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Analysis of Rainfall Variability and Trends Over Nzoia River Basin, Kenya

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Nzoia river is mainly rain fed and the basin is one of the regions that is highly vulnerable to climate change in Kenya. Understanding rainfall variability and trends is important for better water resources management and economic development in the basin. The aim of this study is to assess variability and trends in rainfall at 13 sites within Nzoia River Basin over the period, 1970 to 2001, using the parametric test of Linear regression analysis and the non-parametric Mann–Kendall statistical test. Data for this study was obtained from the Kenya Meteorological Department (KMD). The basin experiences four rainfall seasons in a year as a result of the Inter-Tropical Convergence Zone (ITCZ). There are two rainy seasons and two dry seasons. Annual rainfall through Linear regression analysis shows 6 stations, Kaimosi Tea Estate Ltd, Kakamega Meteorological Station, Bungoma Water Supply, Nzoia Forest Station, Malava Forest Station and Webuye Agricultural Office with declining rainfalls. The remaining 7 stations, Leissa Farm Kitale, Turbo Forest Nursery, Chorlim ADC Farm, Kaptagat Forest Station, Kimilili Agricultural Department, Bunyala Irrigation Scheme and Kadenge Yala Swamp showed increasing rainfalls. The majority of stations with increasing annual rainfall are in the upper catchment whereas those with decreasing rainfall are in the middle and lower catchment. Only 3 out of the 13 stations showed statistically significant trends

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in rainfall with two in the upper catchment and one in the middle; the remaining 10 stations had statistically insignificant trends. These observed changes in rainfall, although most time series are not convincing as they show predominantly no significance, along with the reported climatic warming in most parts of the basin may have future implications on human health, water resources management, various plant and animal species bio-diversity and the overall economic development of the basin.

Keywords: Nzoia river basin; rainfall; variability and trends; linear regression analysis; Mann-Kendall statistical test.

1. INTRODUCTION

Climate change has become a global problem for all. The IPCC [1] discusses the average pattern of global temperatures from 1880 to 2012, which stands at 0.85 degrees Celsius (with a degree of uncertainty ranging between 0.65°C and 1.06 °C). The increase in temperature over the last decade (2003–2012) was +0.780°C (with minimum tempratures at 0.72 °C and maximum tempratures at 0.85 °C). With an anomaly of +0.69 °C (calculated for the period 1880–2014), the National Climatic Data Center (NCDC) considers 2014 to be the warmest year ever reported [2]. According to the World Meteorological Organization (WMO), the years 2011–2015 were the hottest on record, with 2015 being the hottest year since modern records started in the late 1800s. Rainfall is expected to increase in a variety of regions around the world as the global temperature rises. Under the influence of high temperatures, the hydrological cycle can modify, resulting in more rainfall and evaporation [3]. Several research on rainfall evolution in many parts of the world, including North Africa, indicate that climate change leads to wetter conditions [4,5], as well as a rise in rainfall and the occurrence of extreme events [3,6].

Rainfall variability and trends is one of the most critical aspects of climate change research, and many attempts to study both spatial and temporal variation of rainfall have been made around the world. Precipitation trends have been observed in many parts of the world over the last century. Precipitation rose dramatically in eastern parts of North and South America, northern Europe, and northern and central Asia during this period, while it fell in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia [7]. Suppiah and Hennessy [8] reported rising rainfall trends in Australia, while Burns et al. [9] reported rising trends in New York, USA. On the other hand, Buffoni et al. [10] found declining rainfall trends in Central-South Italy, Kipkorir, [11] noted declining rainfall in Kenya , and Northeast Brazil had declining rainfalls as reported by Silva, [12]. Modarres and Silva [13] found mixed patterns of rising and decreasing rainfall in Iran.

Rodrigo et al. [14] used a reconstructed 500-year sequence from historical sources to study rainfall variability in Andalusia (southern Spain) on decadal to centennial time scales. Rainfall Levels on the Canadian Prairies indicate that the prairies are not becoming drier, but there are seasonal and spatial variations in rainfall patterns [15]. Within the North American Monsoon (NAM) region, Englehart and Douglas [16] provided an empirical explanation of intraseasonal rainfall variability. The monsoon core regions have shown a positive linear trend in intensity as the monsoon season has shortened, while southeast Arizona has shown distinct multidecadal variability. In the time series of standardized precipitation anomalies averaged over Nepal, Ichiyanagi et al. [17] found no major long-term patterns. From the mid-1990s to the present, Ati et al. [18] found an increase in annual rainfall in Kano, but no consistent pattern in the onset of the rainy season. The non parametric Mann-Kendall test was used by Gonzalez et al. [19] to classify patterns in seasonal rainfall observed in Mexico from 1920 to 2004. Rainfall in the arid and semi-arid areas, as well as the tropical humid regions, has risen by 1.8 percent and 0.9 percent per year, respectively.

Several studies on the changing pattern of rainfall in India found no clear trend of increasing or decreasing average rainfall across the region [20,21]. Several studies have found significant trends in rainfall on a regional scale, despite the fact that long-term trends in monsoon rainfall have not been observed on an all-India scale [22,23,24]. According to some reports, the amount of heavy rainfall events has decreased in many parts of Asia, although the number of rainy days and average annual precipitation has decreased [25,23].

Conway et al. [26] found significant variability in rainfall and river flows in Sub-Saharan Africa during the twentieth century. East Africa's rainfall is notorious for its inter-annual instability, which has exacerbated crippling droughts and floods [27]. The El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and movement of the inter-tropical convergence zone (ITCZ) are all related to large-scale climate variability in this area, according to several studies [28]. The warming of the ocean temperature causes a rise in rainfall and a shift in the path of the ITCZ, and ENSO has several effects on precipitation [29]. IOD, on the other hand, reflects the tropical Indian Ocean's sea surface temperature variability, which has a major impact on the climates of East Africa, Indonesia, India, and some areas of Australia and Asia [30]. In general, large-scale climate forcings and changes in sea surface temperature modulate rainfall variability in East Africa, especially inter-annual variability, which affects rainfall amount (e.g., decrease during the long-rain season; March-May) by changing wind patterns and moisture fluxes [31].

Many African regions lack full long-term rainfall data from the past century, making it difficult to draw any conclusions about annual rainfall trends during this period; additionally, many regional datasets differ when compared to one another, making it difficult to draw any conclusions about annual rainfall trends during this time [32,33,34]. Rainfall patterns in East Africa display a growing trend in those regions with complete long-term data; however, rainfall patterns in East Africa are highly characterized by temporal and spatial variability due to several components [35,27]. Nicholson et al. [36] note that since the 1970s, patterns of rising aridity in rainfall over the Sahel region have been observed. Williams and Funk [37] report that rainfall in East Africa has decreased during the long rainy season (March/May/June) over the last three decades, confirming this trend. Lyon and DeWitt [38] also report that seasonal rainfall in East Africa has decreased over the same time span. The rapid warming of the Indian Ocean [37] is one possible explanation for this drying trend, and this warming trend is thought to amplify the drying effect of warm ENSO events in the area [35]. It's also likely that increased frequency and persistence of strong ENSO events have been observed in recent years as a result of global warming [35]. However, according to Nicholson et al. [36], this pattern should not be interpreted as a long-term trend toward aridity, but rather as a series of historical rainfall fluctuations. The extent to which human-induced changes in land cover and climate change lead to fluctuations in African rainfall is still unknown [39,35]. Funk [40] claims that there have been significant decreases in rainfall in Kenya between 1960 and 2009 (during the long rain-season, March to June) and claims that if these observed changes continue until 2025, extensive parts of Kenya will experience more than a 100 mm decrease in rainfall during the long rain-season. In addition, the Kenyan government estimates that rainfall amounts for the long rain season have been smaller in recent years than they were in the early 1960s [41].

Extreme weather events have become more common across the world, and they are expected to become more common in the twenty-first century (IPCC 2014). Several studies [42,43,37,38] have found that the frequency of severe events such as droughts and heavy rainfall has increased in Eastern Africa over the last 30-60 years. According to Williams and Funk [37], the Indian Ocean's warming has resulted in a higher frequency of East African droughts in the spring and summer seasons over the last 30 years. However, Lyon and DeWitt [38] note that it is unclear if the aforementioned changes are the result of human intervention or natural variability.

The people of the Nzoia River Basin face a significant threat as a result of climate change. Climate change is causing the basin to experience more erratic rainfall, as well as the total failure of seasonal rains. It is a basin with significant regional variations, which are reflected in its climatic vulnerability. Increased temperatures and severe droughts threaten the lowlands, posing a threat to human economic activity. Higher temperatures, combined with more extreme and erratic rainfall, can cause erosion in the highlands, resulting in lower total agricultural output. Climate change poses a greater threat to the basin as a result of this, particularly as the population grows. However, there are few comprehensive studies on the variability and trends of rainfall in the basin. Rainfall in the Nzoia River Basin during the long rainy season causes severe damage to human life, crops, and life and infrastructure, especially in the Bunyala plains, where floods have caused devastating damage in recent decades. Man's actions have resulted in irreversible changes in landscapes, resulting in the extinction of the region's fragile biodiversity. As a result, there is a pressing need to examine rainfall variability and trends in Nzoia River Basin in order to develop long-term strategies to mitigate and restore ecosystem harm. Variation in rainfall frequency and distribution as a result of climate change, according to the IPCC [7], should be examined regionally in order to manage resources, establish preparedness plans, and adapt to the changing climate. The key method in determining the state of a region's environment is trend analysis of climate variables, which offers an overall estimation of the variations in the climate variables. Since understanding climate variability and trends is critical in so many ways, accurate forecasting and prediction of climate variables is critical for policymakers, planners, and those involved in water resource management, as well as mitigation and adaptation steps to deal with climate change. Furthermore, such forecasts are crucial for controlling water supply and demand, preventing floods and droughts, sustaining river water levels, planning and preparing for disasters, minimizing uncertainty by providing information on potential water availability, and optimizing water resource distribution, among other things [44]. Understanding the uncertainties associated with rainfall patterns would provide a knowledge base for improved water management in the basin, including agriculture, irrigation, domestic water supply, and other water-related activities.

2. MATERIALS AND METHODS

2.1 Study Area

Nzoia River Basin is located entirely within Kenya, along the Ugandan border in the Lake Victoria Basin. It has an area of 12,959 km2 and a river length of 334 km up to its outfall into Lake Victoria, and is situated between latitudes 10 30' N and 00 05' S and longitudes 340 E and 350 45' E. The counties of Trans Nzoia in the upper catchment, Kakamega in the middle catchment, and Busia in the lower catchment were chosen for this analysis. The basin has a population of around 3.7 million people and is located within Kenya's Lake Victoria basin, which is one of the world's poorest and fastest growing areas. The basin is made up of nine counties; Elgeyo/Marakwet, West Pokot, Trans Nzoia, Uasin Gishu and Nandi (in former Rift Valley province); Kakamega, Bungoma and Busia (in former Western province) and Siaya (in former Nyanza province) [45].

2.2 Water Resources

Mt. Elgon and the Cherengani Hills Forest are the sources of Nzoia River. The Mt. Elgon forest catchment is situated north of Lake Victoria, on the Kenyan-Ugandan border. The forest belt is protected by the National Park and Forest Reserves, and Elgon acts as the upper catchment area for two major rivers, Nzoia and Turkwel. It also feeds the Malakisi and Malaba rivers, which flow through a small farming area south of the mountain before draining into Uganda's Lake.

