson's correlation coefficient

The Pearson correlation coefficient r (also known as the Pearson product-moment correlation coefficient) is a test statistic that determines the statistical relation, or association, between two continuous variables. The test statistics were established by Karl Pearson (1948) based on a related idea proposed by Sir Francis Galton in the late 1800s [44]. Because it is based on the method of covariance, it is known as the best method for quantifying the relationship between variables of interest. It provides information on the magnitude and direction of the relationship. Pearson's Correlation Coefficient assumes that: cases should be independent to each other; two variables should be linearly related to each other; the residuals scatterplot should be roughly rectangular-shaped [45,46,47]. The range of coefficient values is +1 to -1, with +1 indicating a perfect positive association, -1 indicating a perfect negative relationship, and 0 indicating no relationship. It is independent of the unit of measurement. For example, if one variable's unit of measurement is in inches and the second variable is in quintals, even then, Pearson's correlation coefficient value does not change. Correlation of the coefficient between two variables is symmetric. This means between X and Y or Y and X, the coefficient value of will remain the same.

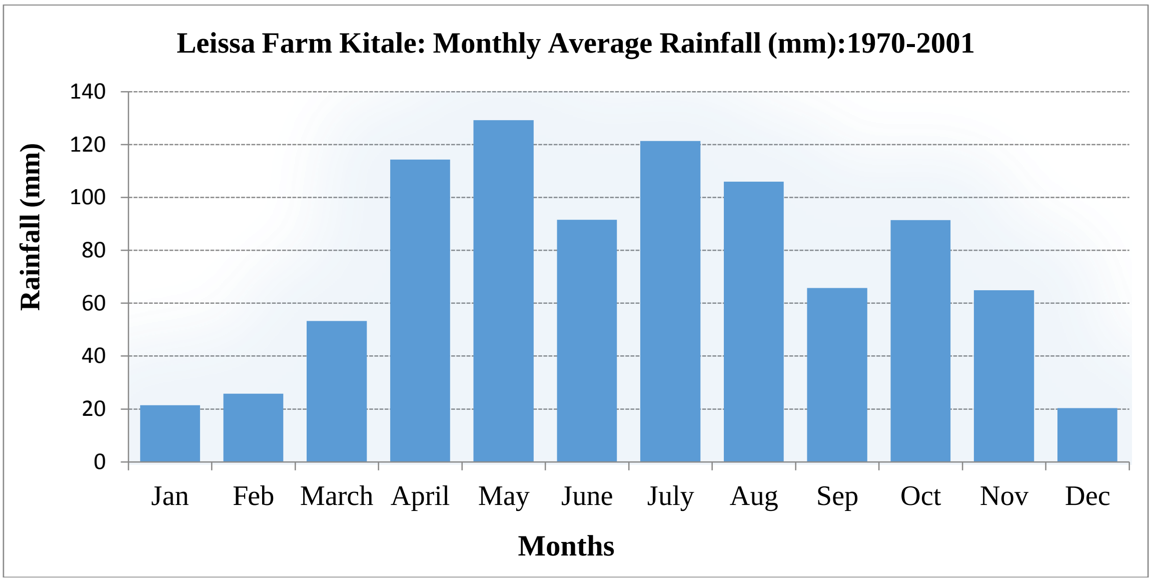
3. RESULTS AND DISCUSSION

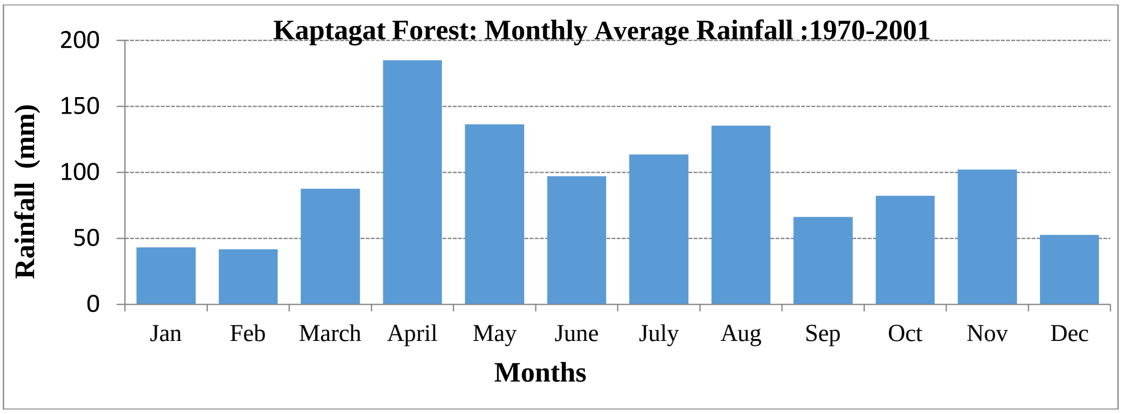
3.1 Changes in Climate: Rainfall and Temperature trends in Nzoia River Basin

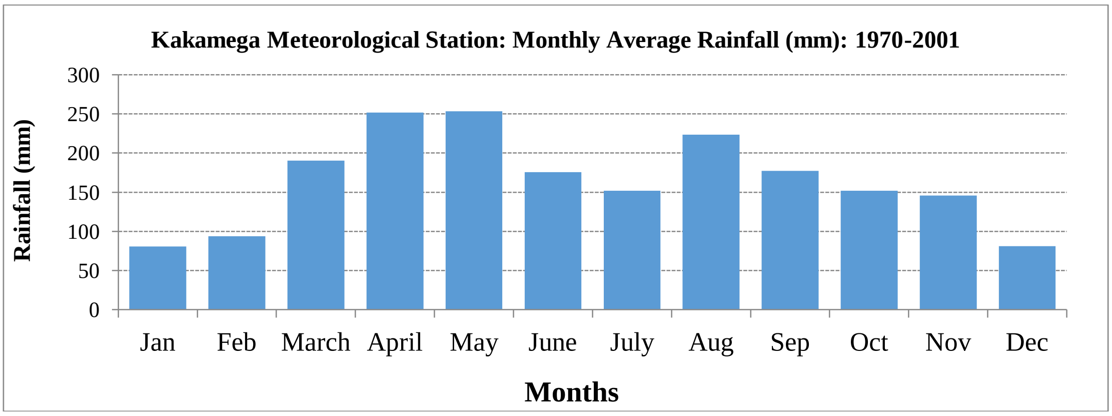
3.1.1 Trends in monthly and annual rainfall

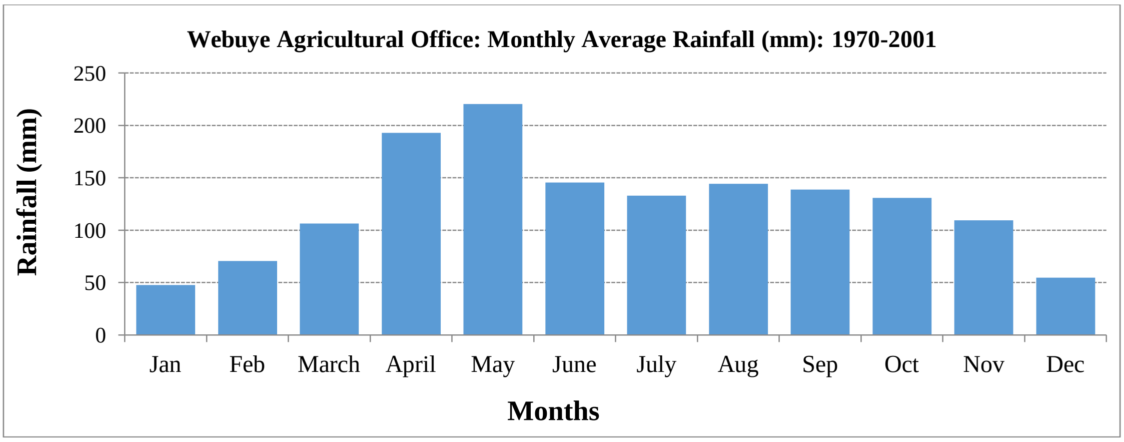
The Rainfall stations used in this study are shown in Table: 2. Fig. 2 shows monthly rainfall distribution for Leissa Farm Kitale, Kaptagat Forest Station, Kakamega Meteorological Station, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp with 31 years data covering the period 1970 to 2001. These are the Rainfall stations in close proximit of the two hydrological stations. A better understanding of the rainfall pattern is important for formulating efficient water resource management and climate change adaptation policies.

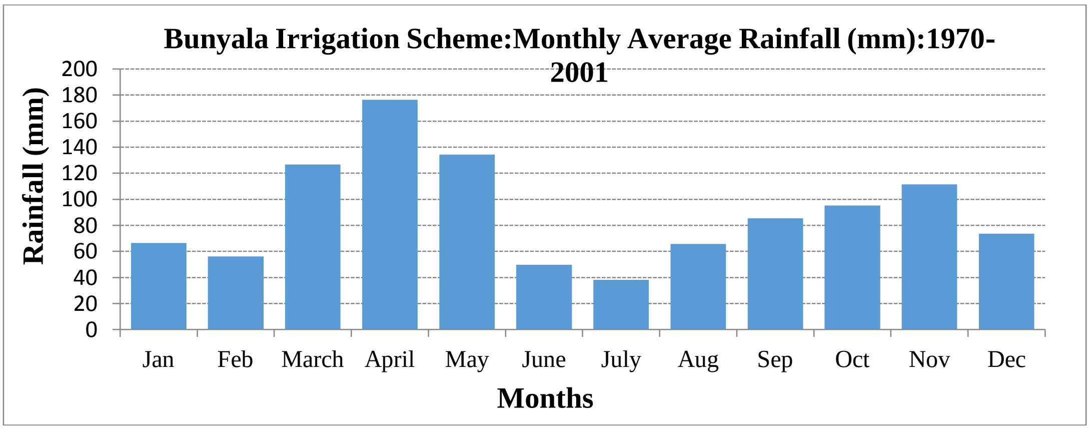
Leissa farm recorded a monthly mean rainfall of 82.27 mm in the period 1970 - 2001. The region experienced a major peak in May (139.92 mm) after which monthly rainfall gradually decreased with a minor peak in July and August. From there, the monthly rainfall continued to decrease until a minimum was reached in December (20.90 mm) and January for the next cycle to begin. Kaptagat Forest Station showed from 1970 to 2001 a monthly mean rainfall of 103.04 mm. The station experienced a major peak of 195.61 mm in April, followed by other minor peaks in May and August. From then, the monthly rainfall continues to decrease until a minimum of 55.67 mm is reached in February. Kakamega Meteorological Station showed from 1970 to 2001 a monthly mean rainfall of 164.48 mm. The station shows a major peak in its mean monthly rainfall of 251.47 mm in May and 248.00 in April followed by other peaks in March and August, then the rainfalls decrease reaching the lowest levels of 71.88 mm in December. Webuye Agricultural Office showed from 1970 to 2001 a monthly mean rainfall of 131.91 mm. The station shows a major peak of 236.80 mm in May followed by another minor peak in April, then the rainfalls decrease reaching the lowest levels of 45.18 mm in December for the next cycle to begin. Bunyala Irrigation Scheme showed from 1970 to 2001 a monthly mean rainfall of 92.16 mm. The station showed a major peak of 180.80 mm in April with monthly rainfall reducing to the lowest amount of 40.06 mm in July. Kadenge Yala Swamp showed from 1970 to 2001 a monthly mean rainfall of 90.99 mm The station shows a major peak of 181.94 mm in April followed by other peaks in May and November, then a decrease which results to June having 43.50 mm as the least recorded rainfall in the year.




Kaptagat Forest: Monthly Average Rainfall :1970-2001
Rainfall (mm)
200
150
100
50
0
Jan
Feb
March
April
May
June
July
Aug
Sep
Oct
Nov
Dec
Months


Kakamega Meteorological Station: Monthly Average Rainfall (mm): 1970-2001
Rainfall (mm)
300
250
200
150
100
50
0
Jan
Feb
March
April
May
June
July
Aug
Sep
Oct
Nov
Dec
Months


Webuye Agricultural Office: Monthly Average Rainfall (mm): 1970-2001
Rainfall (mm)
250
200
150
100
50
0
Jan
Feb
March
April
May
June
July
Aug
Sep
Oct
Nov
Dec
Months


Bunyala Irrigation Scheme:Monthly Average Rainfall (mm):1970-2001
Rainfall (mm)
200
180
160
140
120
100
80
60
40
20
0
Jan
Feb
March
April
May
June
July
Aug
Sep
Oct
Nov
Dec
Months

