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SPATIO-TEMPORAL ANALYSIS OF RAINFALL DISTRIBUTION IN THE NORTHERN PART OF KATSINA STATE, NIGERIA

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ABSTRACT
The study analysed the characteristics and distribution of rainfall in northern Katsina State. Gridded monthly rainfall data (0.5 by 0.5) spanning a period of sixty (60) years (1962-2021) was used for the analysis. 5-year moving average, linear trend line equation, Cramer's test, and student's t-test were used to achieve this aim. The linear trend analysis results revealed that the annual and monthly rainfall amounts for June, August, and September had increased in the last two decades while the May rainfall has decreased. The results of the 5-year moving average and Cramer's test indicated that the 1970s and 1980s were drier, while from 2000 to the end of the study period, experienced wetter conditions. Findings also revealed that the 1992-2021 climatic period was wetter than 1962-1991. It is recommended that scientists should develop genetically modified seeds suitable for the recent increase in rainfall in the study area. Farmers should acquire weather information to explore opportunities associated with climate change, significantly increasing rainfall in this drought-prone ecological zone. Lastly, communities and authorities should always take precautionary measures against floods, as the recent increase in rainfall exposes the area to flood risk.

Keywords: Decade, moving average, rainfall, sub-period, trend

INTRODUCTION

Rainfall trend analyses on different spatial and temporal scales have been of great concern to scientists in the past century (Longobardi & Villani, 2010). Changes in rainfall characteristics such as rainfall amount, frequency, intensity, and duration are expected to increase due to the increase in the concentration of greenhouse gases over the past century (Ojoye, 2012).

A more significant spatial variability in the global precipitation trend has been observed (Adler *et al.,* 2017; Gulev *et al.,* 2021; Kazemzadeh *et al.,* 2021). The IPCC Sixth Assessment Report of 2021 reported spatial variability of the long-term (1901–2019) precipitation trend, which indicated that northern Europe and Asia, eastern North America, north-western Australia, and southern South America experienced a significant increase in precipitation. However, a significant decrease was observed in southern Asia and Western and tropical Africa. The recent short-term precipitation trend worldwide (1981–2019) revealed that land precipitation significantly increased over Eastern Europe, America, tropical Africa, Central Asia, and the maritime continent. On the other hand, North Africa, central South America, the Middle East, and western North America experienced a significant decrease in precipitation. Global trends for 1980–2019 show a general increase in annual precipitation over land (Gulev *et al.,* 2021). Kazemzadeh *et al.* (2021) reported that in all continents except Asia, decreasing trends covered larger areas than corresponding increasing trends. However, like Asian continents, there have been significant increasing trends in arid climates over the last 20 years.

The long-term trend indicated that tropical Africa has a decreasing rainfall trend. In contrast, recent trends show that West and Tropical Africa have an increasing rainfall trend and a decreasing trend in North Africa (Gulev *et al.,* 2021). The Sahel had a widespread decreasing rainfall trend from the late 1950s to the late 1980s (Dai et al., 2004; Biasutti, 2011; Biasutti, 2019), while the recent trends indicate increasing trends in most of the Sahel.

Similarly, after the positive trends of the 1950s, most of Nigeria witnessed a decreasing rainfall trend up to the end of the century (Oguntunde *et al.,* 2011). There has been an increasing rainfall trend in many parts of the country recently (Ogunrinde *et al.,* 2019). The Sudano-Sahelian zone of Nigeria that was devastated by drier conditions since the late 1970s is witnessing wetter conditions since early 2000s (Abaje, Ati and Iguisi, 2012; Bose *et al.,* 2015; Murtala *et al.,* 2018; Abaje, Achiebo and Matazu, 2018; Ogunrinde *et al.,* 2019; Abaje and Oladipo, 2019: Matawalli, 2021). Negative trends persisted in Katsina until the late 2000s (Murtala *et al.,* 2018; Abaje and Ogoh, 2018). The area is experiencing increased annual and monthly rainfall (Abaje *et al.,* 2015; Tikya *et al.,* 2019; Abaje and Magaji, 2022). While rainfall in the area is seasonal and a reasonable amount of rainfall that is effective for crop production is concentrated in only three months, most of the studies in the area focused on annual rainfall trends rather than monthly. Unfortunately, gauge stations have low spatial coverage in Nigeria and Katsina State. Thus, the major shortcoming of the previous studies is using a single location to generalize for a wide geographical area. Regarding the study area, most studies used only Katsina synoptic data to characterize rainfall in the whole state. Based on this gap, this study aims to analyze the rainfall characteristics and distribution of the area using monthly gridded rainfall data (0.5 by 0.5) spanning a period of sixty (60) years (1962-2021).

MATERIALS AND METHODS

Study Area

The study area (northern part of Katsina State) is located between Latitude 12°25'00" and 13°20'32"N, and between Longitude 6°59'20" and 9°02'50"E. It is bounded by the Republic of Niger to the North, Kano and Jigawa States to the East, Zamfara State to the West, and the central part of the state (Matazu and Danmusa Local Government Areas) to the South (Figure 1).