Nzoia River is one of Western Kenya's main rivers, draining into Lake Victoria and adding to the waters that feed the Nile River. It’s catchment area comprises of distinct drainage areas originating from Mt Elgon area; Cheranganyi, Bungoma, Kimilili and Nandi hills including Kakamega area and the Lower Nzoia area up to Lake Victoria. Nzoia River Basin is situated between the basins of Lake Victoria and Lake Turkana. Streams flowing west of the Cheranganyi watershed feed Nzoia river system, which empties into Lake Victoria, while streams flowing to the east feed the Kerio river system. Nzoia River and its tributaries provide a constant supply of water, but the flows differ depending on the season. From an elevation of approximately 2,286 meters above sea level, the river's main streams flow from the western side of the Elgeyo escarpment (Sergoi, Sosiani, and Kipkelion tributaries) and the Cherengani hills (Chepkotet and Kaisungur tributaries). It has several tributaries and a basin elevation of 1,917 meters above sea level. The tributaries that flow from Mt. Elgon's high slopes reach a maximum elevation of 4,300 meters above sea level in the river basin. Kuywa, Sioso Ewaso, Rongai, and Koitobos are some of Mt. Elgon's tributaries. The river flows from north to south, with a mean slope of 0.010 percent from source to discharge into Lake Victoria at a distance of around 1,000 meters [45].

Nzoia River joins Lake Victoria a short distance north of Yala Swamp, and the plains along the river's downstream reaches are prone to flooding. Moiben, Kapolet, Koitobos, Rongai, Kimilili, Kipkaren, Lusumu, Isiukhu, and Wuoroya are the major tributaries of Nzoia River. Nzoia River Basin's mean discharge is about 118 m3/s, with the lowest flow being 2.8 m3/s, the highest probable flood being 1,000 m3/s, and the 100-year flood being 930 m3/s. The average channel width of the river is 40 meters, and the average gradient is 1 in 240 meters [45].

2.3 River Basin Geology

From metamorphic basement rocks to volcanic rocks to quaternary sedimentary rocks, the geology of Nzoia River Basin is very diverse. Tertiary volcanic rocks, mostly phonolites and agglomeratic tuffs, dominate the landscape around Mt. Elgon. Tertiary volcanic rocks, such as phonolites and agglomeratic tuffs, characterize the plateau regions, which include Uasin Gishu and parts of Nandi. The metamorphic basement rocks covering the catchment's middle zone are mostly gneissic rocks. Kitale, parts of Bungoma, and West Pokot are among these regions. Volcanic rocks of the Kavirondian basin characterize the catchment's lower reaches. Meta-sediments, grits, and conglomerates are among them. Areas like Busia, Butere, and parts of Bungoma and Webuye have this sort of geological formations. Granitic rocks intrude on the kavirondian system rocks in some areas (Mumias granite). Volcanic rocks from the Nyanzian system, which include basalts, rhyolites, andesites, and rhyolitic tuffs, are found in some areas of the lower Nzoia River Basin, such as Siaya. Within the wider catchment, the volcanic rocks overlie the basement system.

The basin is divided into three physiographic regions: the highlands (which include Mt. Elgon and the Cherangani hills), the upper plateau (which includes Eldoret and Kitale), and the lowlands (which includes Busia that experiences the majority of flooding in the basin). The Eldoret and Kitale plains have rolling hills and lowlands as their dominant topography. The soils of the upper Nzoia River Basin are defined as light clay with good drainage and moisture ability, as well as high fertility. Clay (77 percent), loamy (9 percent), and sandy soil textures are found in Nzoia River Basin (14 percent). The Ferralsol form well-drained soils in the basin, which are mostly found on level to undulating land. The Acrisols in the basin form clay-rich soils that sustain forestry and are associated with humid tropical climates; while the Nitisols make up thick, well-drained red tropical soils that are mostly found in the highlands and cover more than 75% of the catchment [45].

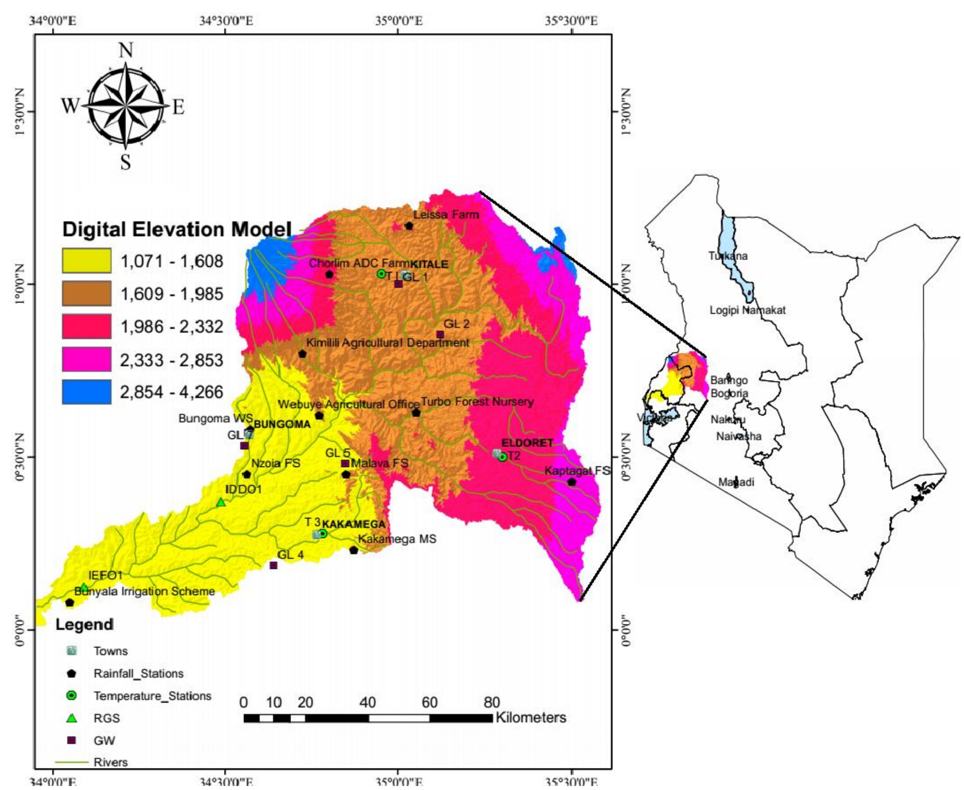


Fig. 1. Map of Nzoia River Basin, Kenya

2.4 Climate and Land use

The climate of Nzoia River Basin is mainly tropical humid, with day temperatures ranging from 16°C in Cheranganyi and Mt. Elgon to 28°C in Bunyala's lower semi-arid plains. Temperatures at night range from 4°C in the highlands to 16°C in the semi-arid lowlands. The highest annual rainfall ranges from 1100 to 2700 mm. The lowest annual rainfall ranges from 600 to 1100 mm. Maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava are the main food crops grown in the area, while coffee, sugar cane, tea, wheat, rice, sunflower, and horticultural crops are the main cash crops. In addition to conventional livestock keeping, the residents of the basin also practice dairy farming [45].

2.5 Data Sources

Monthly rainfall data were collected for thirteen stations; Leissa Farm Kitale, Turbo Forest Nursery, Chorlim ADC Farm, Kaptagat Forest Station, Kaimosi Tea Estate Ltd, Kakamega Meteorological Station, Bungoma Water Supply, Nzoia Forest Station, Malava Forest Station, Kimilili Agricultural Department, 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.1. The rainfall data are expressed in millimetre (mm).

Rainfall stations 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 rainfall for each of the stations. Mean annual rainfall were obtained by averaging the monthly values for each year. Further information regarding the measurement uncertainty is given in Roman et al. [46]. 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. [47]; Bilbao et al. [48]; Miguel et al. [49] and Roman et al. [46]. Instrumentation and alteration of surrounding land cover might create non-homogeneity and/or inconsistencies in meteorological data recordings (Gocic and Trajkovic, [50].

2.6 Methodology

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. Different scholars have used different methodologies for trend detection. Kundzewicz, [51] has discussed the change detection methodologies for hydrologic data. In general, the magnitude of trend in a time series is determined either using regression analysis (parametric test) or using Sen's estimator method (non-parametric method) Sen, [52]. Both methods assume a linear trend in the time series. For effective water resource management, trend analysis of rainfall time series data is essential by Mann-Kendall (MK), Sen's slope estimator, and multiple regression models. Considerable studies have been conducted to detect the regional rainfall trends on annual, seasonal, and monthly bases using the non-parametric Mann-Kendall (MK) test, regression analysis, and Sen's slope estimator test. For example, Caloiero et al. [53] used the Mann-Kendall (MK) and linear regression method to analyze annual and seasonal rainfall variability in Calabria, Southern Italy and obtained a decreasing trend in annual, autumn, and winter precipitation and an increasing trend in summer. The trends in annual mean precipitation show uniform uncertainty over nearly all of China, except for the northwest by using Mann-Kendall test [54]. Furthermore, significant increasing trends in annual and seasonal precipitation was observed in Northwest China from 1960–2013 using the MK test [55].

2.7 Regression Analysis

Regression analysis is conducted with time as the independent variable and rainfall as the dependent variable. The regression analysis is carried out directly on the time series or on the anomalies (i.e. deviation from mean). A linear equation, $y = mt + c$, defined by c (the intercept) and trend m (the slope), is fitted by regression. The linear trend value represented by the slope of the simple least-square regression line provides the rate of rise or fall in the rainfall.

2.8 Sen's Slope Estimator Test

The MK test does not provide an estimate of the magnitude of the trend, hence for this purpose, different statistical estimators have been used over the world to study the climatological time series, eg.rainfall. The magnitude of a trend in a time series can be determined using a non-

Table 1. 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 (m.a.s.l)	Mean Annual Rainfall (mm/year)
		UPPER CATCHMENT				
R I	8835039	Leissa Farm Kitale	1.17	35.03	1968	995
R 2	8935170	Turbo Forest Nursery	0.63	35.05	2001	1307
R 3	8834013	Chorlim ADC Farm	1.03	34.80	1951	986
R 4	8935010	Kaptagat Forest Station	0.43	35.50	2624	1212
R 5	8934072	Kaimosi Tea Estate Ltd	0.15	34.93	1902	2021
		MIDDLE CATCHMENT				
R 6	8934028	Kakamega Meteorological Station	0.23	34.87	1804	1982
R 7	8934134	Bungoma Water Supply	0.58	34.57	1509	1515
R 8	8934138	Nzoia Forest Station	0.45	34.56	1812	1196
R 9	8934130	Malava Forest Station	0.45	34.85	1636	1834
R 10	8934060	Kimilili Agricultural Department	0.80	34.72	1804	1467
R 11	8934119	Webuye Agricultural Office	0.62	34.77	1681	1532
		LOWER CATCHMENT				
R 12	8934139	Bunyala Irrigation Scheme	0.08	34.05	1232	1099
R 13	8934140	Kadenge Yala Swamp	0.03	34.18	1256	1095

parametric method known as Sen's estimator [52]. To estimate the true slope of an existing trend such as the amount of change per year, Sen's non-parametric method is used. Sen's Slope method involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope. The Sen's method assumes that the trend is linear.

This approach provides a more robust slope estimate than the least-squares method because it is insensitive to outliers or extreme values and competes well against simple least squares even for normally distributed data in the time series Fan and Yao [56]. The climate variability study of data series and its analysis requires trends and their statistical significance to be evaluated. Trend evaluations in seasonal and annual rainfall can be performed using the Theil-Sen (TTS) estimator and its 95% (α = 0.05) confidence interval (95CI). This estimator can be calculated following the methods proposed by Sneyers, [57]; Gilbert, [58]. The results provide the most suitable trend values due to the sensitivity of the method to extreme data, Sayemuzzaman et al. [59]. Similar tests have also been used by Sayemuzzaman et al. [59]; Roman et al. [46]; Espadafor et al. [60]; Gocic and Trajkovic, [50].