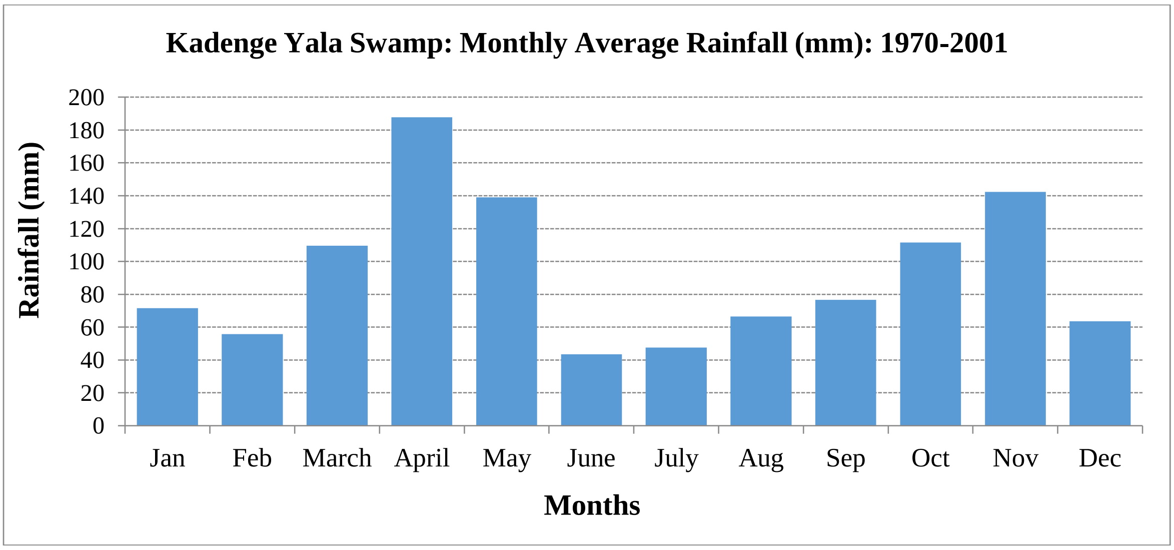
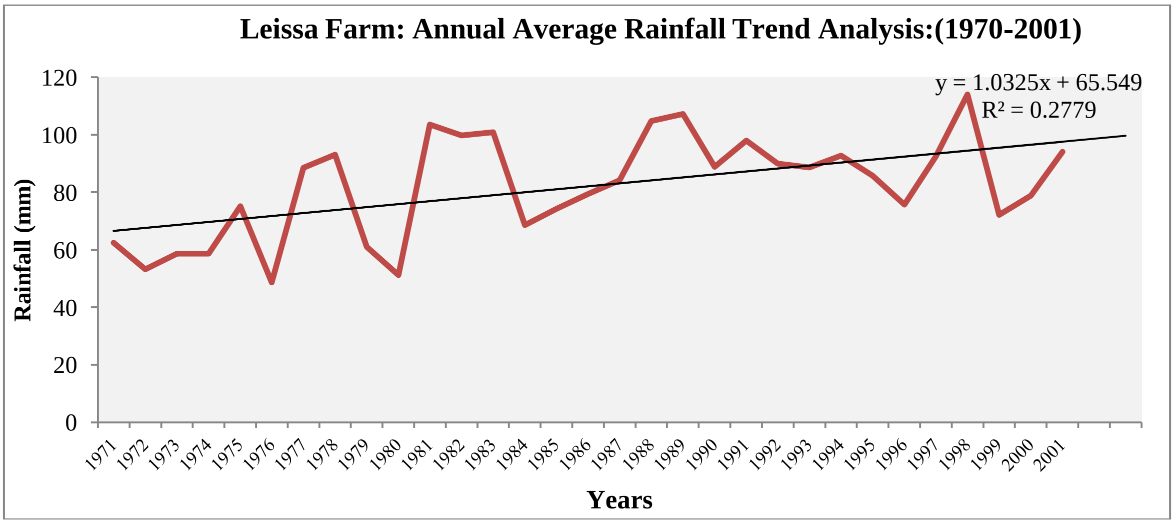
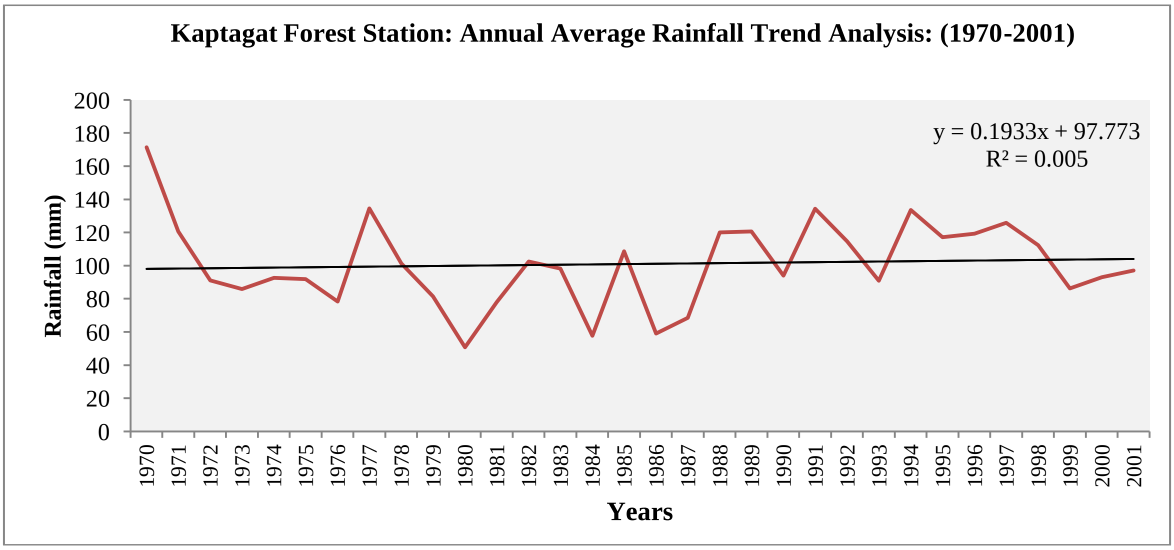
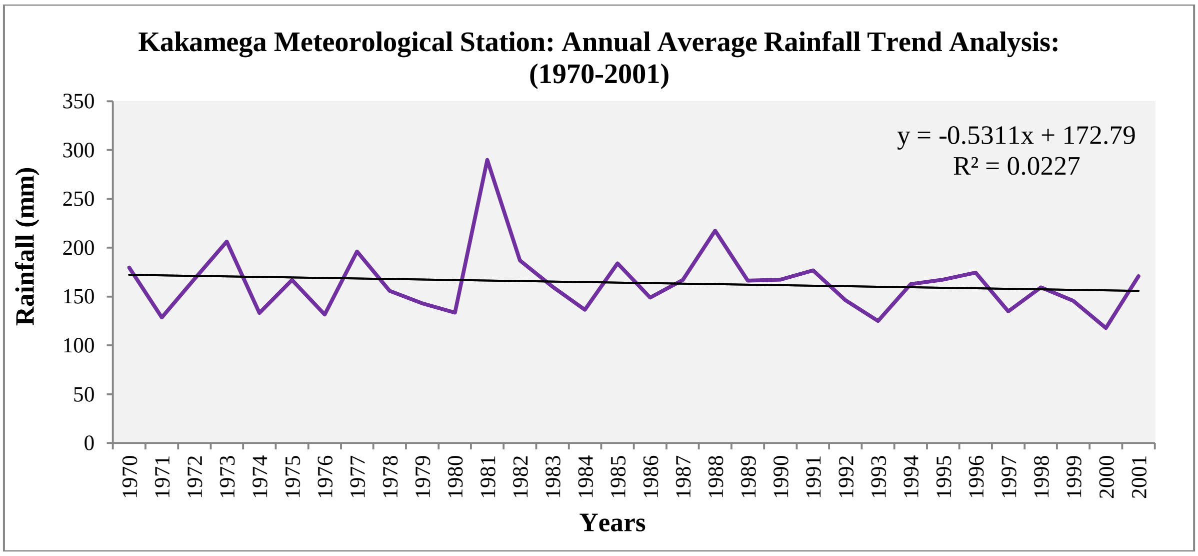
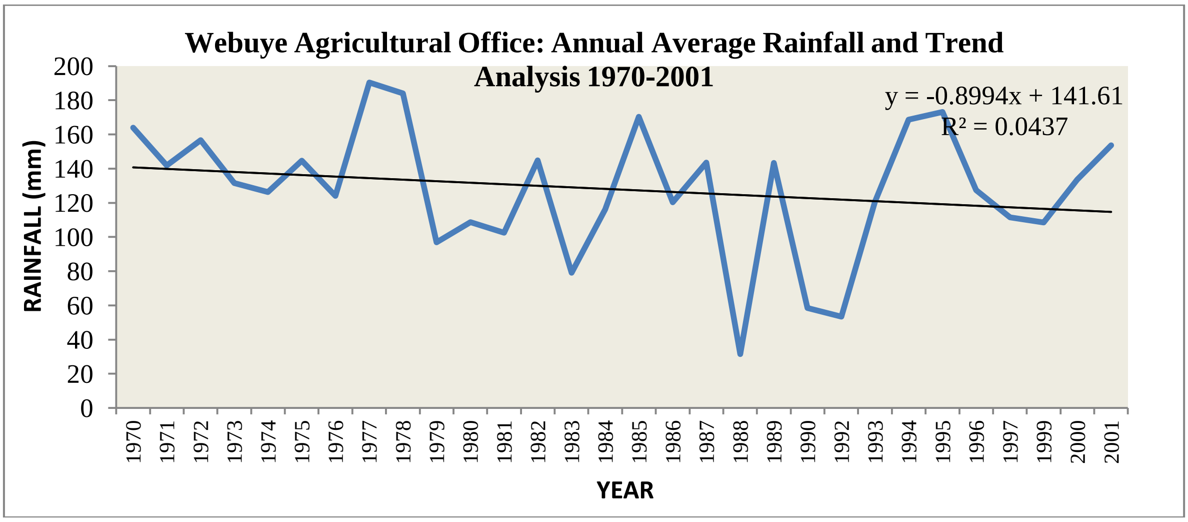


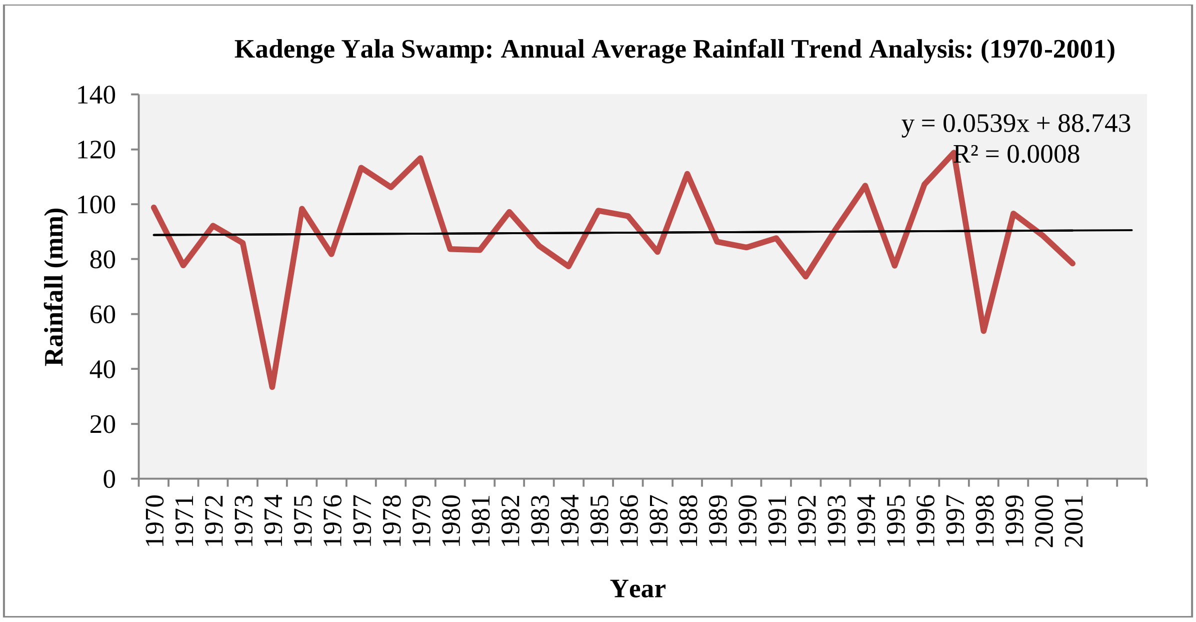
Fig. 2. Monthly average rainfall distribution for selected rainfall stations within Nzoia River Basin, Kenya






Kakamega Meteorological Station: Annual Average Rainfall Trend Analysis: (1970-2001)
y = -0.5311x + 172.79
R² = 0.0227
Rainfall (mm)
Years


Webuye Agricultural Office: Annual Average Rainfall and Trend Analysis 1970-2001
y = -0.8994x + 141.61
R² = 0.0437
RAINFALL (mm)
YEAR


Kadenge Yala Swamp: Annual Average Rainfall Trend Analysis: (1970-2001)
y = 0.0539x + 88.743
R² = 0.0008
Rainfall (mm)
Year

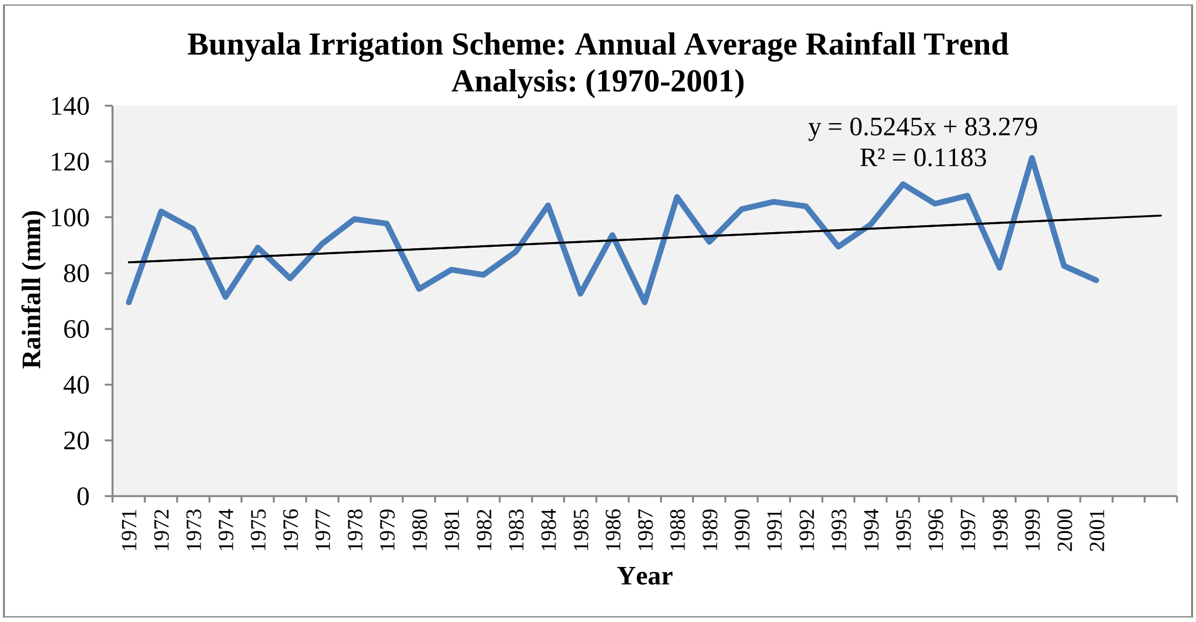


Fig. 3. Annual mean rainfall trends for selected rainfall stations within Nzoia River Basin, Kenya