The area's climate is tropical continental wet and dry, which falls under the Aw climate of Koppen's classification. The mean annual rainfall varies in the study area. The northern part of the study area around Kaita and Zango has 590–700 mm of average annual rainfall, while the southern part around Kusada and Charanchi has 701–750 mm (James *et al.,* 2018). The rainfall occurs mainly between May and September and peaks in August, while the dry season starts in November and ends in April (Abaje *et al.,* 2012).

The movement of two air masses influences seasonal variations in rainfall: the warm, moist tropical maritime air mass (mT) that originates in the Atlantic Ocean and the relatively cool and dry tropical continental air mass (cT) that originates in the Sahara Desert and is known as harmattan. The air masses meet at a boundary called Inter-tropical Discontinuity (ITD). The rainy season in the area reaches its peak in August when the ITD moves north across the state (around latitude 21 to 22°N), and its dry season peaks in January or February when ITD moves to the southernmost part of the country (approximately at 6°N) (Abaje *et al.,* 2012). The highest mean monthly temperature in the area occurs in April, and the lowest is in December through February. The maximum daily temperature is above 30°C, and the minimum daily temperature falls below 20°C at night. This results in a high daily range of more than 10°C in the area, especially in April.

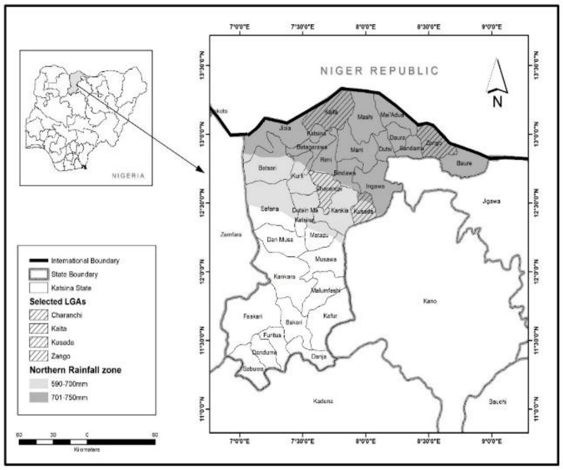

Figure 1: Map of Katsina State showing the Study Area
Source: Adopted from the office of the Surveyor General Katsina State.

High relative humidity (about 80%) occurs in the rainy season and reaches its peak in August, while low relative humidity is about 10% in the dry season. The area is located within the savanna vegetation zone. Sahel vegetation is found in the northernmost part of the study area, while the Sudan vegetation characterizes the southern part (Abaje, 2007; Tukur *et al.,* 2013).

Data Collection Procedure

Gridded monthly rainfall data spanning 60 years (1962-2021) was used for this study. The data was collected from the Climate Research Unit (CRU) of the University of East Anglia, United Kingdom, and the National Center for Atmospheric Science (NCAS) (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.04/ge/). The latest version of CRU gridded monthly rainfall data, CRU, TS 4.05, is at a monthly scale and 0.5 x 0.5 latitude and longitude. This data was interpolated at this spatial resolution based on ground station data, and the version has a period of 101 years (1901–2021).

Cluster sampling was used to select four subareas in the semiarid zone of Katsina State. Two rainfall zones with low mean annual rainfall of 590–700 mm and 701–750 mm, as found in James et al. (2018), were used for the study. Each zone was divided into two longitudinal clusters, making four clusters. Then, one grid was selected from each cluster. The grids selected represent the Charanchi, Kaita, Kusada, and Zango subareas.

Data Analysis

The statistical packages used to analyze the data are Microsoft Excel (2013) and the Statistical Package for Social Science (SPSS) (Version 20). However, the statistical tools for the analysis are descriptive statistics such as frequency, mean, standard deviation, and charts.

The standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics, as defined by Brazel and Balling (1986), were calculated for the annual and for May to September. This was used to test for each area's normality in rainfall series. The standardized coefficient of Skewness (Z_1) was calculated as:

$$Z_1 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{3}/N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2}/N \right)^{3/2} \right] \Big/ \left(6/N \right)^{1/2} \quad \text{(Eq. 1)}$$

and the standardized coefficient of Kurtosis (Z_2) was determined as follows:

$$Z_2 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{4}/N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2}/N \right)^{2} \right] - 3 \Big/ \left(24/N \right)^{1/2} \quad \text{(Eq. 2)}$$

where $\bar{x}$ is the long-term mean of x_i values, and N is the number of years in the sample. These statistics test the null hypothesis that the individual temporal samples came from a population with a normal (Gaussian) distribution. If the absolute value of Z_1 or Z_2 is greater than 1.96, a significant deviation from the normal curve is indicated at the 95% confidence level.