2.9 The Mann-Kendall Non-Parametric Trend Test of Significance

The Mann Kendall test [61,62] is a statistical test widely used for trend analysis in climatological and hydrological time series [63]. This is a rank based method which is non-parametric and is based on an alternative measure of correlation called Kendall's τ. The Mann-Kendall tests are based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks with the samples [62]. The statistic τ is defined as the difference between the probabilities of concordance and discordance between the two variables. Mann [61] originally used MK test and

Kendall [62] subsequently derived the test statistic distribution. The Mann-Kendall statistical test is frequently used to quantify the significance of trends in meteorological time series. The advantage of the method is that normal distribution of data is not expected. The result is seldom influenced by the fewer abnormal values and calculation is simple. There are two advantages of using this test. First, it is a non-parametric test and does not require data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series [64]. Any data reported as non-detects are included by assigning them a common value that is smaller than the smallest measured value in the data set.

A score of +1 is awarded if the value in a time series is larger, or a score of −1 is awarded if it is reduced. The overall score for the time-series data is the Mann–Kendall statistic which is then compared to a critical value to test whether the trend in rainfall is increasing, decreasing or if no trend can be observed. The strength of the trend is proportional to the magnitude of the Mann–Kendall Statistic. Sgn (Xj − Xk) is an indicator function that results in the values 1, 0, or −1 according to the significance of Xj − Xk where j > k, the function is calculated as follows:

sgn (Xj − Xk) = 1 → if , Xj − Xk > 0

sgn (Xj − Xk) = 0 → if , Xj − Xk = 0

sgn (Xj − Xk) = −1 → if , Xj − Xk < 0

where Xj and Xk are the sequential rainfall values in months J and K (J > k) respectively; whereas, a positive value is an indicator of increasing (upward) trend and a negative value is an indicator of decreasing (downward) trend.

In the equation, X1, X2, X3,…,Xn represents 'n' data points (monthly), where Xj represents the data point at time J. Then the Mann–Kendall statistics (S) is defined as the sum of the number of positive differences minus the number of negative differences, given by:

$$\mathrm{S} = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn} = (\,xj - xk)$$

where

sgn (Xj − Xk) = 1 → if , Xj − Xk > 0

sgn (Xj − Xk) = 0 → if , Xj − Xk = 0

sgn (Xj − Xk) = −1 → if , Xj − Xk < 0

Trends considered at the study sites were tested for significance. A normalized test statistic (Z-score) is used to check the statistical significance of the increasing or decreasing trend of mean rainfall values. The trends of rainfall are determined and their statistical significance is tested using Mann–Kendall trend significant test with the level of significance 0.05 (Z_α/2 = ± 1.96).

$$Z = \frac{\mathrm{n}-1}{\sqrt{\mathrm{Var}\,(\mathrm{S})}} \quad \rightarrow \text{if } \; S > 0$$

Z = 0 → if , S = 0

$$Z = \frac{\mathrm{n}-1}{\sqrt{\mathrm{Var}\,(\mathrm{S})}} \quad \rightarrow \text{if } \; S < 0$$

Hypothesis testing Ho = μ = μo (there is no significant trend/stable trend in the data).
Ha = μ_ μo (there is a significant trend/unstable trend in the data) If $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$ accepts the hypothesis or else reject the null hypothesis. Powerfully increasing or decreasing trends indicate a higher level of statistical significance [65].

3. RESULTS AND DISCUSSION

3.1 Monthly Rainfall Distribution

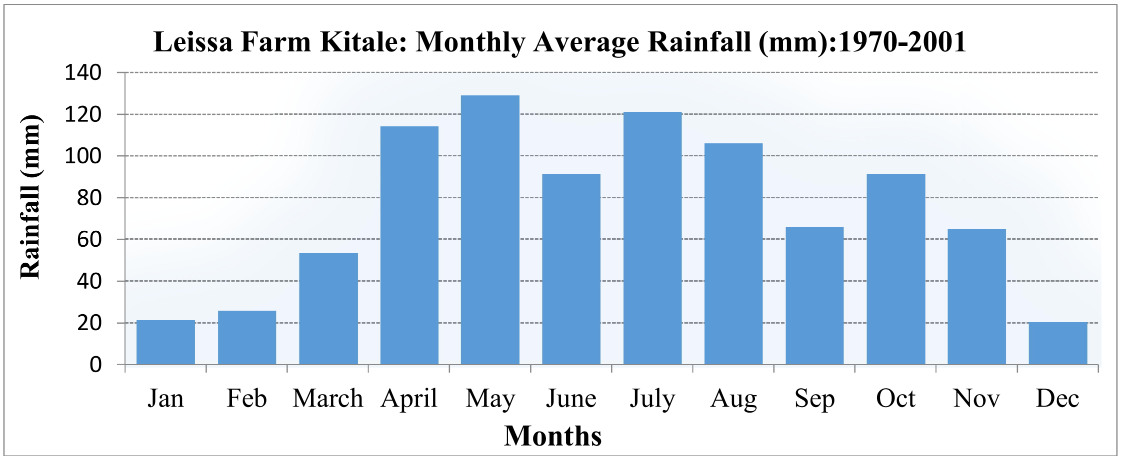
Figure.2 shows monthly rainfall distribution for Leissa Farm Kitale, Turbo Forest Nursery, Chorlim ADC Farm, Kaptagat Forest Station, Kaimosi Tea Estate Ltd, Kakamega Meteorological Station, Bungoma Water Supply, Nzoia Forest Station, Malava Forest Station, Kimilili Agricultural Department, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp with 31 years data covering the period 1970 to 2001. A better understanding of the rainfall pattern is important for formulating efficient water resource management and climate change adaptation policies [45].

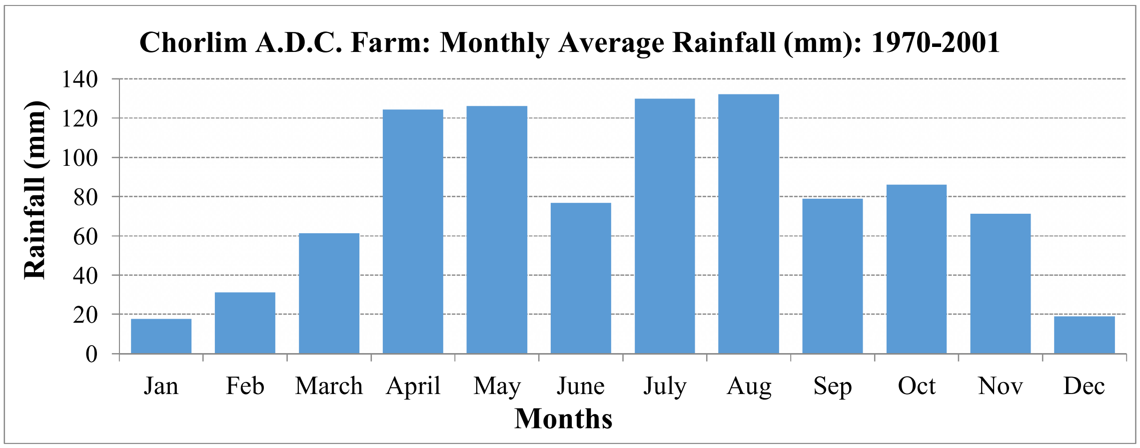
Leissa farm recorded a monthly mean rainfall of 82.27 mm in the period 1979 - 2001. The region experienced a major peak in May (139.92 mm) after which monthly rainfall gradually decreased with a minor peak in July and August. From there, the monthly rainfall continued to decrease until a minimum was reached in December (20.90 mm) and January for the next cycle to begin. Chorlim A.D.C Farm on the other hand recorded a monthly mean rainfall of 86.37 mm in the period 1979 – 2001 with a major peak of rainfall at 147.23 mm in August, followed by other peaks occurring in July, May and April, after which from August the total monthly rainfalls declined reaching the lowest level of 16.26 mm in December and January.

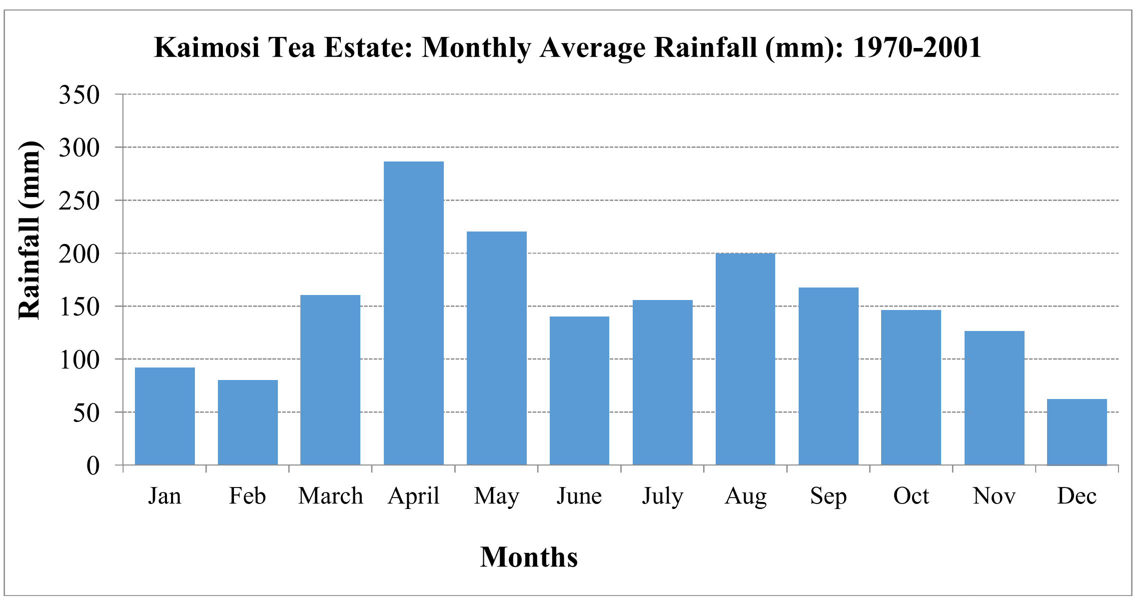
Kaimosi Tea Estate monthly mean rainfall from 1970 to 2001 was found to be 171.66 mm. The station indicates a major peak in April with 300.79 mm after which monthly rainfall gradually decreases with minor peaks in May and August. From then, the monthly rainfall continues to decrease until a minimum is reached in December with 70.71 mm for the next cycle to begin. Malava Forest Station showed from 1970 to 2001 a monthly mean rainfall of 158.01 mm. The station experiences a major peak of 251.37 mm rainfall in May, followed by other peaks in April and August. From then, the monthly rainfall continues to decrease until a minimum of 48.26 mm is reached in December for the next cycle to begin. Bungoma Water Supply monthly mean rainfall from 1970 to 2001 was found to be 126.58 mm. The water supply shows a major peak in rainfall of 237.81 mm in April and May, then the rainfalls decrease gradually towards August-September followed by a slight increase to a minor peak in October, after which a decrease to a minimum of 55.58 mm in January and December occurs and then an increase sets in to begin the yearly cycle. 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.