As a result of the inter-tropical convergence zone (ITCZ), the Nzoia River Basin experiences two rainy seasons and two dry seasons in a year. Long rains fall between March and May (MAM), whereas short rains fall between October and December (OND), both of which are linked to the ITCZ. The months of December, January, and February (DJF) and, in some areas, June, July, August, and September (JJAS) are dry seasons. The ITCZ, which is made up of zonal and meriodional arms, has a somewhat complicated structure over East Africa. The long and short rainfall seasons, during which a substantial amount of the annual rainfall total is received, are related with the double passing of the zonal arm. The meriodional arm, on the other hand, moves from east to west and back again, with the easternmost extent recorded in July and August. This arm is linked to the rainfall that falls in Kenya's western highlands during these months [48]. The ITCZ's passage over the Equator, the southeast and northeast monsoons, Indian Ocean sea-surface temperature, and other meso-scale phenomena all influence diurnal, seasonal, and annual rainfall patterns [49,50]. Lake Victoria also alters the typical weather pattern, resulting in a third rainfall peak in June. There has also been a general upward trend (increase) in rainfall events from September to February, indicating that the brief rainy season (October-December) is extending into the basin's traditionally hot and dry months of January and February. This could be due to more frequent El-Nino events, which are sometimes accompanied by substantially warmer sea surface temperatures over the western Indian Ocean (around the East African coast) and lower than average sea surface temperatures to the east of the Indian Ocean. Over much of the country, this sea surface temperature pattern is favorable for increased rainfall. In the Nzoia River Basin, it may be stated that a dry period appears to follow the big rains. This raises the question of whether there is a link between heavy rains and dry spells.

Fig. 3 shows the annual mean rainfall trends for Leissa Farm Kitale, Kaptagat Forest Station, Kakamega Meteorological Station, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp rainfall stations. The parametric test of linear regression has been applied to the stations to show the trend, intercepts, slopes and regression lines and the results are as follows; Leissa Farm Kitale annual mean rainfall from 1970 to 2001 was found to be 82.23 mm. The lowest and highest recorded rainfall in the period was 48.60 (1976) and 114.03 (1998) mm per year, respectively. Rainfall at Leissa Farm Kitale has been increasing over the years at the rate of 1.0325 mm/31 years (0.033 mm/ year). The increase in rainfall shows a statistically insignificant trend. Kaptagat Forest Station annual mean rainfall from 1970 to 2001 was found to be 103.04 mm. The lowest and highest recorded rainfall in the period was 57.63

(1984) and 171.44 (1970) mm per year, respectively. Rainfall at Kaptagat Forest Station has been increasing over the years at the rate of 0.1933 mm/31 years (0.006 mm/ year). The increase in rainfall shows a statistically significant trend. Kakamega Meteorological Station annual mean rainfall from 1970 to 2001 was found to be 164.48 mm. The lowest and highest recorded rainfall in the period was 117.85 (2000) and 217.38 (1988) mm per year, respectively. Rainfall at Kakamega Meteorological Station has been decreasing over the years at the rate of - 0.5311 mm/31 years (-0.017 mm/ year). The decrease in rainfall shows a statistically significant trend. Webuye Agricultural Office annual mean rainfall from 1970 to 2001 was found to be 131.91 mm. The lowest and highest recorded rainfall in the period was 62.42 (1988) and 190.32 (1977) mm per year, respectively. Rainfall at Webuye Agricultural Office has been decreasing over the years at the rate of - 0.8994 mm/31 years (-0.029 mm/ year). The decrease in rainfall shows a statistically insignificant trend. Bunyala Irrigation Scheme annual mean rainfall from 1970 to 2001 was found to be 92.16 mm. The lowest and highest recorded rainfall in the period was 69.48 (1987) and 121.33 (1999) mm per year, respectively. Rainfall at Bunyala Irrigation Scheme has been increasing over the years at the rate of 0.5245 mm/31 years (0.017 mm/ year). The increase in rainfall shows a statistically insignificant trend.

Kadenge Yala Swamp annual mean rainfall from 1970 to 2001 was found to be 90.99 mm. The lowest and highest recorded rainfall in the period was 37.78 (1974) and 116.78 (1979) mm per year, respectively. Rainfall at Kadenge Yala Swamp has been increasing over the years at the rate of 0.0539 mm/31 years (0.002 mm/ year). The increase in rainfall shows a statistically insignificant trend.

There is variation in annual rainfalls within the six rainfall stations with some recording declining and others increasing rainfall trends (Table. 4). Using the parametric test of Linear regression analysis on annual rainfall; two stations; Kakamega Meteorological Station and Webuye Agricultural Office showed declining rainfalls. The remaining four stations; Leissa Farm Kitale; Kaptagat Forest Station; Bunyala Irrigation Scheme and Kadenge Yala Swamp had increasing rainfalls. One station recording increasing rainfall was in the upper cartchment whereas the majority of those recording declining rainfalls were in the middle and lower catchments. The implication of increasing and decreasing trends in rainfall is a signal of climate change.

The slopes for all stations are more than -1, indicating that the annual rainfall variation trend in these areas is generally small. The difference of these changes is mainly due to the impact of climate change in different regions of Nzoia River Basin during the decades, and the intensity of human activities.

The non-parametric test, Mann Kendall was used to analyze if there is a monotonic upward or downward trend in rainfall over time. Rainfall has crucial impact on the water cycle in the study area. Annual rainfall data for 6 stations under study in Nzoia River Basin were analyzed for trend using the non-parametric Mann-Kenall test and the results are shown in Table. 5. The Mann Kendall test Statistic (S) indicates that there is an increasing rainfall trend for Leissa Farm Kitale, Kaptagat Forest Station, Bunyala Irrigation Scheme and Kadenge Yala Swamp; and reducing rainfall trends for Kakamega meteorological station and Webuye Agricultural Office.

Table 4. Annual rainfall trend results from Linear regression analysis in Nzoia River Basin, Kenya

Rainfall station	Rainfall trend	Slope (Rate of change)		R^2
Upper Catchment				
Leissa Farm Kitale	Increasing	1.0325 mm/31 years	0.033 mm/ year	0.2779
Kaptagat Forest Station	Increasing	0.1933 mm/31 years	0.006 mm/ year	0.0050
Middle Catchment				
Kakamega Meteorological Station	Decreasing	- 0.5311 mm/31 years	-0.017 mm/ year	0.0227
Webuye Agricultural Office	Decreasing	- 0.8994 mm/31 years	-0.029 mm/ year	0.0437
Lower Catchment				
Bunyala Irrigation Scheme	Increasing	0.5245 mm/31 years	0.017 mm/ year	0.1183
Kadenge Yala Swamp	Increasing	0.0539 mm/31 years	0.002 mm/ year	0.0008

Table 5. Results of the Mann-Kendall test for Annual Rainfall from selected Rainfall Stations in Nzoia River Basin, Kenya

Station name	Mann-Kendall test					
	Mann Kendall Statistic (S)	**Kendall's Tau**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
Upper Catchment						
Leissa Farm Kitale	20.000	0.022	9120.667	0.8423	0.05	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	1	6833.667	< 0.0001	0.05	Reject Ho Statistically significant trend
Middle Catchment						
Kakamega Meteorological Station	1035.000	1	11155.000	< 0.0001	0.05	Reject Ho Statistically significant trend
Webuye Agricultural Office	-63.000	-0.127	3801.667	0.315	0.05	Accept Ho Statistically insignificant trend
Lower Catchment						
Bunyala Irrigation Scheme	113.000	0.243	3461.667	0.057	0.05	Accept Ho Statistically insignificant trend
Kadenge Yala Swamp	30.000	0.057	4165.333	0.653	0.05	Accept Ho Statistically insignificant trend

Table 6. Comparing Linear regression analysis and Mann-Kendall test statistic (S) results for Annual Rainfall from selected Rainfall Stations in Nzoia River Basin, Kenya

Station name	Mann-Kendall test		Linear regression analysis		Mann Kendall Test Statistical Interpretation
	Mann Kendall Statistic (S)	**Rainfall trend**	**Linear regression trend slope**	**Rainfall trend**	
Upper Catchment					
Leissa Farm Kitale	20.000	Increasing	1.0325	Increasing	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	Increasing	0.1933	Increasing	Reject Ho Statistically significant trend
Middle Catchment					
Kakamega Meteorological Station	1035.000	Decreasing	- 0.5311	Decreasing	Reject Ho Statistically significant trend
Webuye Agricultural Office	-63.000	Decreasing	- 0.8994	Decreasing	Accept Ho Statistically insignificant trend
Lower Catchment					
Bunyala Irrigation Scheme	113.000	Increasing	0.5245	Increasing	Accept Ho Statistically insignificant trend
Kadenge Yala Swamp	30.000	Increasing	0.0539	Increasing	Accept Ho Statistically insignificant trend

Out of the six stations, only two showed a statistically significant trend through the MK test at 5% level of significance; and the trend for the remaining four stations is statistically insignificant. Mann-Kendall test and linear regression test have been used to evaluate annual rainfall over Nzoia River Basin. Table 6 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the selected six Rainfall Stations. Leissa Farm Kitale, Kaptagat Forest Station, Bunyala Irrigation Scheme and Kadenge Yala Swamp recorded increasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). Webuye Agricultural Office and Kakamega meteorological station recorded decreasing rainfall under both Linear regression analysis and the Mann-Kendall test statistic (S). This study results follow the same statistical trends and are consistent with what has been reported by Githui [51] for Nzoia River Basin where she found that most of the rainfall stations with increasing rainfall were in the upstream part of Nzoia River.

3.1.2 Trends in monthly and annual temperatures

The temperature stations used in this study are shown in Table 3. As shown in Fig. 4, Kitale meteorological station's monthly mean maximum temperatures in the period 1979 to 2014 shows a gradually declining trend from February to July. Beginning with January at 28.3 ^{0}C, the maximum temperature rises to 28.6 ^{0}C in February (hottest month of the year) and then falls gradually to 23.9 ^{0}C in July (coldest month of the year), followed by a gradual rise reaching 26.3 ^{0}C in December to repeat the annual cycle. The monthly mean maximum tempratures for Kitale meteorological station in the period 1979 to 2014 has been gradually decreasing from January to December. The annual mean maximum temperatures at Kitale meteorological station have gradually increased from 1979 to 2014 at the rate of 0.000626 ^{0}C/year. The lowest mean maximum temperature of 25.1 ^{0}C was recorded in 1975 (coldest year in the period). The highest mean maximum temperature of 25.9 ^{0}C was recorded in 1980 (hottest year in the period).

Kitale meteorological station's monthly mean minimum temprature in the period 1979 to 2014 depict a slowly decreasing trend from January to December. Beginning from January with 10.7 ^{0}C (lowest temperature recorded in the year within the period), the temperature rises to 13.3 ^{0}C in April (highest temperature recorded in the year within the period) and then falls gradually to 10.9 ^{0}C in December to repeat the annual cycle. Annual mean minimum temprature for Kitale meteorological station in the period 1979 to 2014 has been rising at 0.001163 ^{0}C/year. Lowest mean minimum temperatures in the period were recorded at 10.5 ^{0}C in 1976 and the highest temperature ever recorded in the period was at 12.6 ^{0}C in 1998. The monthly mean temprature for Kitale meteorological station in the period 1979 to 2014 depicts a decreasing trend from January to December. Beginning from January with 19.1 ^{0}C, the temperature rises to 20.3 ^{0}C in March (highest temperature recorded in the year within the period) and then falls gradually to 17.9 ^{0}C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 18.8 ^{0}C in October and a fall to 18.6 ^{0}C in December to repeat the annual cycle. The Annual mean temprature for Kitale meteorological station has been increasing at the rate of 0.000894 ^{0}C/year. Lowest mean temperatures in the period were recorded at 10.5 ^{0}C in 1975 and the highest temperature ever recorded in the period was at 15.6 ^{0}C in 2013. The results in Fig. 4 shows that based on the standard seasons of December-January-February (DJF), March-April-May (MAM), June-July August (JJA) and September- October-November (SON) in Nzoia River Basin, there has been small fluctuations in monthly minimum, maximum and mean temperatures for the period between 1979 and 2014.