Linear trend line and five-year moving average were calculated and plotted using Microsoft Excel (2013) for the area's monthly and annual rainfall (mm). Linear regression was used to determine the linear trends of the area's rainfall, and changes in rainfall were calculated. The formula for the linear regression is given as:

$$y = a + bx \quad \text{................................ (Eq. 3)}$$

Where the intercept of the regression line on the y-axis; b is the slope of the regression line. The values of a *and* b can be obtained from the following equations:

$$a = \frac{\sum y - b\left(\sum x\right)}{n} \quad \text{.............................. (Eq. 4)}$$

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \quad \text{.....................(Eq. 5)}$$

The 5-year running mean was calculated and plotted to smoothen the time series, reducing irregular fluctuations and highlighting regular ones. Given a set of numbers y_1, y_2, y_3, - - - y_n, a moving average of order *n* is defined by the sequence of arithmetic means:

$$\frac{y_1 + y_2 + --- + y_n}{n}, \frac{y_2 + y_3 + --- + y_n + 1}{n}, \frac{y_3 + y_4 + --- + y_n + 2}{n}, etc. \quad \text{(Eq. 6)}$$

The sum in the numerators of equation 7 is called moving totals of order *n*. Here, the order is 5.

The rainfall series was then subdivided into decadal non-overlapping sub-periods (1962-1971, 1972-1981, 1982-1991, and 1992-2001 through 2012-2021). The means of the sub-periods and the mean of the entire record period were then compared using Cramer's test, as described by Lawson *et al.* (1981). By using

Cramer's test, the mean **(** $\bar{X}$ **),** and the standard deviation (δ), were calculated for each sub-areas in the study area for the total number of years (*N),* under study. This statistic aimed to measure the difference in terms of a moving *t*-statistic between the mean ($\bar{X}$) for each successive n-year period and the mean ($\bar{X}$) for the entire period. The t-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1+\tau_k^2\right)} \right)^{1/2} \tau_k \quad \text{.............................. (Eq. 7)}$$

Where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad \text{................................ (Eq. 8)}$$

Where $\bar{x}$k is the mean of the sub-period of n–years. $\bar{x}$ and are the mean and standard deviation of the entire series, respectively, and t_k is the value of the student *t*–distribution with *N–2* degrees of freedom. This was then tested against the "students" *t*–distribution table at a 95% confidence level appropriate to a two-tailed test form. When t_k is outside the bounds of the two-tailed probability of the Gaussian distribution (equal to 1.96 at 95% confidence level), a significant shift from the mean is assumed.

The annual rainfall was further subdivided into two non-overlapping sub-periods, 1962-1991 and 1992–2021. The student's t-test, t_d, was then used to analyze the relative contribution of the two sub-periods to the rainfall characteristics of the area. The statistics, t_d, is determined as:

$$t_d = \frac{\left(\bar{X}_2 - \bar{X}_1\right) - \left(\mu_2 - \mu_1\right)}{\left[\frac{N_2 S_2^2 + N_1 S_1^2}{N_2 + N_1 - 2} \cdot \frac{1}{N_2} + \frac{1}{N_1} \right]^{1/2}} \quad \text{....... (Eq. 9)}$$

where ($\bar{X}_2$ - $\bar{X}_1$) represents the difference in group means (μ_2 -μ_1) is the expected differences (set equal to 0), N_2 and N_1 are the number of cases within each sub-sample, and S_2 and S_1 are their standard deviations, respectively. When t_d is outside the bounds of the Gaussian distribution, equal to 1.96 at 95% confidence level, a significant shift from the mean is assumed.

RESULTS AND DISCUSSION

Test for Normality and General Statistics of the Rainfall

The results for the normality test of the annual and monthly rainfall data are shown in Tables 1, 2, 3, and 4 for Charanchi, Kaita, Kusada, and Zango, respectively. The results of the standardized coefficient of skewness (Z_1) and kurtosis (Z_2) show that both the annual and monthly rainfall data for all grid points are normally distributed except for (Z_1) for May and June for Charanchi and Zango, June for Kaita and Kusada; and (Z_2) for June for Kusada. Based on the result, the data were accepted as normal at 95% confidence level. Therefore, no transformation was done to the data.

Table 1: Test for Normality and General Statistics of Rainfall for Charanchi

Statistics	May	June	July	August	September	Annual
Mean	37.57	88.83	179.19	224.26	108.21	661.23
Standard Dev. (δ)	23.13	40.29	46.43	56.82	41.98	125.37
Skewness(Z_1)	2.07*	2.78*	0.93	-1.39	1.91	-1.07
Kurtosis(Z_2)	-0.14	1.77	-0.37	0.72	0.81	0.31
Minimum(mm)	2.3	21.9	91.2	64.1	26.4	370.4
Maximum(mm)	97.2	213.1	310.3	358.9	233.4	926.8
Rate of change (mm/y)	0.08	0.15	0.03	0.27	0.18	0.70
Total Change(mm/60yrs)	5.04	9.24	1.68	16.24	10.68	40.8

*Significant at $p < 0.05$
Source: Authors' computation, 2023

The mean annual rainfall for Charanchi is 661.23 mm per year, as shown in Table 1. The highest annual rainfall throughout the study period was 926.8 mm, which was received in the year 1964, while the lowest annual rainfall was 370.4 and was received in 1987. This year was the peak of the drought of the 1980s (Abaje & Magaji, 2022). The highest monthly rainfall received is 358.9 mm, and it was in August, the month of maximum rainfall. The lowest monthly rainfall is 2.3 mm and was received in May.

Table 2 shows the rainfall distribution for Kaita. The result indicates that the mean annual rainfall is 550.38 mm. The highest annual rainfall of 875.2 mm was received in 2020, while the lowest total rainfall of 275.1 mm was received in 2015. The highest monthly rainfall is 333.2 mm in August, while the lowest is 0.9 mm, recorded in May.