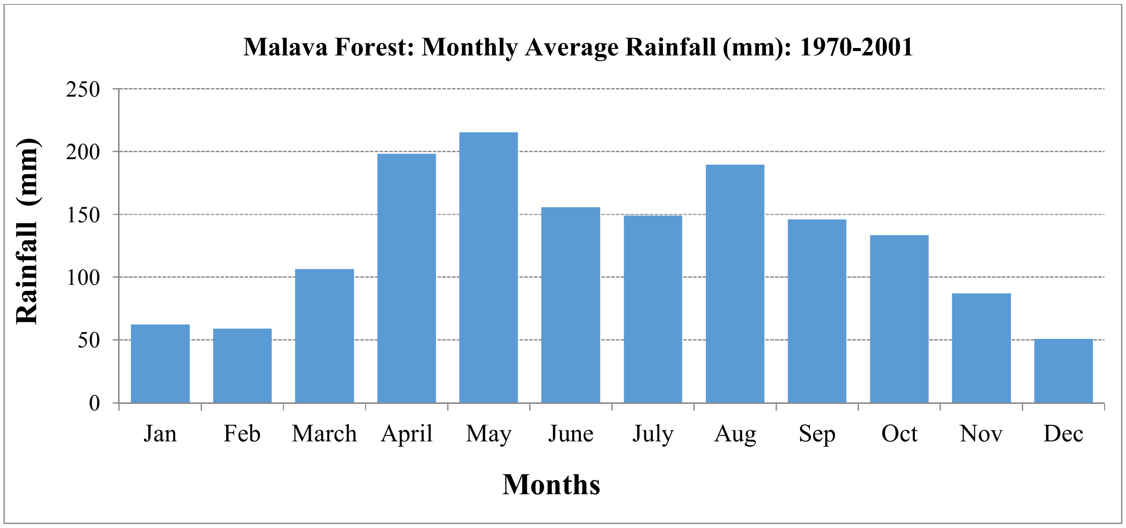
Kaptagat Forest Station showed from 1970 to 2001 a monthly mean rainfall of 103.04 mm. The station experienced a major peak of 195.61 mm in April, followed by other minor peaks in May and August. From then, the monthly rainfall continues to decrease until a minimum of 55.67 mm is reached in February. Nzoia Forest Station showed a monthly mean rainfall of 104.01 mm from 1970 to 2001. The station experiences a major peak of 193.95 mm in August, followed by other minor peaks in April and July. From then, the monthly rainfall continues to decrease until a minimum of 32.26 mm is reached in December for the next cycle to begin. Turbo Forest Nursery showed from 1970 to 2001 a monthly mean rainfall of 111.66 mm. The station shows a major peak of 207.52 mm in August, followed by other minor peaks in July, May and April, then the rainfalls decrease reaching the lowest levels of 30.68 mm in December for the next cycle to begin. Kimilili Agricultural Department showed from 1970 to 2001 a monthly mean rainfall of 123.60 mm. The staion had a major peak of 221.74 mm in May which decreased up to July and then increased to a minor peak in October, after which a decrease follows that results to December having the least total monthly rainfall of 49.43 mm in the year. 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. 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.

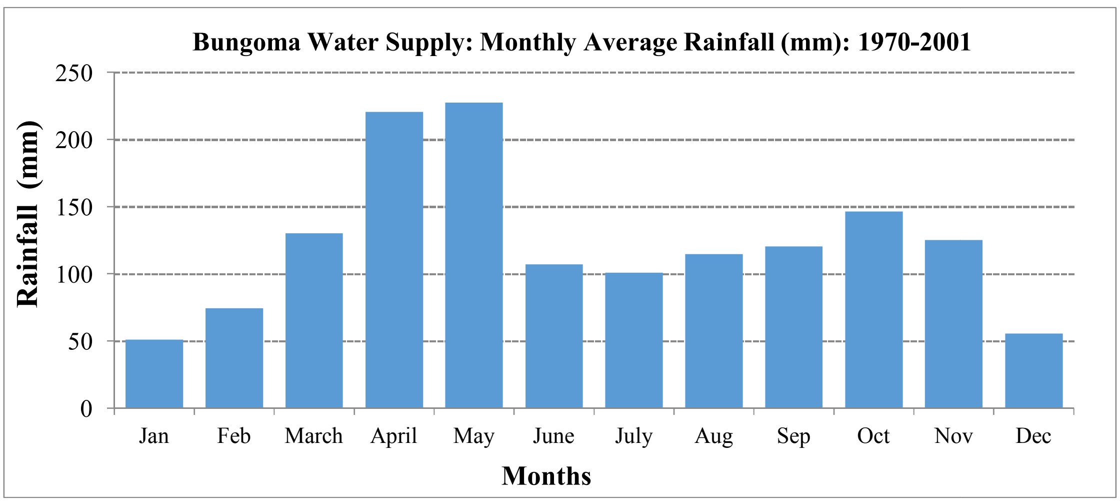
As a result of the inter-tropical convergence zone (ITCZ), Nzoia River Basin has four rainfall seasons each year. There are two rainy seasons and two dry seasons. Long rains come between March and May (MAM), while short rains fall between October and December (OND), both of which are linked to the ITCZ. There is no distinct dry season, although the months of December, January, and February (DJF) and, in some areas, June, July, August, and September (JJAS) are dry seasons in comparison to the rainy seasons. The local relief and influences of Lake Victoria alter the normal weather pattern, resulting in a third rainfall peak from June to August. The ITCZ has a rather complex structure over the East Africa region that consists of the zonal and meriodional arms. The double passage of the zonal arm is associated with the long and short rainfall season during which a large portion of the annual rainfall total is received. On the other hand, the meriodional arm fluctuates from east to west and vice versa, with the easternmost extent noted in July and August. This arm is linked to the rainfall that falls in Kenya's western highlands during these months [66]. The ITCZ's migration over the Equator, the southeast and northeast monsoons, Indian Ocean sea-surface temperature, and other meso-scale systems all influence diurnal, seasonal, and annual rainfall patterns [67,68].