Fig. 5 shows that Eldoret international airport's monthly mean maximum temprature in the period 1999 to 2014 depicts a declining trend from January to December. The monthly mean maximum temperatures beginning with January at 16.8 ^{0}C, rises to 18.4 ^{0}C in March (hotest month of the year) and then falls gradually to 16.1 ^{0}C in July (coldest month of the year), followed by a gradual rise to 17.5 ^{0}C in October and a fall to 17.0 ^{0}C in December to repeat the annual cycle. Annual mean maximum temprature for Eldoret international airport in the period 1999 to 2014 depict a declining trend at the rate of -0.00202 ^{0}C/year. There was a drastic fall in temprature between 2005 and 2008 reaching the lowest temprature ever experienced in the period at 23.02 ^{0}C. This was followed by a steady rise in temprature between 2008 and 2009 reaching 24.93 ^{0}C which is the highest temperature ever recorded in the period. Thereafter, a gradual fall continued until 2013.

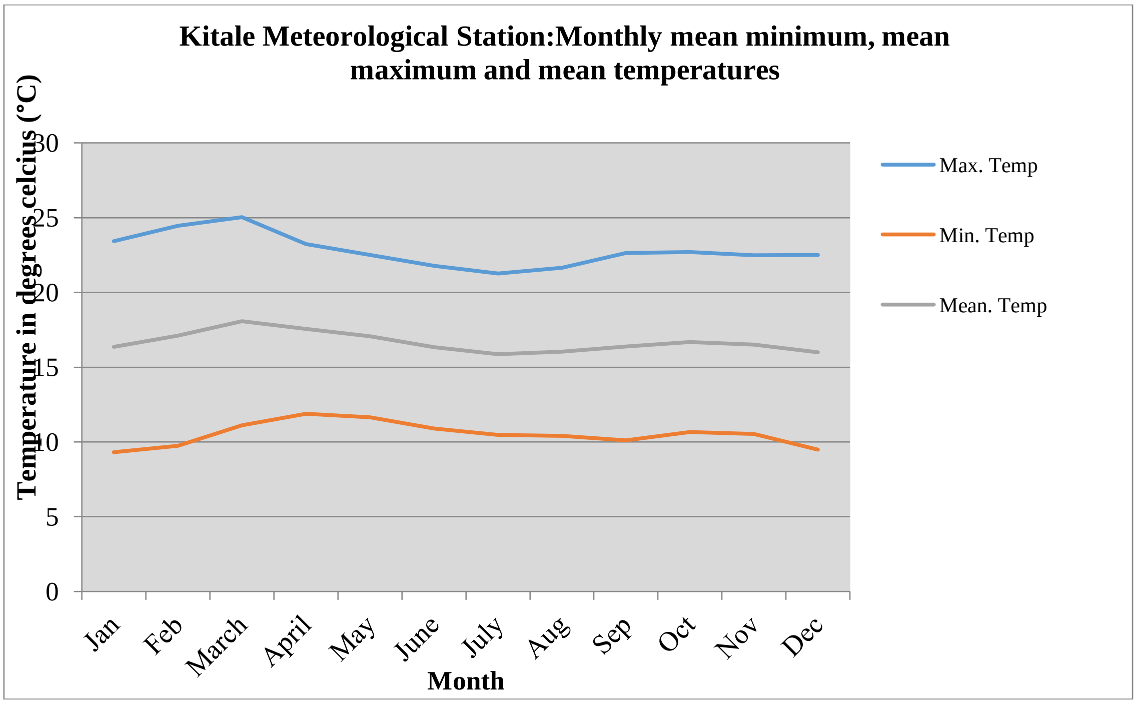


Fig. 4. Comparison of monthly mean minimum, mean maximum and mean temperatures for Kitale meteorological station between 1979 and 2014

The monthly mean minimum tempratures for Eldoret international airport in the period 1999 to 2014 depict a rising trend from January to December. Beginning from January with 8.6 ^{0}C, the temperature rises to 11.6 ^{0}C in April (highest temperature recorded in the year within the period) and then falls gradually to about 10.0 ^{0}C in July and September (lowest temperatures recorded in the year within the period), followed by a gradual rise to 10.7 ^{0}C in November and a fall to 9.7 ^{0}C in December to repeat the annual cycle. The Annual mean minimum tempratures for Eldoret international airport in the period 1999 to 2014 depict a slowly rising trend at the rate of 0.000813 ^{0}C/year. A gradual rise in tempratures was noted between 2000 and 2006 reaching the highest tempratures ever experienced in the period of 11.08 ^{0}C. This was followed by a steady fall in tempratures between 2006 and 2009 reaching 7.42 ^{0}C which is the lowest temperature ever recorded in the period.

The monthly mean tempratures for Eldoret international airport in the period 1999 to 2014 depict a declining trend from January to December. Beginning from January with 16.8 ^{0}C, the temperature rises steadly to 18.4 ^{0}C in March (highest temperature recorded in the year within the period) and then falls gradually to 16.1 ^{0}C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 17.4 ^{0}C in October and a fall to 17.0 ^{0}C in December to repeat the annual cycle. The Annual mean tempratures for Eldoret international airport in the period 1999 to 2014 depict a slowly declining trend at the rate of -0.00142 ^{0}C/year. A slow rise in tempratures was noted between 1999 and 2005 reaching the highest tempratures ever experienced in the period of 17.66 ^{0}C. This was followed by a steady fall in tempratures between 2006 and 2008 reaching 16.41 ^{0}C which is the lowest temperature ever recorded in the period.

The results in Fig. 5 shows that based on the standard seasons of December-January-February (DJF), March-April-May (MAM), June-July August (JJA) and September- October-November (SON) in Nzoia River Basin, there has been fluctuations in monthly minimum, maximum and mean temperatures for the period between 1999 and 2014.

Fig. 6 shows that Kakamega meteorological station's monthly mean maximum tempratures in the period 1999 to 2014 depicts a declining trend from January to December. Beginning from January at 28.7 ^{0}C, the temperature rises to 29.5 ^{0}C in February (hottest month of the year) and then falls gradually to 25.8 ^{0}C in July (coldest month of the year), followed by a gradual rise reaching 27.8 ^{0} C in December to repeat the annual cycle again. The Annual mean maximum tempratures for Kakamega meteorological station in the period 1979 to 2014 depict a rising trend at the rate of 0.000771 ^{0} C/year. Lowest mean maximum temperatures in the period were recorded at 26.7 ^{0} C in 1989 and the highest temperature ever recorded in the period was at 28.3 ^{0} C in 2009. The monthly mean minimum tempratures for Kakamega meteorological station in the period 1979 to 2014 depict a slowly declining trend from January to December. Beginning from January with 13.9 ^{0} C, the temperature rises to 15.1 ^{0} C in April (highest temperature recorded in the year within the period) and then falls gradually to 13.57 ^{0} C in September (lowest temperature recorded in the year within the period). The Annual mean minimum tempratures for Kakamega meteorological station depicts a rising trend from 1979 to 2014 at the rate of 0.000471 ^{0} C/year. Lowest mean minimum temperatures in the period were recorded at 13.4 ^{0}C in 1990 and the highest temperature ever recorded in the period was at 15.0 ^{0}C in 2010.

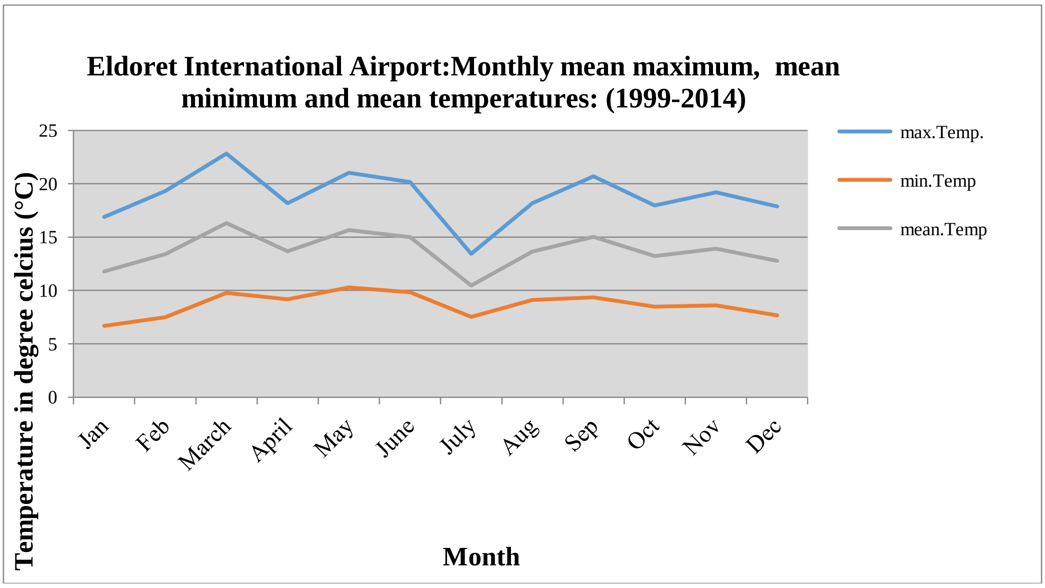


Fig. 5. Comparison of monthly mean minimum, mean maximum and mean temperatures for Eldoret international airport between 1999 and 2014

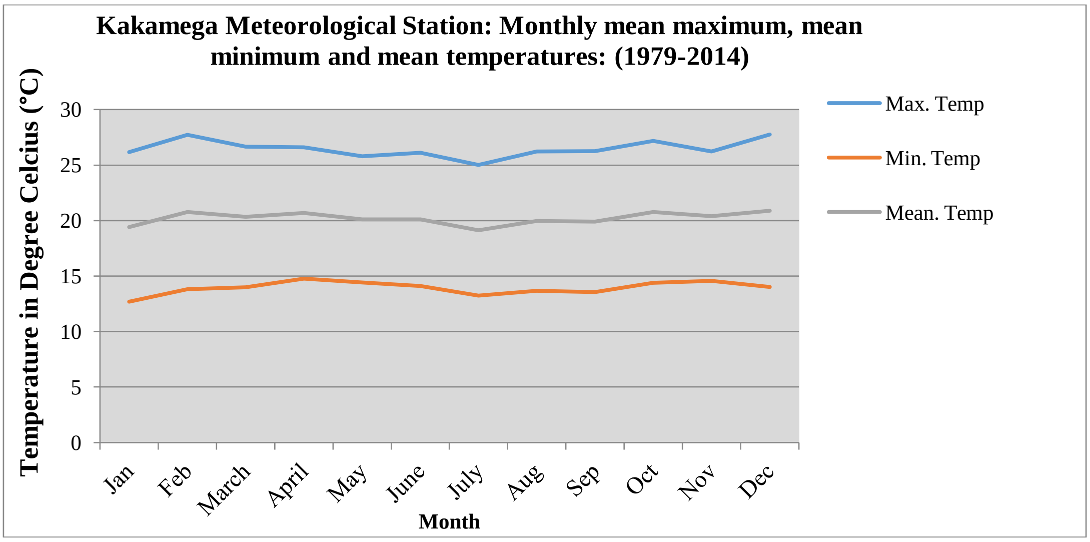


Fig. 6. Comparison of monthly mean minimum, mean maximum and mean temperatures for Kakamega meteorological station between 1979 and 2014

The monthly mean tempratures for Kakamega meteorological station in the period 1979 to 2014 depict a declining trend from January to December. Beginning from January with 21.3 ^{0}C, the temperature rises to 22.0 ^{0} C in March (highest temperature recorded in the year within the period) and then falls gradually to 19.7 ^{0}C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 20.9 ^{0}C in December to repeat the annual cycle. The Annual mean tempratures for Kakamega meteorological station depicts a rising trend from 1979 to 2014 at 0.000623 ^{0}C/year. Lowest mean temperatures in the period were recorded at 20.1 ^{0} C in 1990 and the highest temperature ever recorded in the period was at 21.6 ^{0}C in 2005.

The results in Fig.6 shows that based on the standard seasons of December-January-February (DJF), March-April-May (MAM), June-July August (JJA) and September- October-November (SON) in Nzoia River Basin, there has been fluctuations in monthly minimum, maximum and mean temperatures for the period between 1979 and 2014. Comparing the monthly maximum, minimum and mean temperatures across Nzoia River Basin for the period 1979 to 2014 (Figs. 7, 8 and 9) based on the standard seasons of December-January- February (DJF), March-April-May (MAM), June-July August (JJA) and September- October-November (SON); the results show that there has been temperature fluctuations all the year round. The temperature fluctuations also vary across Kitale, Kakamega and Eldoret international airport temperature stations. Kakamega has highest minimum temperatures, followed by Kitale and the lowest temperatures are found at Eldoret international airport meteorological station. The same partern still holds for both maximum and mean temperatures across the three stations. This trend seems to go with altitude since the lowest temperatures are found at highest altitudes and highest temperatures at lowest altitudes; the altitude of Kakamega is 1501 masl, Kitale, 1825 masl and Eldoret is 2120 masl.

The trend for Maximum temperatures in Nzoia River Basin has shown the monthly mean maximum tempratures in the period 1979 to 2014 depicting a declining trend from January to December. The lowest tempratures occur in the month of July with tempratures ranging between 16.1 ^{0}C (Eldoret) to 25.8 ^{0}C (Kakamega).