Table 2: Test for Normality and General Statistics of Rainfall for Kaita

Statistics	May	June	July	August	September	Annual
Mean	23.46	69.19	162.11	198.41	74.81	550.38
Standard Dev (δ)	14.37	32.35	45.38	51.12	34.65	106.92
Skewness(Z_1)	1.75	2.89*	1.15	-0.93	1.53	-0.73
Kurtosis(Z_2)	-0.64	1.88	-0.64	0.95	0.16	0.49
Minimum (mm)	0.9	16.9	74.1	52.7	17.2	275.1
Maximum (mm)	62	166.6	285	333.2	165	875.2
Rate of change (mm/y)	0.08	0.16	0.03	0.3	0.02	0.54
Total Change(mm/60yrs)	4.5	9.84	1.68	18	0.96	28.2

*Significant at $p < 0.05$
Source: Authors' computation, 2023.

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Table 3 shows that the mean annual rainfall for Kusada is 795. 61 mm. The highest and lowest annual rainfalls are 1064.5 and 504.8 mm, recorded in 2020 and 1973, respectively. The highest monthly rainfall is 345 mm, while the lowest is 4.7 mm, received in August and May, respectively.

Table 3: Test for Normality and General Statistics of Rainfall for Kusada

Statistics	May	June	July	August	September	Annual
Mean	60.05	113.39	191.79	294.03	239.8	795.61
Standard Dev (δ)	30.88	44.09	43.39	51.03	48.2	128.25
Skewness(Z_1)	1.72	3.47*	1.86	-1.66	1.93	-1.55
Kurtosis(Z_2)	0.15	2.89*	0.76	1.01	-0.77	-0.54
Minimum (mm)	4.7	44.8	105.	81.9	60.7	504.8
Maximum(mm)	152.5	266.1	326.2	345	263	1064.5
Rate of change(mm/y)	0.01	0.17	0.15	0.36	0.34	1.05
Total Change(mm/60yrs)	0.86	10	8.7	21	20.2	0.64

*Significant at $p < 0.05$
Source: Authors' computation, 2023

Table 4 presents the rainfall distribution for Zango. Zango's highest and lowest total annual rainfall were 796.6 mm and 254.1 mm in 1964 and 1987, respectively. The mean annual rainfall is 551.94 mm. The highest and lowest monthly rainfalls were 342 and 0.5 mm, respectively, recorded in August and May.

Table 4: Test for Normality and General Statistics of Rainfall for Zango

Statistics	May	June	July	August	September	Annual
Mean	24.69	65.47	163.03	201.91	84.28	551.94
Standard Dev (δ)	16.97	32.88	46.75	54.19	35.75	114.62
Skewness(Z_1)	2.21*	3.5*	1.59	-1	1.93	-0.96
Kurtosis(Z_2)	-0.52	1.87	0.82	0.19	0.6	0.3
Minimum (mm)	0.5	16.4	68.8	61.4	20.5	254.1
Maximum (mm)	66.4	165.2	299.8	342	188.6	796.6
Rate of change (mm/y)	0.08	0.25	0.01	0.4	0.06	0.75
Total Change(mm/60yrs)	4.67	15	0.5	24	3.3	44.75

*Significant at $p < 0.05$
Source: Authors' computation, 2023.

The results show that the years with the lowest annual rainfall coincided with the driest years in the second half-century of the 21st century, where severe and extreme droughts were recorded throughout the region (Oladipo, 1993; Abaje, 2023). The findings show that the rainfall in the study area decreases northward. Thus, it agrees with Oguntunde *et al.* (2011) that there is latitudinal variation in rainfall in Nigeria, which decreases from south to north. The lowest monthly rainfall is 2.3 mm and was received in May, a month characterized by either early or false onset of the rainy season. One of the major implications of this false start is that farmers usually mistaken it as the beginning of the raining season. It also shows that August is the month of maximum rainfall; hence, it is the peak of the rainy season (Oguntunde *et al.,* 2011).

Trend Analysis of Rainfall
Charanchi
Annual rainfall for Charanchi showed an increasing trend of about 40.86 mm from 1962 to 2021 at a rate of 0.7 mm per annum as indicated by Appendix I. May showed rainfall slightly decreasing trend of 0.084 mm per annum and a total decrease of 5.04 mm throughout the study period. On the other hand, the linear trend line indicated an increase of 9.24 mm at a rate of 0.154 mm per annum in June. The 5-year moving average was above the long-term mean from the beginning of the data to 1970 and from early 2000 to the end of the study period for both the annual and June rainfall. Conversely, it was above the long-term mean from 1980 to 1984, 1991-1995, and from 2004 to 2012 for May.
The linear trend line for the past 60 years indicated a slight increase in rainfall of about 0.12 at a rate of 0.002 mm per year in July, a total increase of 16.44 mm at a rate of 0.274 mm per annum in August, an increase of 10.68 mm at a rate 0.178 mm every year. The 5-year moving average was above the long-term mean from 1978 to 1984, from 2000 to 2005, and the last 2 years of the study for July. For August, it was above the long-term mean from the beginning of the data to 1971 and from 1999 to the end of the period. The 5-year moving average was above the long-term mean from the beginning of data to 1970, between 1997 and 2002, and from 2006 to 2014 for September.