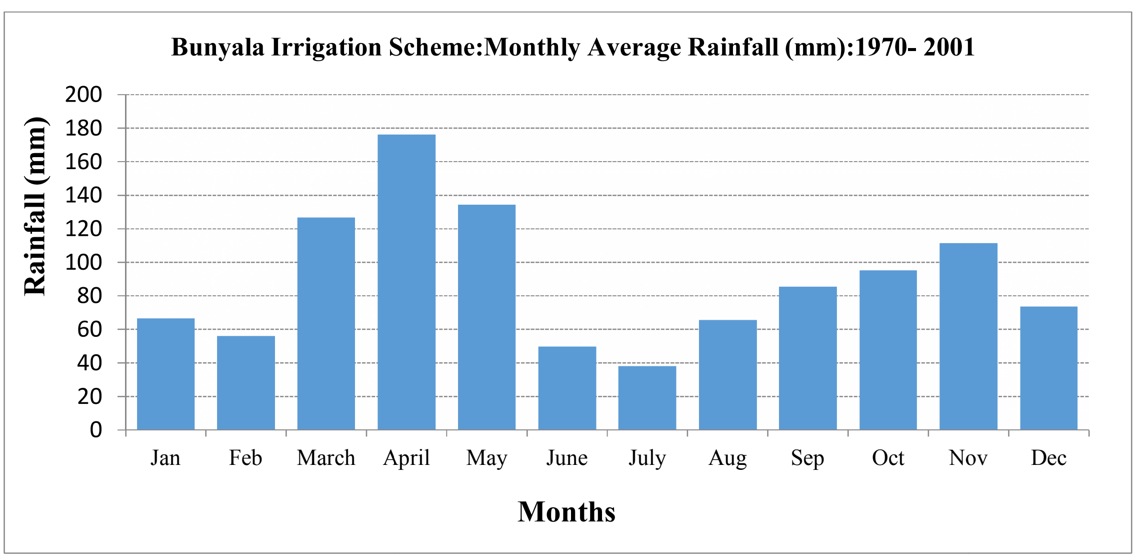


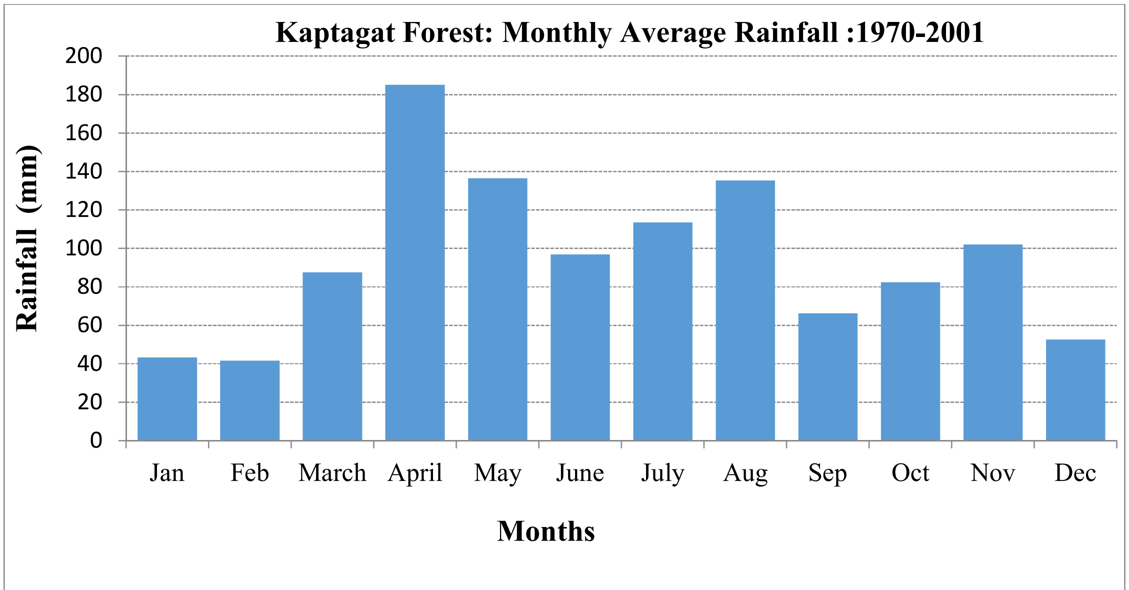


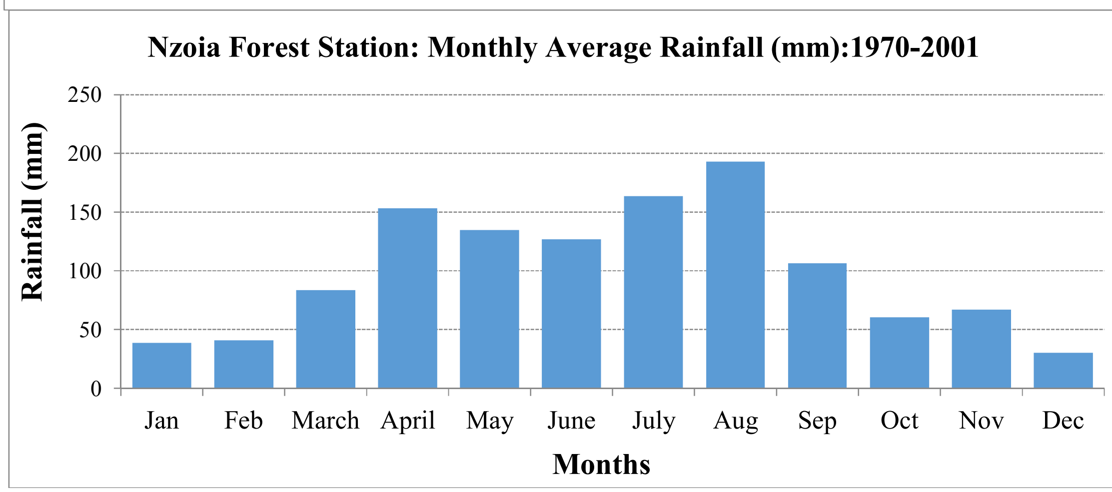


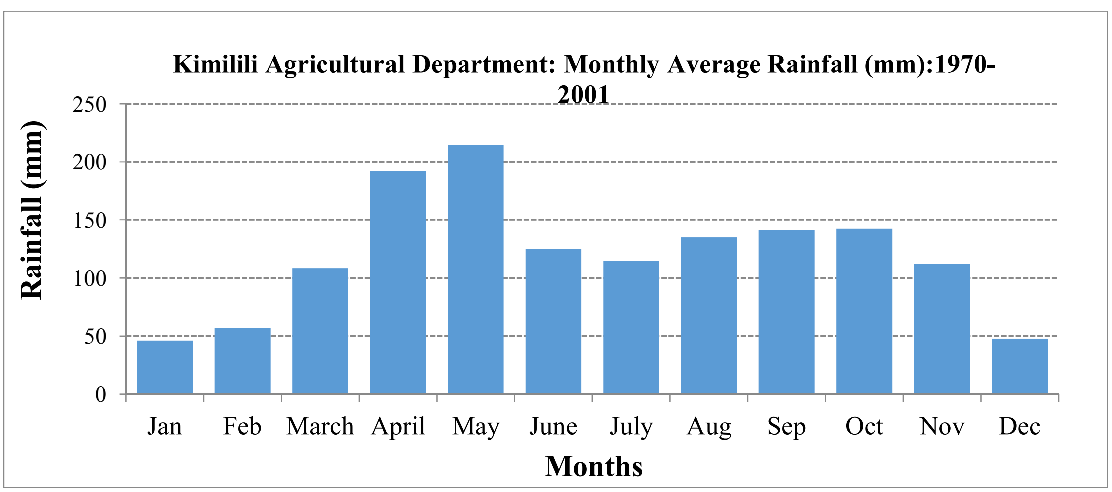

Malava Forest: Monthly Average Rainfall (mm): 1970-2001
Rainfall (mm)
250
200
150
100
50
0
Jan
Feb
March
April
May
June
July
Aug
Sep
Oct
Nov
Dec
Months


Bungoma Water Supply: 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


Kaptagat Forest: Monthly Average Rainfall :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


Nzoia Forest Station: 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


Kimilili Agricultural Department: 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

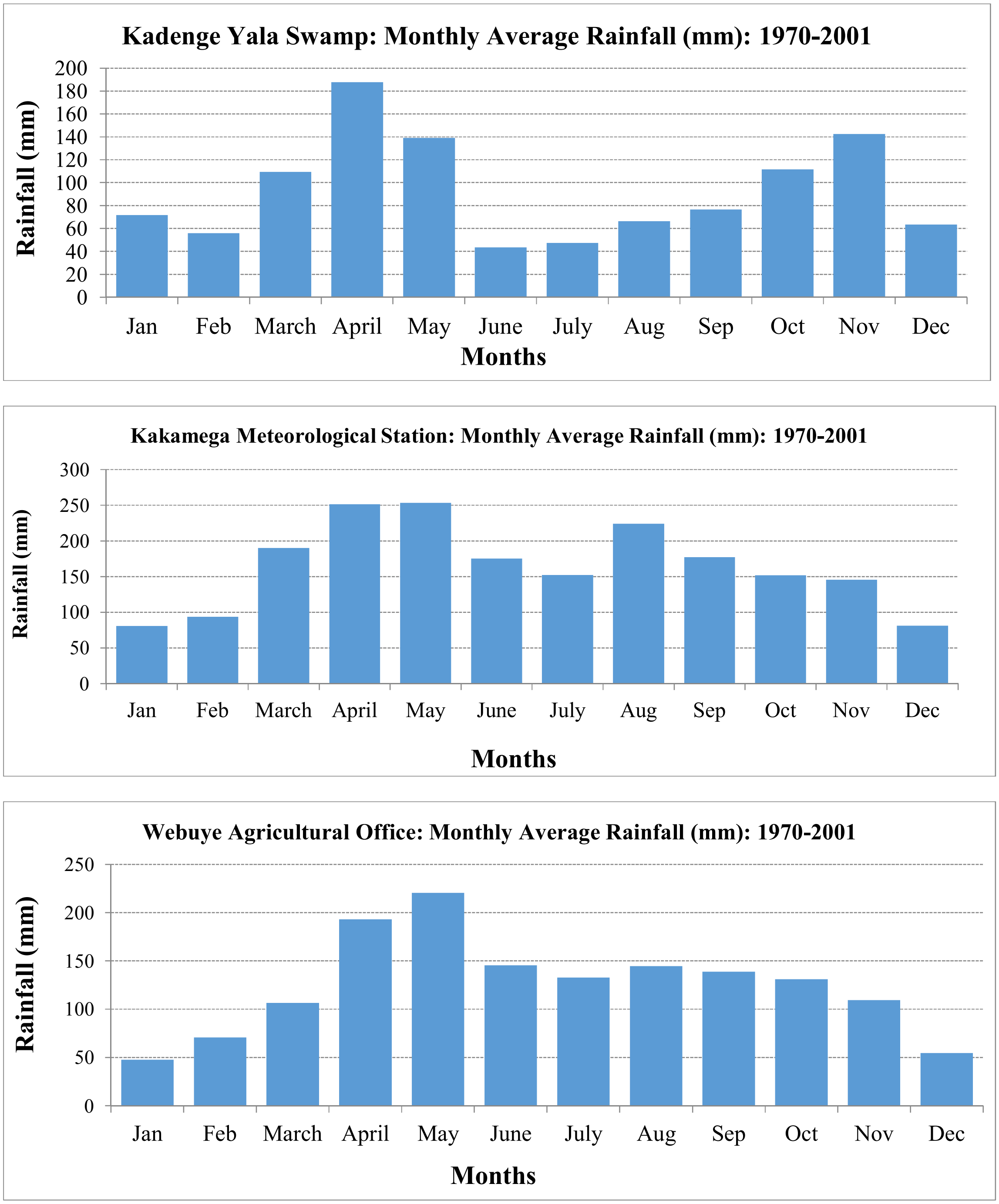


Fig. 2. Monthly average rainfall distribution for selected rainfall stations within Nzoia River Basin, Kenya

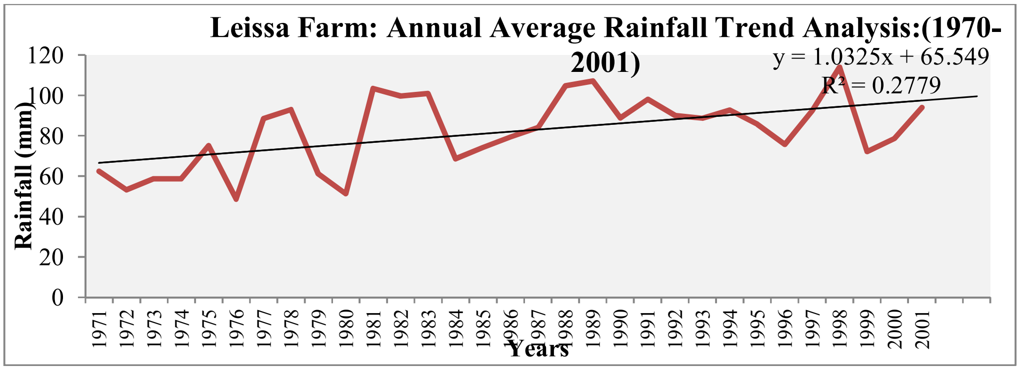
As shown in Figure 2, the mean monthly rainfall in the basin ranges from about 16.26 mm in January and December (Chorlim ADC. Farm) to about 300.79 mm in April (Kaimos Tea Estate) from 1970 to 2001. There has also been a general upward trend (increase) in rainfall events from September to February, indicating that the short rainy season (October-December) is extending into the basin's usually hot and dry months of January and February. This may be due to more frequent El-Nino events, which are often accompanied by relatively warmer sea surface temperatures over the western Indian Ocean (along the East African coast) and cooler than normal 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 Nzoia River Basin, it can be concluded that a dry spell seems to set in immediately after the heavy rainfalls. This leaves us to wonder whether there is a relationship between heavy rainfalls and dry spells.

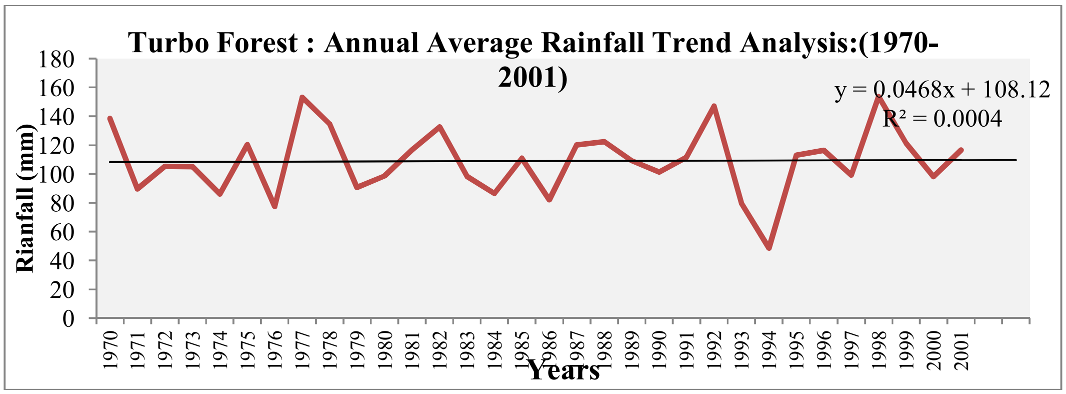
3.2 Annual Rainfall Analysis

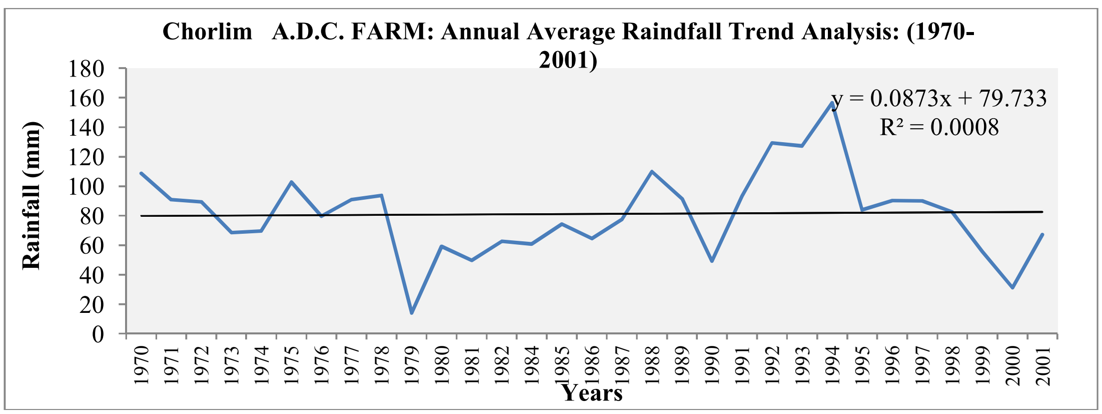
Figure.3 shows the annual mean rainfall trends for Leissa Farm Kitale, Turbo Forest Nursery, Chorlim ADC Farm, Kaptagat Forest Station, Kaimosi Tea Estate Ltd, Kakamega Meteorological Station, Bungoma Water Supply, Nzoia Forest Station, Malava Forest Station, Kimilili Agricultural Department, Webuye 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. Turbo Forest Nursery annual mean rainfall from 1970 to 2001 was found to be 111.66 mm. The lowest and highest recorded rainfall in the period was 77.48 (1976) and 154.59 (1998) mm per year, respectively. Rainfall at Turbo Forest Nursery has been increasing over the years at the rate of 0.0468 mm/31 years (0.002 mm/ year). The increase in rainfall shows a statistically significant trend.