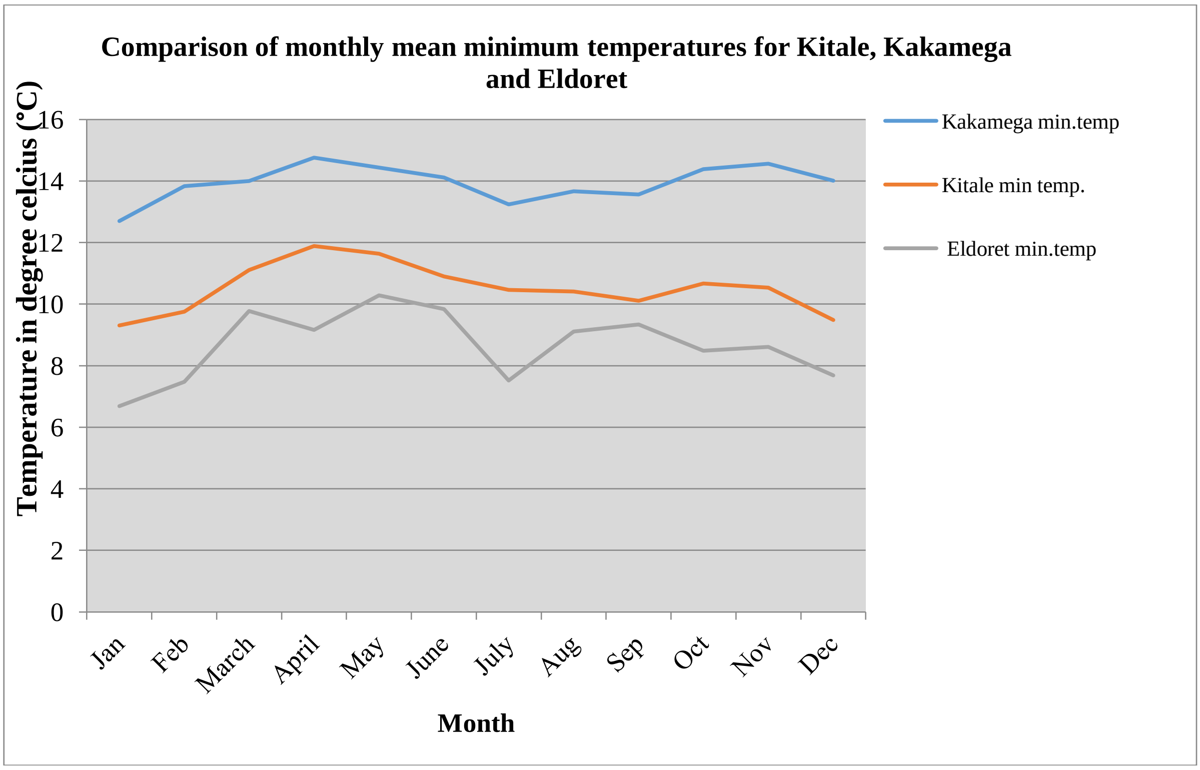


Fig. 7. Comparison of monthly minimum temperatures for Kitale, Kakamega and Eldoret international airport meteorological stations

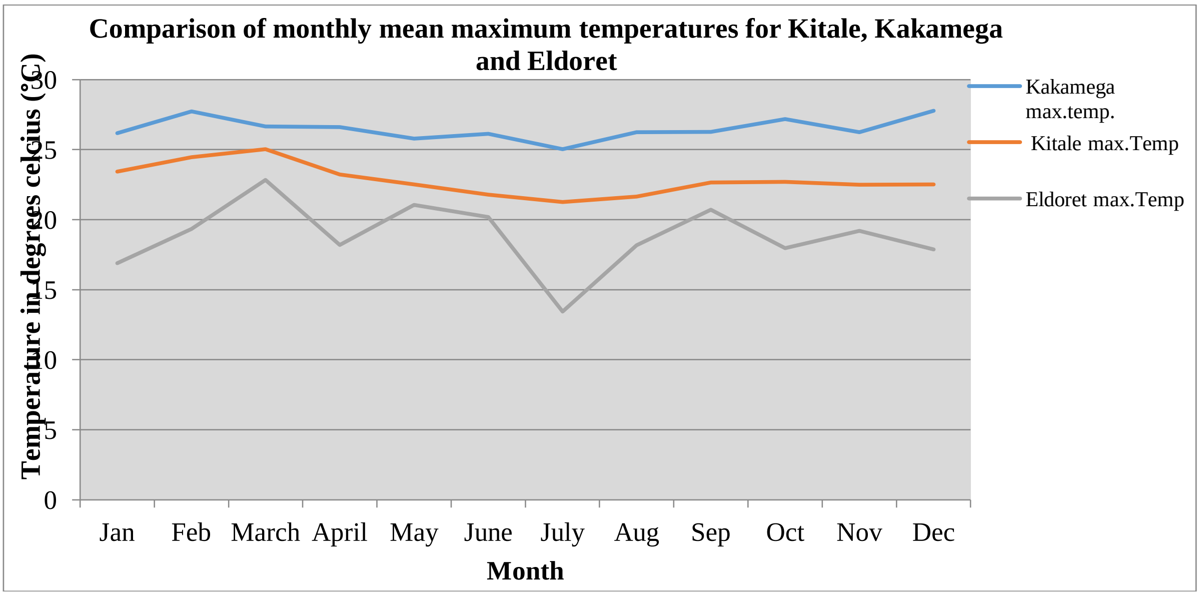


Fig. 8. Comparison of monthly maximum temperatures for Kitale, Kakamega and Eldoret international airport meteorological stations

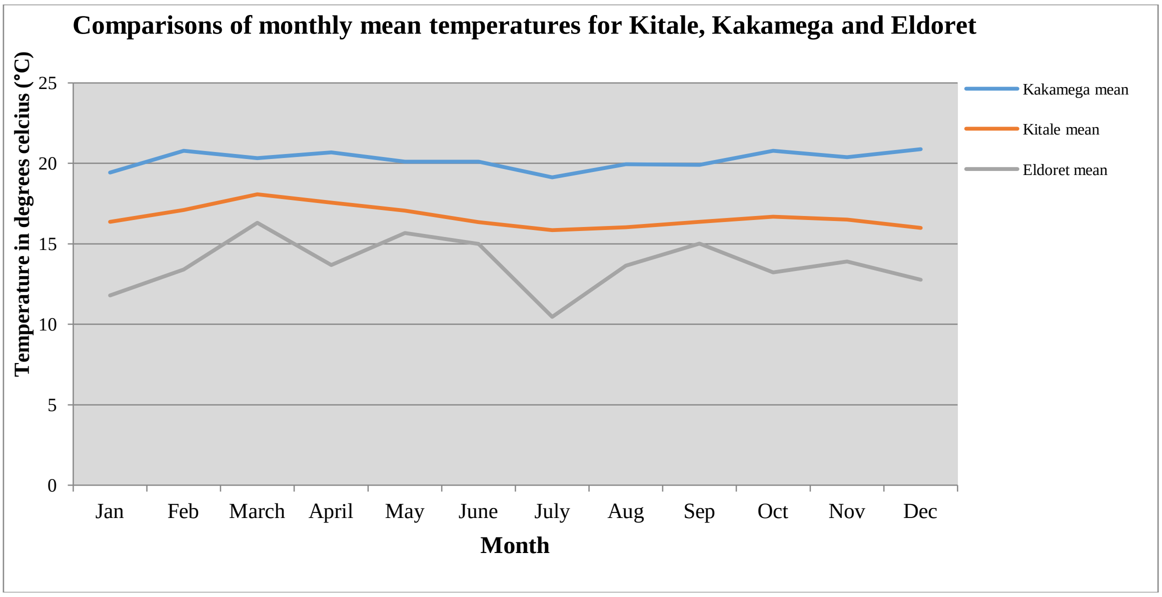


Fig. 9. Comparison of monthly mean temperatures for Kitale, Kakamega and Eldoret international airport meteorological stations

Highest tempratures occur in the months of February and March with tempratures ranging between 18.4 ^{0} C (Eldoret) to 29.5 ^{0} C (Kakamega). The annual mean maximum tempratures for the basin depict both declining (Eldoret) and rising (Kitale and Kakamega) trends from 1979 to 2014. The lowest tempratures in the period were recorded in the year 2008 at 23.02 ^{0} C (Eldoret) and the highest tempratures in the year 2009 at 28.3 ^{0} C (Kakamega). In the basin, maximum tempratures at Kitale meteorological station has been rising at 0.0219 ^{0} C/35 year (0.000626 ^{0} C/year). For Eldoret international airport, maximum tempratures has been falling at -0.0303 ^{0} C/15 year (-0.00202 ^{0} C/year). Kakamega meteorological station has had rising maximum tempratures at 0.027 ^{0} C/35 year (0.000771 ^{0} C/year). Of the three stations, Kakamega has experienced the fastest rising annual maximum temprátures. The trend for Minimum temperatures in the basin has shown the monthly mean minimum tempratures in the period 1979 to 2014 depicting both declining (Kitale and Kakamega) and rising (Eldoret) trends from January to December. The lowest tempratures occur in the months of January, July and September with tempratures ranging between 10.0 ^{0} C (Eldoret) to 13.6 ^{0} C (Kakamega). Highest tempratures occur in the month of April with tempratures ranging between 11.6 ^{0} C (Eldoret) to 15.1 ^{0} C (Kakamega). The annual mean minimum tempratures for the basin depict a rising trend from 1979 to 2014. The lowest tempratures in the period were recorded in the year 2009 at 7.42 ^{0} C (Eldoret) and the highest tempratures in the year 2010 at 15.0 ^{0} C (Kakamega). In the basin, minimum tempratures at Kitale meteorological station has been rising at 0.0407 ^{0} C/35 year (0.001163 ^{0} C/year). For Eldoret international airport, minimum tempratures has been rising at 0.0122 ^{0} C/15 year (0.000813 ^{0} C/year). Kakamega meteorological station has had rising minimum tempratures at 0.0165 ^{0} C/35 year (0.000471 ^{0} C/year). Of the three stations, Kakamega has experienced the fastest rising annual minimum tempratures.

The trend for Mean temperatures in the basin has shown the monthly mean tempratures in the period 1979 to 2014 depicting a declining trend from January to December. The lowest tempratures occur in the month of July with tempratures ranging between 16.1 ^{0} C (Eldoret) to 19.7 ^{0} C (Kakamega). Highest tempratures occur in the month of March with tempratures ranging between 18.4 ^{0} C (Eldoret) to 22.0 ^{0} C (Kakamega). The annual mean tempratures for the basin depicts both falling (Eldoret) and rising (Kitale and Kakamega) trend from 1979 to 2014. The lowest tempratures in the period were recorded in the year 1976 at 10.05 ^{0} C (Kitale) and the highest tempratures in the year 2005 at 21.6 ^{0} C (Kakamega). In the basin, mean tempratures at Kitale meteorological station has been rising at 0.0313 ^{0} C/35 year (0.000894 ^{0} C/year). For Eldoret international airport, mean tempratures has been falling at -0.0213 ^{0} C/15 year (-0.00142 ^{0} C/year).

Kakamega meteorological station has had rising mean tempratures at 0.0218 ^{0} C/35 year (0.000623 ^{0} C/year). Of the three stations, Kitale has experienced the fastest rising annual mean tempratures. Linear regression analysis was used to analyse annual temperature trends for Kitale, Eldoret and Kakamega and the results are shown in Figs. 10, 11 and 12 respectively.

There has been small fluctuations in annual minimum, maximum and mean temperatures for Kitale in the period between 1979 and 2014.

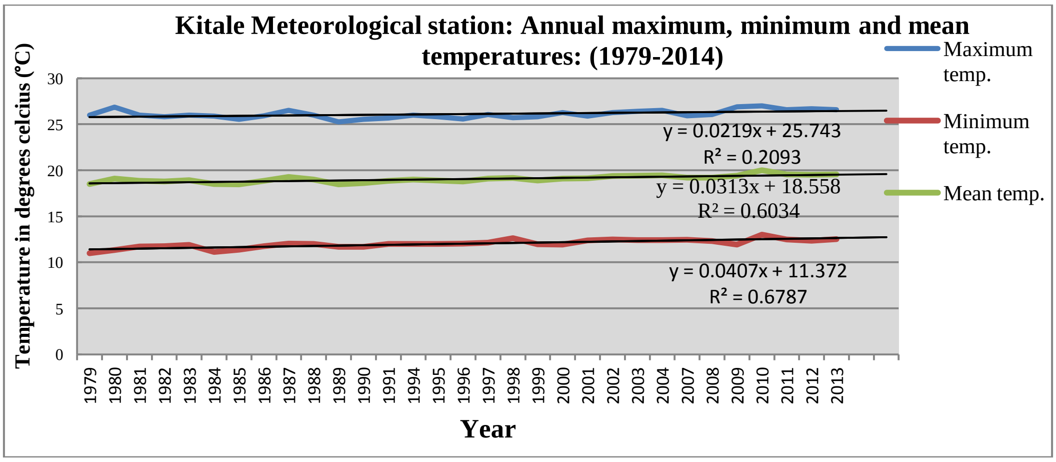


Fig. 10. Comparison of annual minimum, maximum and mean temperatures trends for Kitale meteorological station

Table 7. Comparison of monthly and annual Kitale meteorological station temperature trends

Temprature	Monthly trend	Annual trend	Linear regression analysis results for annual tempratures	
Maximum	Decreasing	Increasing	0.000626 ^{0} C/year	0.0626 ^{0} C/100 years
Minimum	Decreasing	Increasing	0.001163 ^{0} C/year	1.163 ^{0} C/100 years
Mean	Decreasing	Increasing	0.000894 ^{0} C/year	0.894 ^{0} C/100years