Kaita
Annual and monthly rainfall trends for Kaita are shown in Appendix II. Annual rainfall shows a trend of 0.47 mm per year and a total increase of 28.2 mm for the past 60 years. The 5-year moving average was above the long-term mean from the beginning of the data to 1970, from 1978-1982, and 2000 upward. May rainfall has a relatively decreasing trend of 0.075 mm. This accounts for the decrease of 4.5 mm in the study area over the 60 years. However, 1971-1972, 1979-1984, 1991-1996 and 2004-2014 shows a moving average above the long-term mean. For June, the trend shows an increase of 0.164 mm per year, with an overall increase of 9.84 mm throughout the study period. The 5-year moving average for June was above the long-term mean from the beginning of the data to 1970, 1979 to 1984, and from 2004 upward.
July rainfall trend slightly decreased at the rate of 0.028 mm per year. The sum of the entire decrease in rainfall trend for the study period is 1.68 mm. The moving average was above the long-term mean from the beginning of the data to 1971, 1979 to 1983, and 2001 to 2015. For August, there was an increasing trend at a rate of about 0.3 mm per year, while from 1962 to 2021, the overall increase in rainfall was 18 mm. The 5-year moving average was

above the long-term mean from the beginning of the data to 1970 and from 2001 upwards. September rainfall trend slightly decreased at a rate of 0.016 mm per annum, while for the entire study period, there was a total decrease of 0.96 mm. It also shows that the 5-year moving average was above the long-term mean from the beginning of the study period to 1970, 1976 to 1978, 1998 to 2004, and 2006 to 2014 (see Appendix II).

Kusada

Annual and monthly rainfall trends for Kusada are presented in Appendix iii. The annual rainfall trend increased at a rate of about 1.05 mm annually. This indicates that there was an increase of 63 mm during the study. The 5-year moving average was above the long-term mean from the beginning of data to 1971, from 1978 to 1981, and from 1998 to 2006. However, the linear trend for May shows a decreasing trend at a rate of 0.014 mm per year, with an overall decrease of 0.86 mm for the whole study period. The 5-year moving average for May was above the long-term mean from 1980 to 1984, 1992 to 1996, and from 2004 to 2014. Conversely, the June rainfall linear trend also increased at a rate of 0.168 mm per year, while the overall increase for the entire period of the study is about 10 mm. 5-year moving average was above the long-term mean from the beginning of the data to 1970, 1979 to 1982 and from 2004 upwards.

An increasing trend of 0.1448 mm per year was shown by the linear trend for July rainfall in Kusada. A total of 8.7 mm of rainfall increased from 1962 to 2021. The 5-year moving average was above the long-term mean between 1980 and 1983 and from 2000 to 2004. August rainfall linear trend increased at a rate of 0.36 mm per annum and a total increase of about 21 mm for the whole study period. Similarly, the linear trend shows an increase in September rainfall at 0.34 mm per year. The overall increase for the period of the study is 20.2 mm. The 5-year moving average was above the long-term mean from the beginning of the data to 1972, from 1995 to 2003, and from 2006 to 2010 (see Appendix III).

Zango

The annual rainfall trend for Zango increased at a rate of 0.75 mm per year, and there was a total increase of 44.75 mm for the whole study period, as presented in Appendix VI. The 5-year moving average was above the long-term mean from the beginning of the data to 1970 and slightly above from 2000 upwards. May rainfall shows a slightly decreasing trend at 0.08 mm per annum. The total decrease in rainfall was 4.67 mm for the whole study period. The 5-year moving average was relatively above the long-term mean from the beginning of the data to 1984, 1991 to 196, 2004 to 2010, and 2011 to 2014. The linear trend also shows an increase in rainfall for June at a rate of 0.25 mm per year. The trend accounts for an overall increase of about 15 mm for the whole 60 years of the study. The moving average was above the long-term mean from the beginning of the data to 1970 and from 2004 upwards.

The linear trend for July rainfall shows a slight increase of 0.008 mm per year with a total increase of just about 0.5 mm for 60 years of the study. The 5-year moving average was only above the long-term mean from 1979 to 1984 and relatively along the long-term mean from 1990 upwards. In contrast, August rainfall for Zango increased at about 0.4 mm per annum and an overall increase of about 24 mm for the entire period under study. The 5-year moving average was above the long-term mean from the beginning of the data, and it fell from then until 2000 when it rose to the end of the data. Lastly, the September rainfall trend slightly increased to about 0.06 mm yearly. The results show a total increase of 3.3 mm for the study period. The 5-year moving average was above the long-term mean from the beginning of the data to 1970, 1997 to 2003, and 2008 to 2014 (see Appendix VI).