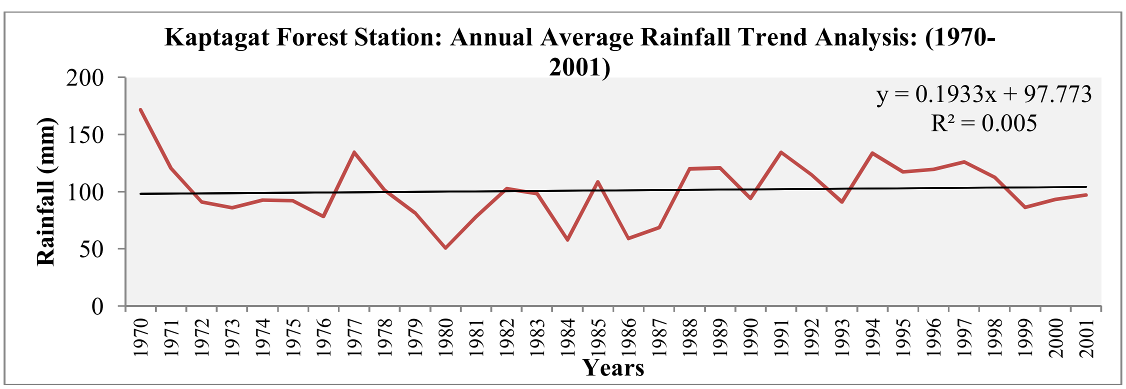
Chorlim ADC Farm annual mean rainfall from 1970 to 2001 was found to be 86.76 mm. The lowest and highest recorded rainfall in the period was 31.65 (2000) and 156.75 (1994) mm per year, respectively. Rainfall at Chorlim ADC Farm has been increasing over the years at the rate of 0.0873 mm/31 years (0.003 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. Kaimosi Tea Estate annual mean rainfall from 1970 to 2001 was found to be 171.66 mm. The lowest and highest recorded rainfall in the period was 140.45 (1998) and 224.91 (1988) mm per year, respectively. Rainfall at Kaimosi Tea Estate Ltd has been decreasing over the years at the rate of - 0.2108 mm/31 years (-0.007 mm/ year). The decrease in rainfall for Kaimosi Tea Estate shows a statistically insignificant 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.

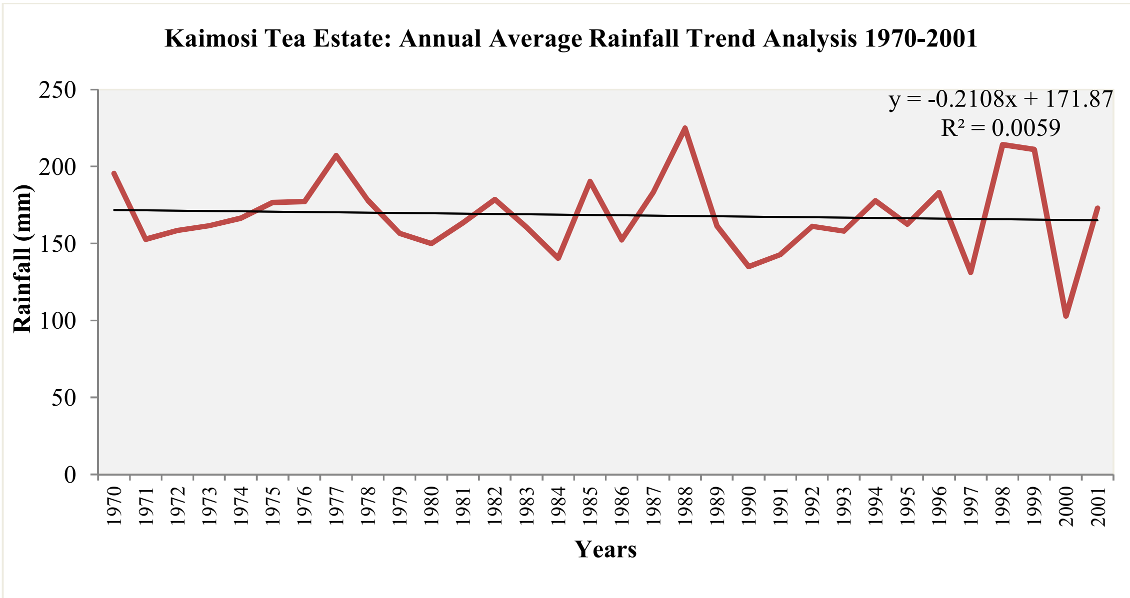
Bungoma Water Supply annual mean rainfall from 1970 to 2001 was found to be 126.58 mm. The lowest and highest recorded rainfall in the period was 75.33 (2001) and 168.78 (1999) mm per year, respectively. Rainfall at Bungoma Water Supply has been decreasing over the years at the rate of - 0.7584 mm/31 years (-0.025 mm/ year). The decrease in rainfall shows a statistically insignificant trend. Nzoia Forest Station annual mean rainfall from 1970 to 2001 was found to be 104.01 mm. The lowest and highest recorded rainfall in the period was 73.33 (1976) and 142.43 (1970) mm per year, respectively. Rainfall at Nzoia Forest Station has been decreasing over the years at the rate of - 0.6486 mm/31 years (-0.021 mm/ year). The decrease in rainfall shows a statistically insignificant trend. Malava Forest Station annual mean rainfall from 1970 to 2001 was found to be 158.01 mm. The lowest and highest recorded rainfall in the period was 110.63 (1971) and 215.22 (1994) mm per year, respectively. Rainfall at Malava Forest Station has been decreasing over the years at the rate of - 0.2056 mm/31 years (-0.021 mm/ year). The decrease in rainfall shows a statistically insignificant trend. Kimilili Agricultural Department annual mean rainfall from 1970 to 2001 was found to be 123.60 mm. The lowest and highest recorded rainfall in the period was 86.77 (1992) and 157.13 (1999) mm per year, respectively

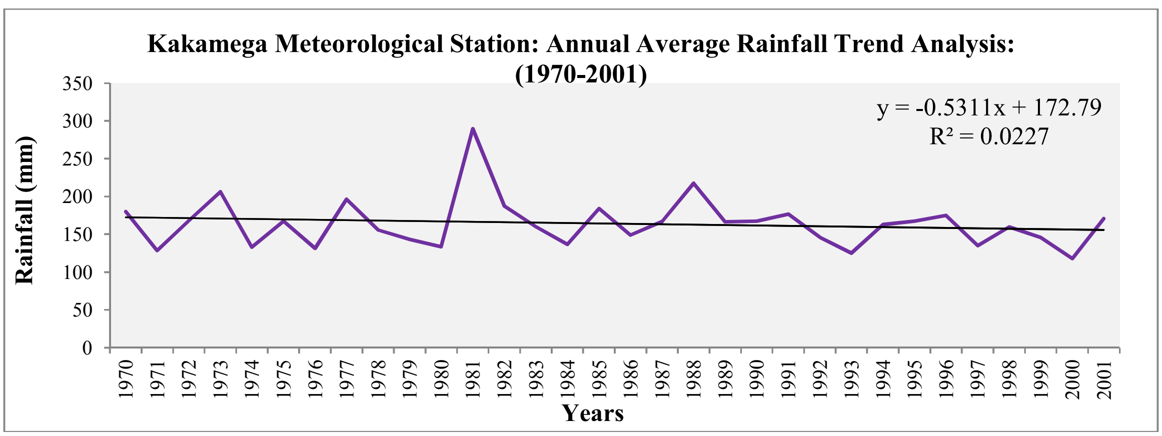

Leissa Farm: Annual Average Rainfall Trend Analysis:(1970-2001)
y = 1.0325x + 65.549
R² = 0.2779
Rainfall (mm)
Years

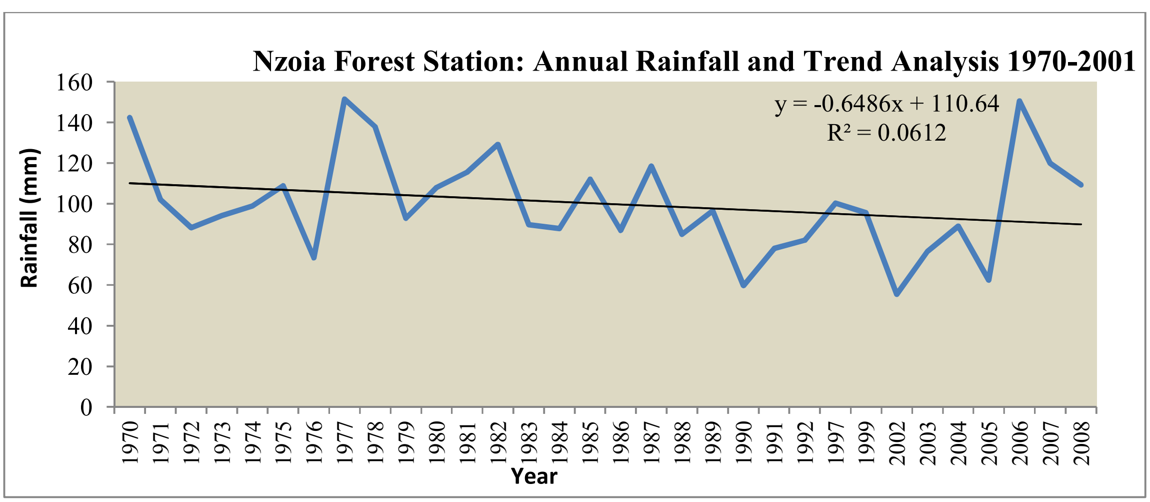

Turbo Forest : Annual Average Rainfall Trend Analysis:(1970-2001)
y = 0.0468x + 108.12
R² = 0.0004
Rianfall (mm)
Years

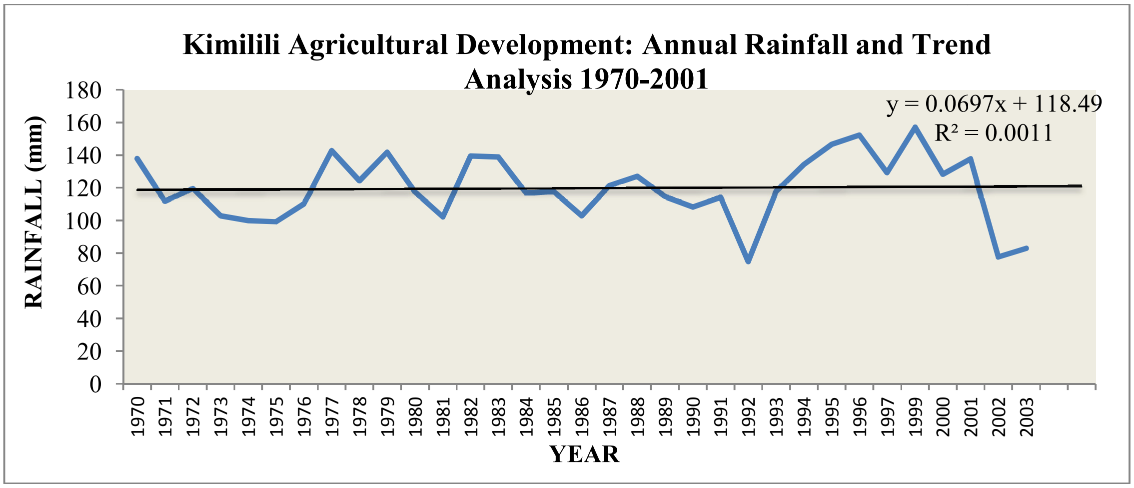

Chorlim A.D.C. FARM: Annual Average Raindfall Trend Analysis: (1970-2001)
y = 0.0873x + 79.733
R² = 0.0008
Rainfall (mm)
Years