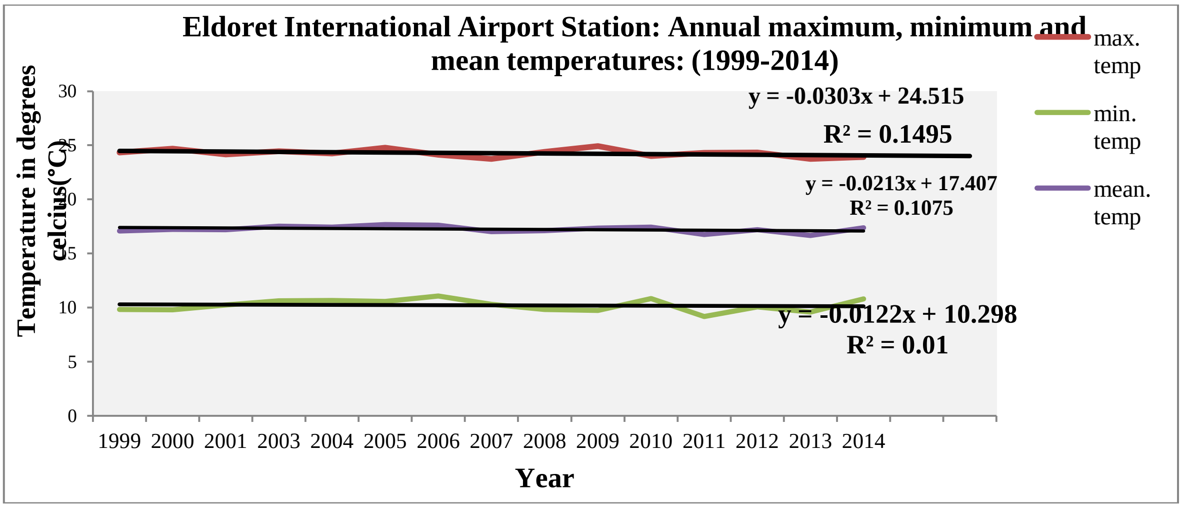


Fig. 11. Comparison of annual minimum, maximum and mean temperatures trends for Eldoret international airport

Table 8. Comparison of monthly and annual Eldoret international airport temperature trends

Temprature	Monthly trend	Annual trend	Linear regression analysis results for annual tempratures	
Maximum	Decreasing	Decreasing	-0.00202 ^{0}C/year	-0.202 ^{0}C/100 years
Minimum	Increasing	Increasing	0.000813 ^{0}C/year	0.0813 ^{0}C/100 years
Mean	Decreasing	Decreasing	-0.00142 ^{0}C/year	-0.142 ^{0}C/100 years

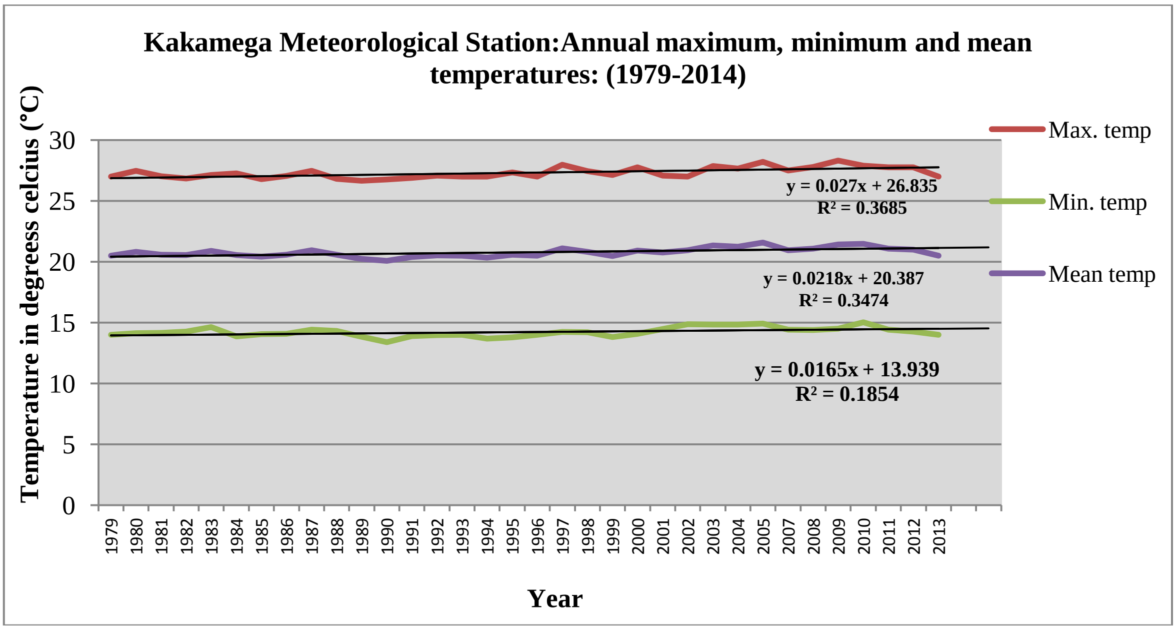


Fig. 12. Comparison of annual minimum, maximum and mean temperatures trends for Kakamega meteorological station

Using a linear regression model, the rate of change is defined by the slope of regression line which in this case for Maximum temprature is 0.0219 ^{0}C/35 year (0.000626 ^{0}C/year). Similarly, for the minimum temperature, its 0.0407 ^{0} C/35 year (0.001163 ^{0} C/year); and the mean temperature, 0.0313 ^{0} C/35 year (0.000894 ^{0} C/year). Table 7. shows a summary of monthly and annual temperature trends at Kitale meteorological station. Fig. 11 shows a Comparison of the Annual Maximun, Minimum and Mean tempratures for Eldoret international airport in the period 1999 to 2014. There has been small fluctuations in annual minimum, maximum and mean temperatures in the period between 1999 and 2014. Using a linear regression model, the rate of change is defined by the slope of regression line which in this case for Maximum temprature is -0.0303 ^{0}C/15 year (-0.00202 ^{0} C/year). Similarly, for the minimum temperature, its 0.0122 ^{0}C/15 year (0.000813 ^{0} C/year). For Eldoret international airport, the mean temperatures are falling at -0.0213 ^{0}C/15 year (-0.00142 ^{0} C/year). Table 8. shows a summary of monthly and annual temperature trends at Eldoret international airport meteorological station.

Fig. 12 shows a Comparison of the Annual Maximun, Minimum and Mean tempratures for Kakamega meteorological station in the period 1979 to 2014. There has been small fluctuations in annual minimum, maximum and mean temperatures in the period between 1979 and 2014.

Using a linear regression model, the rate of change is defined by the slope of regression line which in this case for Maximum temprature is 0.027 ^{0}C/35 year (0.000771 ^{0}C/year).

Similarly, for the minimum temperature, its 0.0165 ^{0}C/35 year (0.000471 ^{0}C/year). For the mean temperature, its 0.0218 ^{0} C/35 year (0.000623 ^{0} C/year). Table 9. shows a summary of monthly and annual temperature trends at Kakamega meteorological station.

The non-parametric test, Mann Kendall method was used to analyze if there is a monotonic upward or downward trend in annual temprature over time as shown in Fig. 10. Air temperature has crucial impact on the water cycle in the study area.

For this test result, the null hypothesis is accepted for Kakamega meteorological station data. In Kakamega meteorological station, annual temperature has shown no trend as the computed p-value is greater than the significance level $\alpha = 0.05$ and the result is statistically insignificant. Of the 3 stations, only 2 showed a statistically significant trend through the MK test at 5% level of significance; and the trend for the remaining 1 station is statistically insignificant. Mann-Kendall test and linear regression test have been used to evaluate annual tempratures over Nzoia River Basin. Apart from this, the linear trend fitted to the data has also been tested with the Student t-test to verify results obtained by the Mann-Kendall test and results are presented in Table 11.

Table 9. Comparison of monthly and annual Kakamega meteorological station temperature trends

Temprature variables	Monthly trend	Annual trend	Linear regression analysis results for annual tempratures	
Maximum	Decreasing	Increasing	0.000771 ^{0}C/year	0.0771 ^{0}C/100 years
Minimum	Decreasing	Increasing	0.000471 ^{0}C/year	0.0471 ^{0}C/100 years
Mean	Decreasing	Increasing	0.000623^{0} C/year	0.0623 ^{0}C/100years

Table 10. Results of the Mann-Kendall test for Annual mean Temperature data for Nzoia River Basin, Kenya

Station name	Mann-Kendall test					
	Mann Kendall Statistic (S)	**Kendall's Tau**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
Kitale Meterological Station	435.00	1	3141.667	< 0.0001	0.05	Reject Ho Statistically significant trend
Eldoret International Airport	-47.000	-0.516	333.667	0.012	0.05	Reject Ho Statistically significant trend
Kakamega Meteorological Station	106.000	0.214	3800.667	0.089	0.05	Accept Ho Statistically insignificant trend

Table 11. Comparing Linear trend fitted on data and Mann-Kendall test statistic (S) results for Annual mean temperature data in Nzoia River Basin, Kenya

Station name	Mann-Kendall test		Fitted Linear trend line		Mann Kendall Test
	Mann Kendall Statistic (S)	**Temperature trend**	**Fitted Linear trend line slope**	**Temperature trend**	**Statistical Interpretation**
Kitale Meterological Station	435.00	Increasing	0.0313	Increasing	Reject Ho Statistically significant trend
Eldoret International Airport	-47.000	Decreasing	- 0.0213	Decreasing	Reject Ho Statistically significant trend
Kakamega Meteorological Station	106.000	Increasing	0.0210	Increasing	Accept Ho Statistically insignificant trend

Table 11 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the 3 temprature stations. Out of the 3 temperature stations, Mann Kendall test statistic (S) showed 2 stations recording increasing temperature similar to the linear trend line. Both analysis methods also showed one station as recording decreasing temperature. Kitale and Kakamega meteorological stations recorded increasing tempratures whereas Eldoret international airport, recorded decreasing temperatures. The results for Kitale and Eldoret stations showed statistically significant trends whereas those for Kakamega station had a statistically insignificant trend. As one would expect, temperatures in Nzoia River Basin are expected to be rising; however, the case of decreasing temperatures recorded at Eldoret international airport might occur because this region of Rift valley has highly protected natural resources and a high forest cover is always present all the year round. Another possible explanation to this could be the changing cloudness around Eldoret station.

3.2 Streamflow Trends and Linkages to Rainfall and Temperature in Nzoia River Basin

3.2.1 Streamflow variability and trends

Long term network of stream gauges is the key to determining changes in floods and droughts within a catchment. Water Resources Management Agency (WRMA) maintains a database representing approximately 37 streamgauges, most of which are still active in Nzoia River Basin. Because climate naturally varies from year to year and decade to decade, streamgauge records of at least 30 years, and preferably more than 50 years, are necessary for assessing trends. Natural changes of this nature can mask or misrepresent a long-term trend. The flow of water in most rivers in Nzoia River Basin reflect some level of human activities such as: river diversions for irrigation, ground-water extraction and land-use changes. To evaluate streamflow variability and change in a climatic context, two stations on Nzoia river were identified; Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1); where the discharge is primarily influenced by climatic variations. The data was analyzed for the period 1974 to 2017, covering a period of 43 years. Streamflow data is one of the most crucial aspects of water resource planning, management, and project design. One of the most important phases in water resource management is identifying possible trends in historical streamflow data. The detection of a substantial trend in streamflow has a major impact on water management and policy decisions [52].

3.2.1.1 Monthly mean streamflow

Monthly mean streamflow is lowest in the basin between January and March when the rainfalls are low. As the long rains approach between March and May flow both in the upstream and downstream stations rise rapidly reaching the highest peaks in May. The short rains period comes in October to December and here flow both in the upstream and downstream stations shows a falling trend from October to December when the short rains diminish.

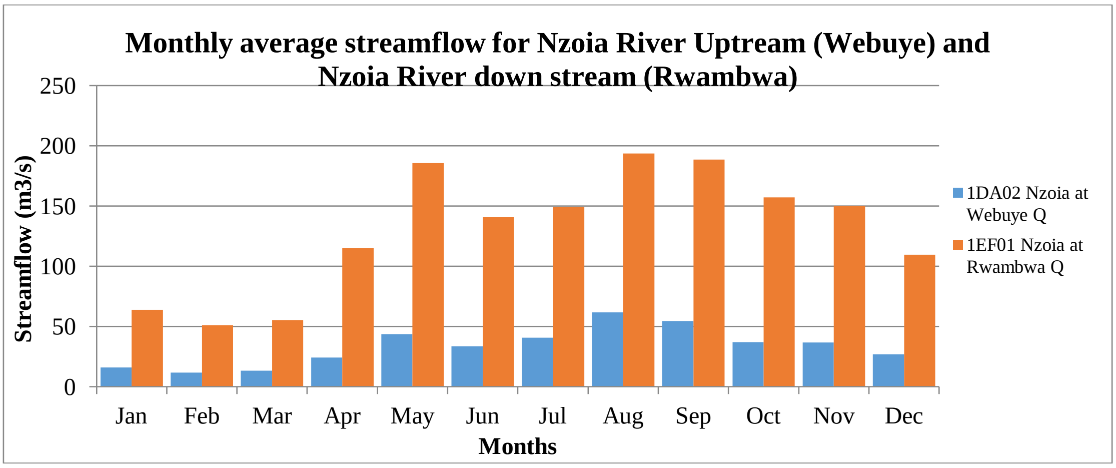


Fig. 13. Monthly average stream flow comparison for Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1)

The period of June, July, August and September experiences good rainfalls and due to the local relief and influences of Lake Victoria, another rainfall peak is experienced in August. This supports the observed flow both in the upstream and downstream stations as shown in Fig.13. In the months of January to March, the rainfall is quite low in the basin and as a result, floods are rare during these periods. However, during the rainy seasons, when rainfall is abundant in both the upstream and downstream catchments, the Nzoia River channel becomes unable to contain the large flows, resulting in flooding in the lower catchment. The flow regime of the Nzoia River is unpredictable due to the variation in rainfall seasons throughout the year, and it can be as low as 20 m^3/s at times. The flow may exceed 1,100 m^3/s in extreme floods, which is the proposed protection level for the dykes for a 25-year return period flood. Siltation is widespread, particularly on the plains, lowering the height of river banks and thereby increasing the spill over on the banks. March and September signal the beginnings of the long and short rains respectively [53]. The sun lies over the equator at this time, causing increased evapotranspiration and hence a reduction in surface water. From May to September, the flow in the Nzoia River is reasonably high, with the maxima coming in May and August-September. As illustrated in Fig. 13, the flow is modest at station 1DD01 but rises to high levels at station 1EF01, which is further downstream. The two stations have mean flows of 950 and 2500 m^3/s, respectively. The upstream region receives consistent high rainfall throughout the year, which keeps the flow high, especially from May to November.