The findings revealed that the annual rainfall trend increased all over the area. This is consistent with recent studies that concluded that the Sudano-Sahelian zone of Nigeria has been experiencing wetter conditions since the 2000s (Abaje et al., 2012; Murtala *et al.,* 2018; Abaje & Oladipo, 2019; Umar & Matazu, 2019; Matawalli, 2021; Ati *et al.,* 2022) as well as Katsina in particular (Abaje *et al,* 2015; Abaje & Magaji, 2022). However, it is not consistent with the findings of Hassan and Abdulhamed (2012), and ideally, it is due to the chronological factor of the study; hence, if recent data are used, the findings will concur with those of other studies. Generally, a 5-year moving average of the annual was above the long-term mean from the beginning of data to 1970 all over the area and declined from then through 1980 up to 2000. From then on, it was above the long-term mean to the end of the study period. This agrees with Abaje *et al.* (2015) and Abaje and Magaji (2022).

The results generally revealed that monthly rainfall trends for June, August, and September increased. This is consistent with the findings of Abaje et al. (2015) and Umar and Matazu (2019). May rainfall was generally decreased, which is in variance from most previous studies (Abaje et al., 2015; Umar & Matazu, 2019) but in line with Hassan and Abdulhamed (2012).

Decadal Trend of Rainfall

Charanchi

Table 5 shows the results of the decadal trend (Cramer's test) for Charanchi. The Cramer's test revealed two decades of statistically significant annual rainfall at a confidence level of 95%. The results indicate that 1962-1971 was statistically wetter than the normal condition, while 1982-1991 was statistically drier than the long-term normal condition. This decade (1982-1991) coincides with the droughts of the 1980s that were more severe than the drought of the 1970s (Oladipo, 1993; Abaje & Magaji, 2022). Conversely, even though the other decades have normal conditions, the results indicate that two decades, 1972-1981 and 1991-2002, were relatively drier while the recent decades were wetter. This is an indication of increasing rainfall in recent years.

Table 5: Decadal Trend of rainfall for Charanchi

Sub-periods	May	June	July	August	September	Annual
1962-1971	0.32	1.38	0.83	1.91	1.76	2.3*
1972-1981	0.7	-0.96	0.17	-0.81	-1.85	-0.85
1982-1991	-0.65	-1.55	-1.48	-2.89*	-2.48*	-3.82*
1992-2001	-0.31	-1.4	0.03	-0.46	1.28	-0.31
2002-2011	0.61	1.69	-1.04	0.91	0.78	0.9
2012-2021	-069	0.85	0.98	1.23	0.41	1.52

*Significant at $p < 0.05$. **Source:** Authors' computation, 2023

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May monthly rainfall for Charanchi was normal for all decades at a 95% significant level. For June, the Cramer's test reveals that all the decades are normal at a 95% significance level. For July, all the *tk* values are not statistically significant. The Cramer's test for August revealed that 1981-1991 was statistically significant with negative *tk* values, which indicates that it was a drier decade, while the other five decades were not statistically significant. September showed a significant negative *tk* value (-2.48) in the decade 1982-1991; therefore, it is significantly drier than the long-term condition.

Kaita

Table 6 shows the decadal trend of the annual and monthly rainfall for Kaita.

Table 6: Decadal Trend of rainfall for Kaita

Sub-periods	May	June	July	August	September	Annual
1962-1971	0.58	0.83	1.18	1.53	2.0*	2.24*
1972-1981	0.78	-0.62	0.57	-0.81	-0.99	-0.52
1982-1991	-0.79	-1.21	-1.83	-2.04*	-2.7*	-3.51*
1992-2001	-0.44	-0.73	-0.19	-1.08	0.77	-0.98
2002-2011	0.63	1.76	-0.91	0.85	0.86	0.92
2012-2021	-0.76	0.84	1.16	1.54	-0.03	1.65

*Significant at $p < 0.05$. **Source:** Authors' computation, 2023

The decadal trend analysis of the annual rainfall revealed that two decades (1962-1971 and 1982-1991) have significant *tk* values, while 1962-1971 was significantly wetter than the long-term condition, and 1982-1991 was significantly drier than the long-term condition. The recent decades (2012-2021) showed an insignificant wetter condition, meaning there has been increasing rainfall in recent years. All the decades have no significant tk values (normal condition) for May, June, and July. June also has a normal condition. August tk values showed that 1982-1991 was significantly drier than long-term conditions. Conversely, the first decade and the last two decades were relatively wetter decades. 1962-1971 and 1982-1991 were the decades with significant tk values for September. While 1962-1971 was significantly wetter than the long-term condition on the one hand, 1982-1991 was significantly drier than the long-term normal condition on the other hand.

Kusada

The Cramer's test results for the Kusada sub-area are presented in Table 7.

Table 7: Decadal Trend of rainfall for Kusada

Sub-periods	May	June	July	August	September	Annual
1962-1971	-0.2	1.27	0.62	0.9	1.14	1.53
1972-1981	0.57	-0.74	0.06	-0.67	-1.88	-0.93
1982-1991	-0.42	-1.71	-1.13	-2.21*	-2.05*	-3.22*
1992-2001	-0.36	-1.47	0.48	0.26	1.38	0.16
2002-2011	1.19	1.64	-0.98	0.59	0.8	0.77
2012-2021	-0.78	1.00	0.94	1.04	0.51	1.49

*Significant at $p < 0.05$. **Source:** Authors' computation, 2023

Cramer's test for the annual rainfall of Kusada (Table 7) revealed that 1982-1991 had significant negative tk values, indicating that it is statistically drier than the normal conditions. However, the last three decades were wet, but not significantly, indicating increasing rainfall in recent years. May, June, and July showed that all the decades have normal conditions. Cramer's test for August rainfall showed that 1982-1991 was significantly drier than the long-term conditions. However, the tk values for the first decade and the last three decades of the study for August indicated that the decades were relatively wetter but insignificant. The tk values for September also indicated that 1982-1991 was statistically drier than the normal conditions.