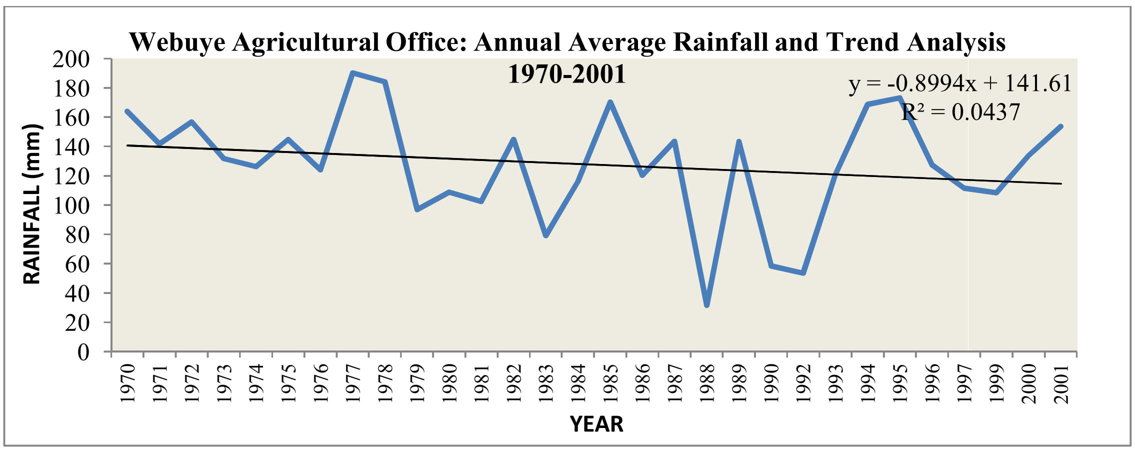

Kaptagat Forest Station: Annual Average Rainfall Trend Analysis: (1970-2001)
y = 0.1933x + 97.773
R² = 0.005
Rainfall (mm)
Years

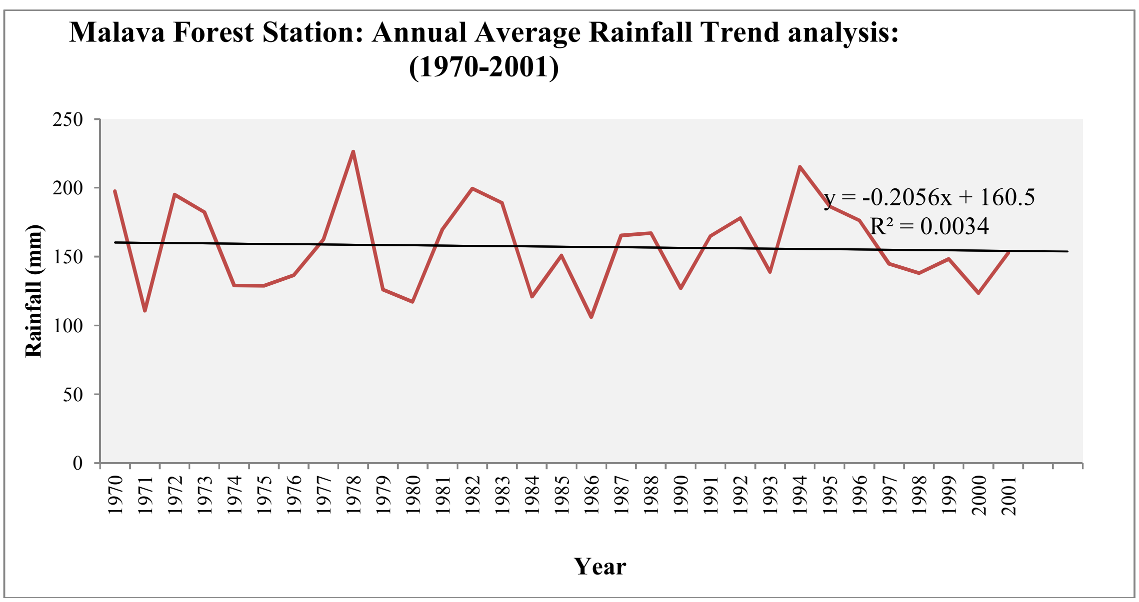

Kaimosi Tea Estate: Annual Average Rainfall Trend Analysis 1970-2001
y = -0.2108x + 171.87
R² = 0.0059
Rainfall (mm)
Years


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


Nzoia Forest Station: Annual Rainfall and Trend Analysis 1970-2001
y = -0.6486x + 110.64
R² = 0.0612
Rainfall (mm)
Year


Kimilili Agricultural Development: Annual Rainfall and Trend Analysis 1970-2001
y = 0.0697x + 118.49
R² = 0.0011
RAINFALL (mm)
YEAR
0
20
40
60
80
100
120
140
160
180
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1999 2000 2001 2002 2003


Webuye Agricultural Office: Annual Average Rainfall and Trend Analysis 1970-2001
y = -0.8994x + 141.61
R² = 0.0437
RAINFALL (mm)
YEAR
0
20
40
60
80
100
120
140
160
180
200
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1992 1993 1994 1995 1996 1997 1999 2000 2001


Malava Forest Station: Annual Average Rainfall Trend analysis: (1970-2001)
y = -0.2056x + 160.5
R² = 0.0034
Rainfall (mm)
Year
0
50
100
150
200
250
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

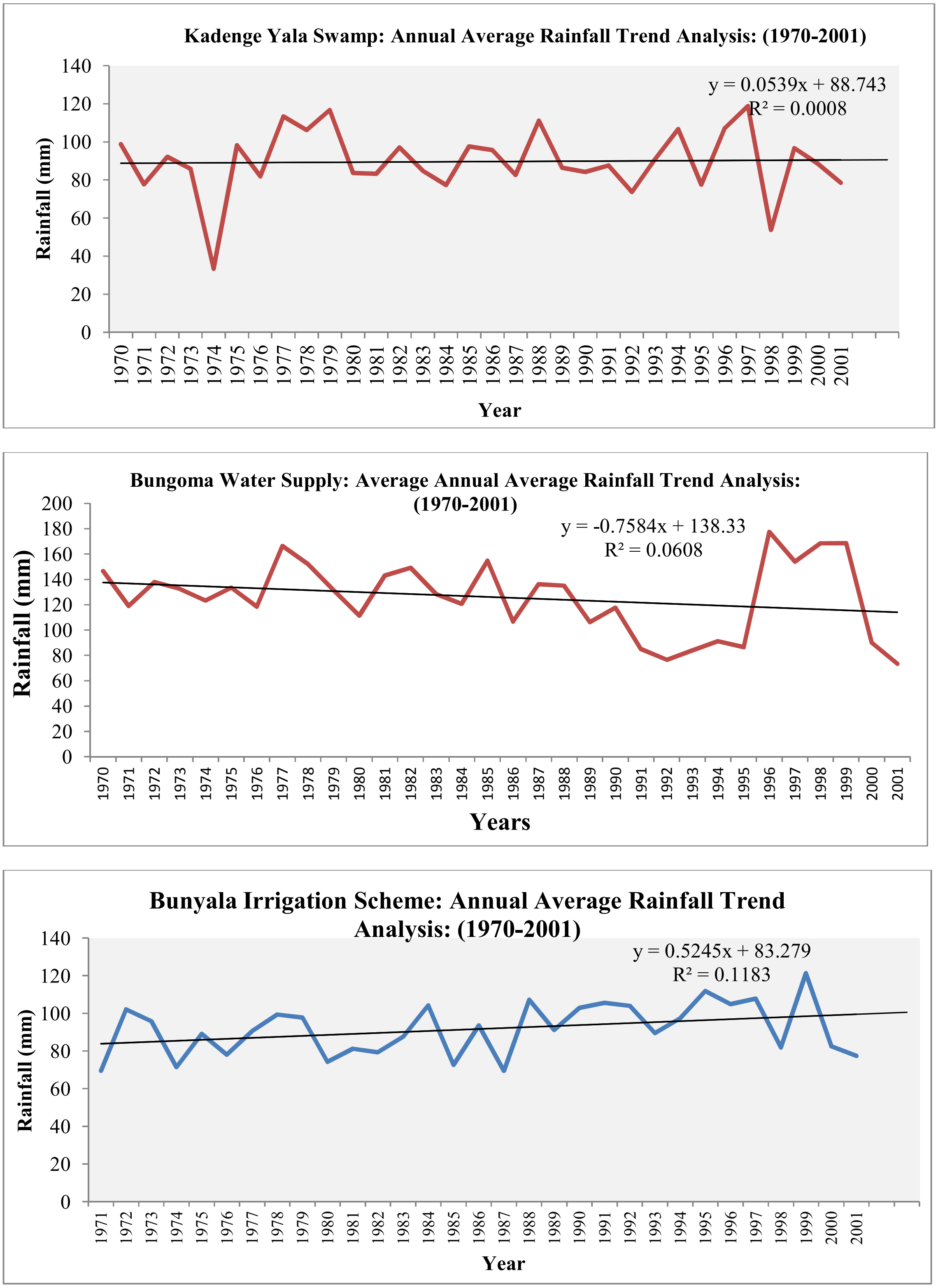


Fig. 3. Annual mean rainfall trends for selected rainfall stations within Nzoia River Basin, Kenya

Rainfall at Kimilili Agricultural Department has been increasing over the years at the rate of 0.0697 mm/31 years (0.002 mm/ year). The increase in rainfall shows a statistically insignificant 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 thirteen rainfall stations with some recording declining and others increasing rainfall trends (Table. 2).

Using the parametric test of Linear regression analysis on annual rainfall; 6 stations; Kaimosi Tea Estate Ltd - 0.2108 mm/31 years (-0.007 mm/ year); Kakamega Meteorological Station - 0.5311 mm/31 years (-0.017 mm/ year); Bungoma Water Supply - 0.7584 mm/31 years (-0.025 mm/ year); Nzoia Forest Station- 0.6486 mm/31 years (-0.021 mm/ year); Malava Forest Station - 0.2056 mm/31 years (-0.021 mm/ year) and Webuye Agricultural Office - 0.8994 mm/31 years (-0.029 mm/ year) showed declining rainfalls. The remaining 7 stations; Leissa Farm Kitale 1.0325 mm/31 years (0.033 mm/ year); Turbo Forest Nursery 0.0468 mm/31 years (0.002 mm/ year); Chorlim ADC Farm 0.0873 mm/31 years (0.003 mm/ year); Kaptagat Forest Station 0.1933 mm/31 years (0.006 mm/ year); Kimilili Agricultural Department 0.0697 mm/31 years (0.002 mm/ year); Bunyala Irrigation Scheme 0.5245 mm/31 years (0.017 mm/ year) and Kadenge Yala Swamp 0.0539 mm/31 years (0.002 mm/ year) had increasing rainfalls. The majority of the rainfall stations recording increasing rainfalls were in the upper cartchment whereas the majority of those recording declining rainfalls were in the middle and lower catchment. The implication of increasing and decreasing trends in rainfall is a signal of climate change and could pose future challenges in water resources availability and access in the basin.