3.2.2 Annual mean streamflow

3.2.2.1 Annual Streamflow by linear regression analysis

Streamflow data for selected stations within Nzoia River Basin shown in Table. 1 were analyzed for trend by fitting the linear trend line as shown in Figs. 14 and 15.

Table 12 summarises the results. The two stations recorded increasing annual streamflow as shown in Figs. 14 and 15.

Table 12. Trend of annual streamflow in Nzoia River Basin, Kenya

Station name	Slope	R^2	Trend
Upstream (Nzoia River at Webuye)	0.6850	0.1541	Increasing
Downstream (Nzoia River at Rwambwa)	0.7438	0.0231	Increasing

The slopes for both stations are more than -1, indicating that the annual streamflow variation trend in these areas is generally small. For Nzoia river upstream at Webuye (IDD01), streamflow has been increasing at 0.685 m^3/s /42years; and for Nzoia river downstream at Rwambwa (IEF01), streamflow has been increasing at 0.7438 m^3/s /42 years.The increase in flow is higher at the lower station.

3.2.2.2 Mann-Kendall test on annual streamflow

Annual streamflow data for selected stations within Nzoia River Basin under Table 1. were analyzed for trend using Mann-Kenall test and the results are shown in Table 13. When the Kendall test statistics are less than 0, it indicates that streamflow is decreasing; and when the values are higher than 0, streamflow is increasing. The Mann Kendall test Statistic (S) indicates that there is an increasing streamflow trend for the two stations selected for analysis, one from upstream (Nzoia river upstream at Webuye, IDD01), and one from downstream, (Nzoia river downstream at Rwambwa, IEFO1) at 5% significance level. The increasing trend in streamflow for the two stations is statistically insignificant. Comparing Fitted Linear trend line and Mann-Kendall test statistic (S) results for annual streamflow data; Mann Kendall test statistic (S) showed the 2 stations recording increasing streamflow similar to the Fited linear regression line.

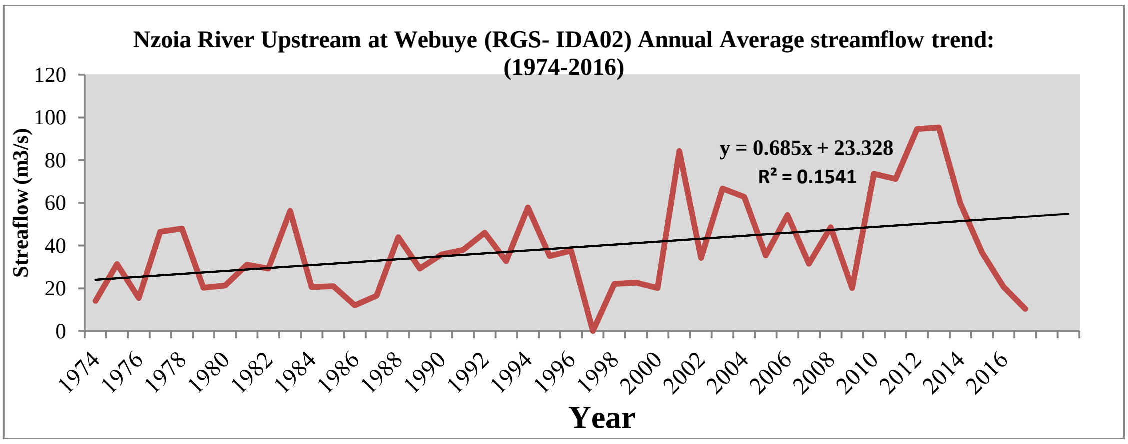


Fig. 14. Annual stream flow trend for Nzoia river upstream at Webuye (IDD01)

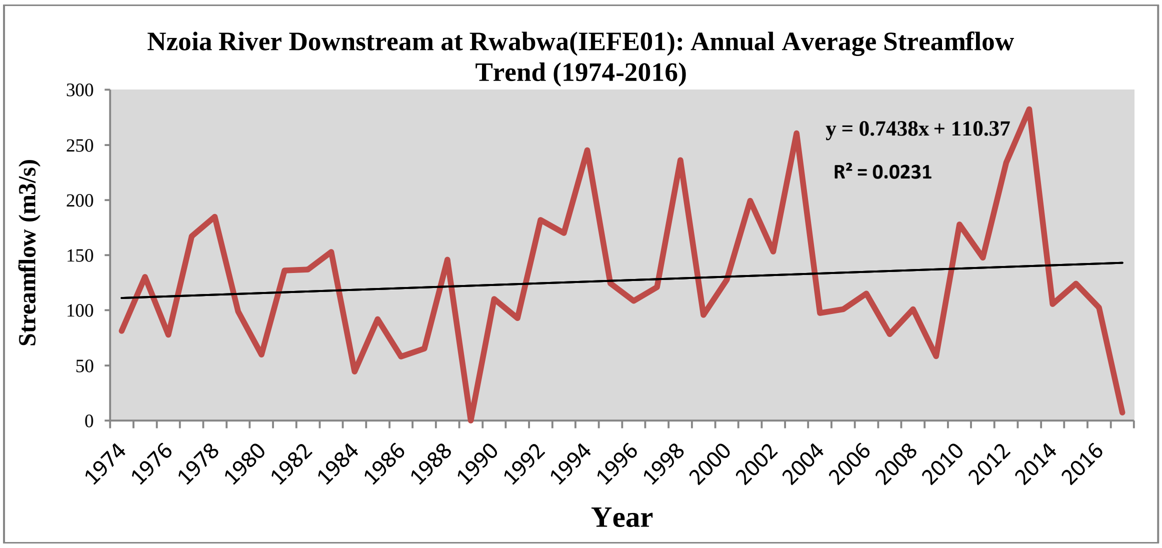


Fig. 15. Annual stream flow trend for Nzoia river downstream at Rwambwa (IEF01)

Table 13. Mann-Kendall test results for annual streamflow data in Nzoia River Basin, Kenya

Station name	Mann-Kendall test			
	Mann Kendall Statistic (S)	Kendall's Tau	Var (S)	p-value (two tailed test)
Upstream (Nzoia River at Webuye)	17.000	0.309	165.000	0.213
Downstream (Nzoia River at Rwambwa)	19.000	0.345	165.000	0.161

The increasing streamflow is due to the deforestation of water catchment areas in the basin, which has resulted in bare land and increased run-off. Deforestation of water catchment areas included the removal of native trees and, in certain cases, the replacement of those trees with exotic species, crop lands, fallow land strips, and grazing land. JICA found that the replacement of rain forest species by pine plantations increased stream flows to the extent of an approximate 18 percent reduction in interception and evapo-transpiration losses in their research of the National water masterplan phase-1 [54]. Increased development in the basin has led to more concrete paved surfaces, which has resulted in higher stormwater flows. Streamflows may also be increased as a result of this. As a result, the observed rise in streamflows may be partly attributed to land use changes in the basin as well as climate change. With the projected annual rainfall generally showing a tendancy to increase slightly over the region, the annual river runoff is expected to increase. However, due to increased temperatures, increased evapotranspiration, and increased water demand resulting from rapidly growing populations for agricultural activities, domestic use, industry, and other emerging uses, modified flows may occur. River tributaries may indicate various responses under forecasted rainfalls due to existing variances in elevations across the river basin. Changes in mean annual runoff will vary both in space and time. Climate change will affect each section of the basin differently. The higher mountain areas (Elgon and Cherengani) are projected to get more rainfall than the middle catchment areas, with the lowest rainfall expected in the lower basin surrounding Lake Victoria. Runoff is likely to decline in most sections of the basin as temperatures rise in the coming years, owing to increased evapotranspiration. Although mean annual precipitation in the basin will not change significantly, variations in seasonal precipitation distribution may play a significant impact in determining changes in mean annual runoff [55]. Streamflow is a measurement of the rate at which water moves through rivers and streams, and it is a valuable resource for residential water supply in many parts of the world. One of the primary variables affecting residential water supply, according to Meuleman et al. [56], is declining streamflow. According to the Intergovernmental Panel on Climate Change, IPCC [57], climate change (mostly temperature and rainfall) would affect streamflow in a variety of ways (resulting in reduced and higher flows, etc.) with significant direct and indirect implications on drinking water supply. Residents of the Nzoia River Basin rely on streamflows for their domestic water supply, either directly or indirectly. The basin's major water sources, which serve both urban and rural populations, are based on the main Nzoia river and its tributaries, and their operations are heavily influenced by seasonal and annual fluctuations in streamflow.

3.3 Relationship between Streamflow and the Climatic variables of Rainfall and Temperature in Nzoia River Basin

The relationship between streamflow and the climatic variables of rainfall and temperature were checked using Pearson Moment Correlation analysis. The stronger the association of the two variables, the closer the Pearson correlation coefficient, *r*, will be to either +1 or -1 depending on whether the relationship is positive or negative, respectively. In quantifying the relationship between streamflow and the climatic variables of rainfall and temperature, a correlation analysis among the annual streamflow at individual stream gauging stations (Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1), rainfall and temperature in the associated meteorological stations was conducted. The result shows a strong positive relationship between rainfall and streamflow at 0.05 significance level for Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1). This shows that as rainfall increases, streamflow at the two stations increase and vice versa. Temperature shows a negative relationship with streamflow at 0.05 significance level for Nzoia river upstream at Webuye (IDD01) and Nzoia river downstream at Rwambwa (IEFO1); implying that as temperature increases, streamflow at the two stations decrease and vice versa. Correlation coefficients between annual rainfall and streamflow ranged from 0.798 to 0.895. The annual correlation coefficients are all exceeding 0.80 for all stations which indicates that the annual streamflow and rainfall has a good correlation. On the contrast, some temperature stations show a negative relationship with streamflow at 0.05 significance level for the two gauging stations whereas some temperatures are not completely associated with streamflow.

This could be explained by the meteorological stations' geographical distribution, which is far from stream gauging stations or uncontrolled climatic stations. The relationship between streamflow, rainfall, and temperature demonstrates the impact of climate on hydrological processes and streamflow. The fact that streamflow and rainfall have a positive association indicates that streamflow fluctuates in response to rainfall. In the Nzoia River Basin basins, changes in streamflow are highly influenced by changes in rainfall, with streamflow following the rainfall temporal pattern closely. Streamflow is positively connected to rainfall and negatively related to temperature, with rainfall sensitivity being substantially greater than temperature sensitivity. Given that rainfall is the primary determinant of runoff production, this is understandable. Higher temperatures cause more evaporation and transpiration, which is a second order effect [58,59]. However, because temperature changes occur at the same time as changes in rainfall attributes such as seasonality, spatial distribution, and intensity, it may be difficult to distinguish between the two. When the temperature rises, streamflow decreases. This is because, under normal rainfall conditions, actual evaporation increases as the temperature rises, but when the temperature rises to a certain point, actual evaporation reaches a maximum that equals wet environmental evapotranspiration [60]. At this point, the streamflow will not decrease, and the temperature elasticity will remain constant. Streamflow-temperature-rainfall correlations are basin-specific and season-dependent. For both annual and seasonal trends, streamflow is reasonably well linked with temperature and rainfall. The relationship between streamflow and rainfall in the upstream portions of the Nzoia River is better in the flood season than in the dry season. In the upstream portion of the river, however, the correlation of streamflow with temperature and rainfall is higher than at the lower station, both for the annual and flood season.

Natural streamflow is the result of rainfall, infiltration, evapotranspiration, and other hydrological cycles, which results in a natural water discharge with periodicity and hydrological anomaly. Runoff will be generated as long as the rainfall intensity is greater than the underlying surface's infiltration rate or the rainfall exceeds the land's storage capacity. Even if the above-mentioned event does not occur, rainfall might still have an indirect impact on future runoff by changing the water content of the ground. Temperature is another important factor in natural water discharge. It has two effects on water discharge: first, it increases potential and actual evaporation, which is bad for discharge yield; and second, it changes the form of precipitation (temperature rises can turn snowfall into rain), which changes the conditions for runoff generation. El Nino-Southern Oscillation (ENSO) and sunspots are two more elements that influence streamflow in the Nzoia River Basin. In the Negro and Uruguay Rivers, Mechoso and Iribarren [61] discovered a link between ENSO phase and streamflow. Xu et al., [62], Gong and Wang, [63], all came to the same conclusion. When evaluating a 60-year timeframe, Li et al., [64] discovered an association between sunspots and natural streamflow, with a correlation coefficient of 0.65. Rising temperatures in the Nzoia River Basin cause increased evaporation and evapotranspiration, which causes vegetation to utilize more water, resulting in reduced river flows. Rising temperatures also increase water demand, resulting in higher abstraction rates from existing water sources, leading to decreasing river flows. Similarly, rising temperatures will increase biological activity in soils, leading to less infiltration, which will result in lower aquifer recharge and reduced river flows. Rising temperatures in the basin mean that the atmosphere can contain more moisture, resulting in higher possible rainfall volumes and increased flooding risks, which affect river flows.