Zango

Cramer's test of annual rainfall for Zango revealed that three decades (1962-1971, 2012-2021, and 1982-1991) were statistically significant at a 95% confidence level, as presented in Table 8.

Table 8: Decadal Trend of Rainfall for Zango

Sub-periods	May	June	July	August	September	Annual
1962-1971	0.46	0.6	0.81	1.97*	1.82	2.08*
1972-1981	1.15	-0.66	0.99	-1.66	-0.64	-0.56
1982-1991	-1.35	-1.3	-1.98*	-2.03*	-3.67*	-3.97*
1992-2001	-0.24	-1.67	-0.08	-1.02	0.9	-0.78
2002-2011	0.58	0.96	-0.89	0.92	0.83	0.96
2012-2021	-0.6	1.12	1.1	1.82	0.46	1.96*

*Significant at $p < 0.05$. **Source:** Authors' computation, 2023.

The annual's first and last decades (1962-1971 and 2012-2021) were significantly wetter, while 1982-1991 was significantly drier than long-term normal conditions. The results showed that none of the decades had a significant *tk* value for May and June, meaning the condition was normal. For July, August, and September, all the *tk* values indicated that the decade 1982-1991 was significantly drier than the long-term condition.

Generally, the results show that the 1970s, 1980s, and 1990s experienced droughts. At the same time, the recent two (2) decades (2002-2011 and 2012-2021) had wetter conditions, indicating decreasing drought conditions and increasing rainfall in recent years. This is consistent with the findings of Hassan and Abdulhamed (2012), Abaje *et al*. (2012, 2023, and 2018), Abaje and Oladipo (2019), Matawalli (2021), and Abaje and Magaji (2022) that rainfall in the northern parts of the country is increasing in recent years.

Thirty (30) Years Non-overlapping Trend of Rainfall

The result of the 30-year non-overlapping sub-period (1962-1991 and 1992-2021) analysis to detect the spatio-temporal changes using the student t-test is presented in Table 9.

Table 9: Thirty (30) Years Non-overlapping Trend of Rainfall

Station	Sub-period	Mean	SD	t_d
Charanchi	1962-1991	635.91	137.52	6.35*
	1992-2021	686.69	108.32	
Kaita	1962-1991	534.14	115.27	4.28*
	1992-2021	566.61	97.09	
Kusada	1962-1991	765.54	134.08	6.72*
	1992-2021	825.68	116.68	
Zango	1962-1991	528.76	126.47	5.75*
	1992-2021	575.11	173.87	

*****Significant at $p < 0.05$
Source: Authors' computation, 2023

The student t-test (td) values are 6.35, 4.28, 6.72, and 5.75 for Charanchi, Kaita, Kusada, and Zango, respectively. The significant positive td values for all the grid points indicated that there has been a significant increase in annual rainfall in the recent 30 years (1992-2021) compared to the 30 previous 30 years (1962-1991). This is consistent with the works of Hassan and Abdulhamed (2012), Abaje *et al*. (2012, 2015, and 2018), Abaje and Oladipo (2019), Matawalli (2021), Abaje and Magaji (2022), and Abaje (2023) that rainfall has increased in recent years in the northern States of the country. However, this result does not concur with some of the earlier conclusions of Oladipo (1993) and Sawa (2002) that the area, and northern Nigeria in general, was experiencing decreasing rainfall. One of the major reasons for the variance of the result is that these previous studies (Oladipo, 1993 and Sawa, 2002) were based on data from the early 1990s and 2000. Studies using recent rainfall data of northern part of Katsina State covering up to 2021 will arrive at the same result as this study.

Conclusion and Recommendations

The amount of rainfall has been increasing for the past two decades in northern Katsina. This is evidence of recovery from devastating 1970s, 1980s, and 1990s droughts in the area. Rainfall is spatio-temporally variable in Katsina. August remains the month where the most rainfall is received all over the area, with an increasing trend in recent years. However, May rainfall generally shows a decreasing trend, possibly indicating a shift in the onset of the rainy season. Given the temporal variability of the rainfall in the area, monthly rainfall analyses are suitable for water resource demand. Moreover, high temporal resolution rainfall data is crucial for rainfall analysis, especially in areas where rain-fed farming is practiced. It is recommended that scientists develop genetically modified seeds suitable for the recent increase in rainfall in northern Nigeria and Katsina State in particular. Farmers should acquire weather information to explore opportunities associated with climate change, especially an increase in rainfall in this drought-prone ecological zone. Communities and authorities should always take preventive measures against floods as the recent increase in rainfall exposes the area to flood risk.