Table 2. 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
Turbo Forest Nursery	Increasing	0.0468 mm/31 years	0.002 mm/ year	0.0004
Chorlim ADC Farm	Increasing	0.0873 mm/31 years	0.003 mm/ year	0.0008
Kaptagat Forest Station	Increasing	0.1933 mm/31 years	0.006 mm/ year	0.0050
Kaimosi Tea Estate Ltd	Decreasing	- 0.2108 mm/31 years	-0.007 mm/ year	0.0059
MIDDLE CATCHMENT				
Kakamega Meteorological Station	Decreasing	- 0.5311 mm/31 years	-0.017 mm/ year	0.0227
Bungoma Water Supply	Decreasing	- 0.7584 mm/31 years	-0.025 mm/ year	0.0608
Nzoia Forest Station	Decreasing	- 0.6486 mm/31 years	-0.021 mm/ year	0.0612
Malava Forest Station	Decreasing	- 0.2056 mm/31 years	-0.021 mm/ year	0.0034
Kimilili Agricultural Department	Increasing	0.0697 mm/31 years	0.002 mm/ year	0.0011
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

Increasing rainfall trends will bring the challenge of flooding and landslides to domestic water supply infrastructure. Decreasing rainfall trends will bring the challenge of water scarcity and droughts. 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. There is a general trend towards increased rainfall in the upper carchment, (where the two high ground areas of Mt. Elgon and Cherengani hills occur) and reduced rainfalls in the middle and lower catchments. Rainfall is also strongly influenced by elevation with greater amounts occurring in the high ground areas. Accurately predicting rainfall trends is vital in the economic development of the basin. The results here highlighted a mix of positive (increasing) and negative (decreasing) trends in annual rainfall. Rahman and Begum [69] noted that ''predicting trends using precipitation time series data is more difficult than predicting temperature trends''.

Throughout the latter half of the century, the Fourth Intergovernmental Panel on Climate Change (IPCC) recorded temporal and spatial variation in precipitation patterns across Asia [1]. Rainfall is the most important factor influencing stream flow changes and human activities in the Nzoia River Basin; therefore, studying the spatial-temporal distribution features of rainfall is critical in understanding drought-climate changes, as well as providing a climatic foundation for drought-flood monitoring and estimation of the basin's hydrological conditions. When the change of sequence trend becomes more obvious, tendency can be intuitively judged by using the change curves. But, when there is no obvious trend change, this intuitive judgment is not reliable, so we need to use statistical methods such as Mann-Kendall test to solve the problem.

3.3 Mann- Kendall Test on Annual Rainfall

The non-parametric test, Mann Kendall method 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 13 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. 3. The Mann-Kendall test gives interesting insight about annual rainfall for Nzoia River Basin. When the Mann Kendall test statistics (S) are less than 0, it indicates that rainfall is decreasing; and when the values are higher than 0, the rainfall is increasing. The Mann Kendall test Statistic (S) indicates that there is an increasing rainfall trend for Leissa Farm Kitale, Turbo Forest Nursery, Kaptagat Forest Station, Kakamega Meteorological Station, Nzoia Forest Station, Kimilili Agricultural Department, Bunyala Irrigation Scheme and Kadenge Yala Swamp; and reducing rainfall trends for Chorlim ADC Farm, Kaimosi Tea Estate Ltd, Bungoma water supply, Malava Forest Station and Webuye Agricultural Office. In recent years, many scholars have done a lot of research on the analysis of the hydrological and meteorological trends using Mann Kendall test; eg. Wang et al., [70] used Mann Kendall method and regression analysis to examine the long-term variation of annual rainfall in Shapotou area. When running the Mann-Kendall statistical test, if the p value is less than the significance level $\alpha = 0.05$, Ho, (there is no trend), hence, the hypothesis is not accepted. Rejecting Ho indicates that there is a trend in the time series, while accepting Ho indicates no trend is detected.

Rejecting the null hypothesis implies that the result is said to be statistically significant at $\alpha = 0.05$ level of significance (Turbo Forest Nursery, Kaptagat Forest Station and Kakamega Meteorological Station). For this test result, the null hypothesis is accepted for Leissa Farm Kitale, Chorlim ADC Farm, Kaimosi Tea Estate Ltd, Bungoma Water Supply, Nzoia Forest Station, Malava Forest Station, Kimilili Agricultural Department, Webuye Agricultural Office, Bunyala Irrigation Scheme and Kadenge Yala Swamp station data. In these stations, annual rainfall has shown no trend as the computed p-value is greater than the significance level $\alpha = 0.05$ (Table 3) and the result is statistically insignificant. Of the 13 stations, only three showed a statistically significant trend through the MK test at 5% level of significance; and the trend for the remaining 10 stations is statistically insignificant. Mann-Kendall test and linear regression test have been used to evaluate annual rainfall 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 the results are presented in Table 4. Table.4 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the selected thirteen Rainfall Stations with 31 years data covering the period 1970 to 2001 in Nzoia River Basin. Leissa Farm Kitale, Turbo Forest Nursery, Kaptagat Forest Station, Kimilili Agricultural Department, Bunyala Irrigation Scheme and Kadenge Yala Swamp recorded increasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S).

Kaimosi Tea Estate Ltd, Bungoma Water Supply, Malava Forest Station and Webuye Agricultural Office recorded decreasing rainfalls under both Linear regression analysis and the Mann-Kendall test statistic (S). Chorlim ADC Farm recorded decreasing rainfall under Mann-Kendall test statistic (S) and increasing rainfall under Linear regression analysis; whereas Kakamega meteorological station and Nzoia Forest station recorded increasing rainfall under Mann-Kendall test statistic (S) and decreasing rainfall under Linear regression analysis.

By analyzing the temporal-spatial variation of rainfall, the prediction of rainfall change in Nzoia River Basin will be more accurate in future and this will provide a reliable basis for anchoring rational development and utilization of water resources for various purposes such as domestic water supply, agricultural, industrial, etc, uses. Based on the above results, it is of immense importance to discuss the ecological, economic, and social impacts affecting household domestic water supply that could result if the observed increasing and decreasing rainfall trends continue in various parts of Nzoia River Basin. Out of the 13 rainfall stations, Mann Kendall test statistic (S) showed 8 stations recording increasing rainfall wherease the linear regression analysis showed 7. The majority of stations with increasing rainfall were in the upper catchment whereas those with decreasing rainfall were in the middle and lower catchment. Only 3 stations (Turbo Forest Nursery, Kaptagat Forest Station and Kakamega Meteorological Station) out of 13 showed statistically significant trends with the two in the upper catchment and one in the middle; the others had statistically insignificant trends. This study results follow the same statistical trends and are consistent with what has been reported by Githui [71] for Nzoia River Basin where she found that most of the rainfall stations with increasing rainfall were in the upstream part of Nzoia River. These changes in rainfall patterns could lead to further water-related disasters in Nzoia River Basin in the near future, such as droughts and floods. Global climate shifts, forest loss, land use changes and practices (e.g., irrigated agriculture), and increased aerosols from anthropogenic activities are all potential causes of changing rainfall trends.

Table 3. 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
Turbo Forest Nursery	741.000	1	6833.667	< 0.0001	0.05	Reject Ho Statistically significant trend
Chorlim ADC Farm	-58.000	-0.061	9775.333	0.564	0.05	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	1	6833.667	< 0.0001	0.05	Reject Ho Statistically significant trend

Kaimosi Tea Estate Ltd	-141.000	-0.190	6833.667	0.090	0.05	Accept Ho Statistically insignificant trend
MIDDLE CATCHMENT						
Kakamega Meteorological Station	1035.000	1	11155.000	< 0.0001	0.05	Reject Ho Statistically significant trend
Bungoma Water Supply	-140.000	-0.171	7929.667	0.118	0.05	Accept Ho Statistically insignificant trend
Nzoia Forest Station	465	1	3461.667	0.237	0.05	Accept Ho Statistically insignificant trend
Malava Forest Station	-129.000	-0.143	9130.333	0.180	0.05	Accept Ho Statistically insignificant trend
Kimilili Agricultural Department	66.000	0.133	3802.667	0.292	0.05	Accept Ho Statistically insignificant 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 4. 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
Turbo Forest Nursery	741.000	Increasing	0.0468	Increasing	Reject Ho Statistically significant trend
Chorlim ADC Farm	-58.000	Decreasing	0.0873	Increasing	Accept Ho Statistically insignificant trend
Kaptagat Forest Station	741.000	Increasing	0.1933	Increasing	Reject Ho Statistically significant trend

Kaimosi Tea Estate Ltd	-141.000	Decreasing	- 0.2108	Decreasing	Accept Ho Statistically insignificant trend
MIDDLE CATCHMENT					
Kakamega Meteorological Station	1035.000	Decreasing	- 0.5311	Decreasing	Reject Ho Statistically significant trend
Bungoma Water Supply	-140.000	Decreasing	- 0.7584	Decreasing	Accept Ho Statistically insignificant trend
Nzoia Forest Station	465	Decreasing	- 0.6486	Decreasing	Accept Ho Statistically insignificant trend
Malava Forest Station	-129.000	Decreasing	- 0.2056	Decreasing	Accept Ho Statistically insignificant trend
Kimilili Agricultural Department	66.000	Increasing	0.0697	Increasing	Accept Ho Statistically insignificant 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

The wide range of negative and positive trends observed at different rainfall stations in the basin highlights the need for more comprehensive climate change research in Nzoia River Basin.

4. CONCLUSION

This study has investigated rainfall variability and trends for 13 rainfall stations in Nzoia River Basin, covering 31 years period from 1970 to 2001 using Linear regression analysis and Mann-Kendall statistical test. From 1970 to 2001, the average monthly rainfall in the basin ranged from 16.26 mm in January and December (Chorlim ADC. Farm) to 300.79 mm in April (Kaimos Tea Estate). There has also been a general upward trend (increase) in rainfall events from September to February, indicating that the short rainy season (October-December) is extending into the basin's usually hot and dry months of January and February. This may be due to more frequent El-Nino events, which are often accompanied by relatively warmer sea surface temperatures over the western Indian Ocean (along the East African coast) and cooler than normal sea surface temperatures to the east of the Indian Ocean. On annual basis, using the parametric test of Linear regression analysis; 6 stations; Kaimosi Tea Estate Ltd -0.007 mm/ year; Kakamega Meteorological Station -0.017 mm/ year; Bungoma Water Supply -0.025 mm/ year; Nzoia Forest Station -0.021 mm/ year; Malava Forest Station -0.021 mm/ year and Webuye Agricultural Office -0.029 mm/ year, showed declining rainfalls. The remaining 7 stations; Leissa Farm Kitale 0.033 mm/ year; Turbo Forest Nursery 0.002 mm/ year; Chorlim ADC Farm 0.003 mm/ year; Kaptagat Forest Station 0.006 mm/ year; Kimilili Agricultural Department 0.002 mm/ year; Bunyala Irrigation Scheme 0.017 mm/ year and Kadenge Yala Swamp 0.002 mm/ year had increasing rainfalls.

The non-parametric Mann–Kendall statistical test showed 8 stations out of 13 recording increasing rainfalls and 5 stations recording declining rainfalls. The majority of stations with increasing rainfall are in the upper catchment whereas those with decreasing rainfall are in the middle catchment. Only 3 (Turbo Forest Nursery, Kaptagat Forest Station and Kakamega Meteorological Station) out of the 13 stations showed statistically significant trends in rainfall with two (Turbo Forest Nursery, Kaptagat Forest Station) in the upper catchment and one (Kakamega Meteorological Station) in the middle; the remaining 10 stations had statistically insignificant trends. Extreme weather events in the basin are becoming more frequent and severe. Data analysis has shown that the magnitude of increase or decrease in rainfall is different between all stations within the basin. The County governments in Nzoia River Basin will be required to put in place proper mitigation and adaptation strategies for the observed variability and trends in rainfall to minimize the impacts of climate change, hence, the results of this study provide a useful basis on which the management of water resource and economic development in the basin can be anchored.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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