3.4 Potential Effect of Human Activities on Streamflow in Nzoia River Basin

The findings of this study suggest that there are some links between observed streamflow trends in the Nzoia River Basin and variations in climatic variables (rainfall and temperature), but we cannot say that this fully explains streamflow variability. Changes in other catchment features, such as river management and land use changes such as forest degradation and urbanization, can greatly contribute to streamflow changes in the basin. Although the climatic effect is the primary element in annual streamflow, land-cover changes will influence annual and seasonal river flows in the basin. The catchment features and water use in the basin will undoubtedly be influenced by urbanization and rapid population growth, among other factors. Although the trends in streamflow, rainfall and temperature have been analyzed as well as their correlations to streamflow, these statistics cannot estimate the effects of human activities on the hydrological processes.

4. CONCLUSION

As a result of the inter-tropical convergence zone (ITCZ), the Nzoia River Basin has four rainy seasons per year. There are two rainy seasons and two dry seasons. The basin's rainfall stations recorded both rising and falling annual rainfall trends. The annual mean temperatures at Kitale and Kakamega weather stations were rising, whereas the annual mean temperatures at Eldoret were declining. Temperatures in the Nzoia River Basin are expected to rise; however, the case of falling temperatures at Eldoret International Airport may be due to the fact that this region of the Rift Valley has highly protected natural resources and a high forest cover that is present all year; another possible explanation could be the changing cloudiness. Annual mean temperatures in Kitale and Kakamega increased by around 0.1 ^{0} C each century, while temperatures in Eldoret decreased by about -1.4 ^{0} C per century. The findings for the Kitale and Kakamega stations are consistent with the IPCC's Third Assessment Report's predicted global warming rate of 0.6 degrees Celsius during the twentieth century, as well as other African and Eastern African research results. Streamflow changes are frequently cited as a key indicator for assessing the impact of climate change on freshwater resources in any river basin. With the basin's temperature becoming warmer and wetter, an overall trend toward higher annual and seasonal streamflow should be projected. Based on current rainfall and temperature patterns, significant regional disparities in streamflow trends are projected in the basin. Changes in streamflow can be pretty well explained by changes in air temperature and rainfall, according to Pearson correlation data. Rainfall has a higher relative impact in the observed streamflow increase, whereas air temperature has a lower relative importance. It's safe to assume that rainfall has the greatest impact on streamflow. The relationship between streamflow and rainfall is rather strong, whereas the relationship between streamflow and air temperature is weak. Because of the significant effects of climate change on the other components of the water balance, the relationship between streamflow and air temperature is more complicated. More research on the systems that limit the effects of climate change on streamflow is urgently required. . This study may be of practical and scientific importance in guiding hydropower development and transboundary water resources management in the basin.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Huntington, T. G. Evidence for intensification of the global water cycle: Review and synthesis. J. Hydrol. 2006; 319:83–95.
2. IPCC. “Synthesis Report. Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on climate change Core writing team. In: Pachauri RK, Reisinger A (eds).,” Cambridge Univ. Press 32 Ave. Am. New York, NY 10013-2473, USA, p. 996, 2007.
3. Oki T, Kanae S. Global hydrological cycles and world water resources Science. 2009;313:1068–1072.
4. Christensen NS, Wood AW. Voisin N. Lettenmaier DP, Palmer RN. The effects of climate change on the hydrology and water resources of the Colorado River basin. Clim Chang. 2004;62:337–363.
5. Immerzeel WW, Konz M. Shrestha A, Bierkens M. Hydrological response to climate change in a glacierized catchment in the Himalayas. Climatic. 2012;110:721–736.
6. Labat D, Goddéris Y, Probst JL, Guyot JL. Evidence for global runoff increase related to climate warming. Adv. Water Resour. 2004;27:631–642.
7. Milliman JD, Farnsworth KL, Jones PD, Xu KH, Smith LC . Climatic and anthropogenic factors affecting river discharge to the global ocean, 1951–2000. Global Planet. Change, 2008;62:187–194.
8. Arnell NW, Gosling SN. The impacts of climate change on river flow regimes at the global scale. J. Hydrol. 2013;486:351–364.
9. Groisman P, Ya RW. Knight TR, Karl DR. Easterling BS, Lawrimore JH. Contemporary changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations. J. Hydrometeor. 2004;5:64–85.
10. Milly PCD, Dunne KA, Vecchia AW. Global pattern of trends in streamflow and water availability in a changing climate. Nature. 2005;438:347–350.
11. Nijssen B, O’Donnell G, Hamlet A, Lettenmaier D. Hydrologic sensitivity of global rivers to climate change. Clim Chang, 2001;50:143–175.

12. Currie RG. Variance contribution of luni-solar (Mn) and solar cycle (Sc) signals to climate data. Int. J. Climatol. 1996;16:1343-1364.
13. Probst J, Tardy Y. Long range streamflow and world continental runoff fluctuation since the beginning of this century. J. Hydrol. 1987;94:289-311.
14. Williams G.R. Cyclical variations in the world-wide hydrological data. J. Hydraul. Div. 1961;6:71-88.
15. Whitfield PH. Linked hydrologic and climate variations in British Columbia and Yukon.Environ. Monit. Assess. 2001;67:217-238.
16. Woodhouse CA. A tree-ring reconstruction of streamflow for the Colorado front range. J. Am. Water Resour. As. 2001;37:561-569.
17. Gedalof Z, Peterson DL, Mantua NJ. Columbia river flow and drought since 1750. J. Am. Water Resour. As. 2004;40:1579-1592.
18. Absalon D, Matysik M. Changes in water quality and runoff in the Upper Oder River basin. Geomorphology. 2007;92:106-118.
19. Sen PK. Estimates of the regression coefficient based on Kendall's tau. J. Am. Stat. Assoc. 1968;63:1379–1389.
20. Odwori EO, Munyendo LLW. Impact of Covid-19 crisis on drinking water utilities in Nzoia River Basin, Kenya. African Journal of Social Sciences and Humanities Research. 2020;3(6):204-215.
21. Odwori, E.O. Climate change and Domestic water supply in Nzoia River Basin, Kenya. PhD. Thesis. Department of Disaster Management and Sustainable Development, Masinde Muliro University of Science and Technology, Kakamega, Kenya;2021.
22. Pfaundler M. Adapting, analysing and evaluating a flexible index flood regionalisation approach for heterogeneous geographical environments. Institute of Hydromechanics and Water Resources Management, IHW Publ. 008, ETH Zurich (189 pp.), 2001.
23. KMD. Monthly Rainfall data for Leissa Farm Kitale, Kaptagat Forest Station, Kakamega Meteorological Station, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp (1970-2001) and Monthly Maximum and Minimum Temperature data for Kitale and Kakamega meteorological stations (1979-2014) and Eldoret international airport (1999-2014). Kenya Meteorological Department (KMD), Nairobi, Kenya; 2017.
24. Roman R, Bilbao J, De Miguel A. Reconstruction of six decades of daily total solar shortwave irradiation in the Iberian Peninsula using sunshine duration records. Atmos. Environ. 2014;99:41–50.
25. El Kenawy A, Lopez-Moreno JI, Stepanekc P, Vicente-Serrano SM. An assessment of the role of homogenization protocol in the performance of daily temperature series and trends: Application to northeastern Spain. Int. J. Climatol. 2013;33:87–108.
26. Bilbao J, De Miguel A, Ayuso A, Franco JA. Iso-radiation maps for tilted surfaces in the Castile and Leon region, Spain. Energy Convers. Manag. 2003;44:1575–1588.
27. Miguel A, Bilbao J, Román R, Mateos D. Measurements and attenuation of erythemal radiation in Central Spain. Int. J. Climatol. 2003;32:929–940.
28. Gocic M, Trajkovic S. Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Glob. Planet. Chang. 2013;100:172–182.
29. Kundzewicz ZW. Change detection in hydrological records – a review of the methodology. Hydrol. Sci., J. 2004;49(1):7–19.
30. Mann, H.B. Nonparametric Tests Against Trend. Econometrica. 1945;13:245.
31. Tabari H, Marofi S, Aeini A, Talaee PH, Mohammadi K. Trend analysis of reference evapotranspiration in the western half of Iran. Agric. For. Meteorol. 2011;151:128–136.
32. Da Silva RM, Santos CAG, Moreira M, Corte-Real J, Silva VCL, Medeiros IC. Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin. Nat. Hazards. 2015;77:1205–1221.
33. Duhan D, Pandey A. Statistical analysis of long term spatial and temporal trends of precipitation during 1901–2002 at Madhya Pradesh, India. Atmos. Res. 2013;122:136–149.
34. Tabari H, Marofi S, AhmadiM. Long-term variations of water quality parameters in the Maroon River, Iran. Environ. Monit. Assess. 2011;177:273–287.
35. Tabari H, Talaee PH. Temporal variability of precipitation over Iran: 1966–2005. J. Hydrol. 2011;396:313–320.

36. Kendall M. Rank Correlation Methods; Charles Griffin: London, UK;1975.
37. Yue S, Pilon P, Cavadias G. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J. Hydrol. 2002;259:254–271.
38. Jain SK, Kumar V. Trend analysis of rainfall and temperature data for India. Curr. Sci. 2012;102:37–49.
39. Muchuru S, Botai JO, Botai CM, Landman WA, Adeola AM. Variability of rainfall over Lake Kariba catchment area in the Zambezi River Basin, Zimbabwe. Theor. Appl. Climatol. 2016;124:325–338.
40. Modarres R, da Silva VDPR. Rainfall trends in arid and semi-arid regions of Iran. J. Arid Environ. 2007;70:344–355.
41. Yue S, Hashino M. Long term trends of annual and monthly precipitation in Japan. J. Am. Water Resour. Assoc. 2003;39:587–596.
42. Koudahe K, Djaman K, Kayode JA, Awokola SO, Adebola AA. Impact of Climate Variability on Crop Yields in Southern Togo. Environ. Pollut. Clim. Chang. 2018;2:148.
43. Sen PK. Estimates of the Regression Coefficient Based on Kendall's Tau. J. Am. Stat. Assoc. 1968;63:1379–1389.
44. Pearson K. Early Statistical Papers. Cambridge, England: University Press;1948.
45. Burns N, Grove S. The Practice of Nursing Research: Conduct, Critique, and Utilization (5 ed.). St. Louis: Elsevier Saunders; 2005.
46. Polit D, Beck C. Essentials of Nursing Research: Methods, Appraisal, and Utilization (6 ed.). Philadelphia: Lippincott Williams & Wilkins; 2006.
47. Cramer D. Fundamental Statistics for Social Research. London: Routledge; 1998.
48. Okoola RE. "Space – Time characteristics of the ITCZ over equatorial East Africa during anomalous rainfall years". PhD. Thesis. Department of Meteorology, University of Nairobi, Kenya; 1996.
49. Mistry VV, Conway D. Remote forcing of East African rainfall and relationship with fluctuations in levels of Lake Victoria. Int J Clim. 2003;23:67–89.
50. Nicholson SE. A review of climate dynamics and climate variability in Eastern Africa. In: Johnson TC, Odada EO (eds) The limnology, climatology and palaeoclimatology of East African Lakes. Gordon and Breach, Melbourne, Australia. 1996;25–56.
51. Githui FW. Assessing the impacts of environmental change on the hydrology of the Nzoia catchment, in the Lake Victoria Basin. Department of Hydrology and Hydraulic Engineering Faculty of Engineering Vrije Universiteit Brussel Pleinlaan 2 1050 Brussels. Ph.D Thesis;2008.
52. Yenigun K, Gumuş V, Bulut H. Trends in streamflow of the Euphrates basin, Turkey, Water Management. 2008;161:189–198.
53. Camberlin P, Okoola RE. The onset and cessation of the ''long rains'' in eastern Africa and their interannual variability. Theor. Appl. Climatol. 2003;75:43–54.
54. WRMA. Water Resources Management Authority Lake Victoria North Catchment Area. Reports. Kakamega, Kenya; 2007.
55. Chang H, C. Gregory K, Marieta PS, Deyan K. Water resource impacts of climate change in southwestern Bulgaria;2002.
56. Meuleman AFM, Cirkel G, Zwolsman GJJ. When climate change is a fact! Adaptive strategies for drinking water production in a changing natural environment. Water Science and Technology. 2007;56:137-144.
57. IPCC. Climate Change. The Physical Science Basis. Cambridge University Press. 2007;996.
58. McCarthy JJ, et al. Climate change 2001: Working group II: Impacts, adaptation and vulnerability. Contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2001.
59. Cai W, Cowan T. Evidence of impacts from rising temperature on inflows to the Murray– Darling Basin. Geophysical Research Letters. 2008;35.
60. Fu GB, Charles SP, Yu JJ, Liu CM. Decadal climatic variability, trends and future scenarios for the North China Plain. J Climate. 2009;22:2111–2123.
61. Mechoso CR, Iribarren GP. Streamflow in Southeastern America and the Southern Oscillation. J. Climate. 1992;5:1535-1539.
62. Xu ZX, Chen YN, Li JY. Impact of climate change on water resources in the Tarim river basin. Water Resour. Manag. 2004; 18:439-458.
63. Gong DY, Wang SW. Impact of ENSO on global precipitation and precipitation in

China during past 100 years. Chinese Sci. Bull. 1999;44:315-320.
64. Li CH, Yang ZF, Huang GH, Li YP. Identification of relationship between sunspots and natural runoff in the Yellow River based on discrete wavelet analysis. Expert Syst. Appl. 2009;36:3309-3318.

Peer-review history:
The peer review history for this paper can be accessed here:
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