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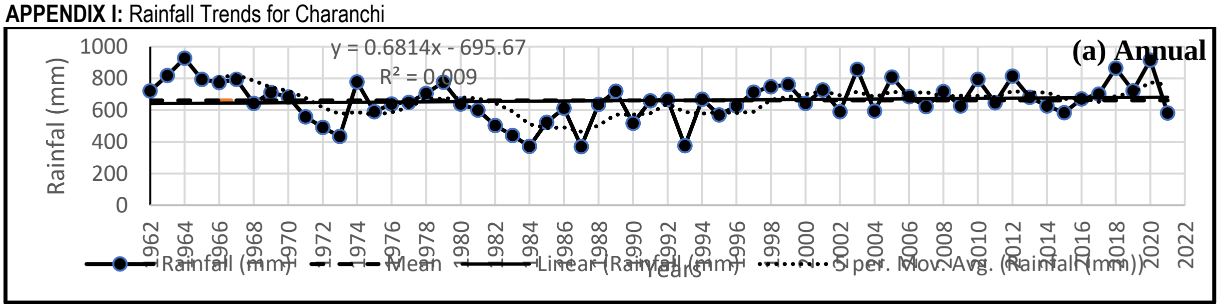
APPENDIX I: Rainfall Trends for Charanchi



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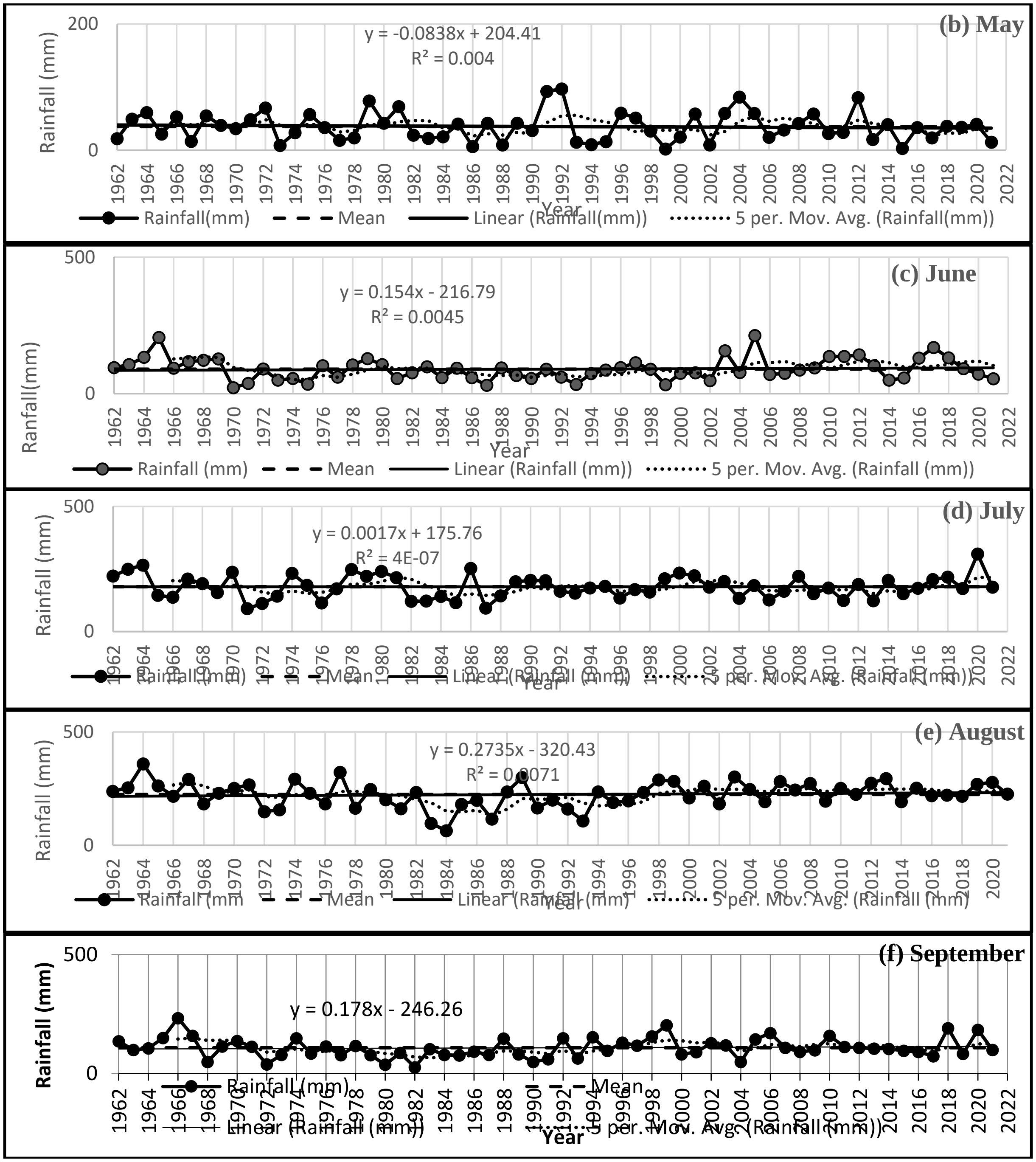

Source: Authors' computation

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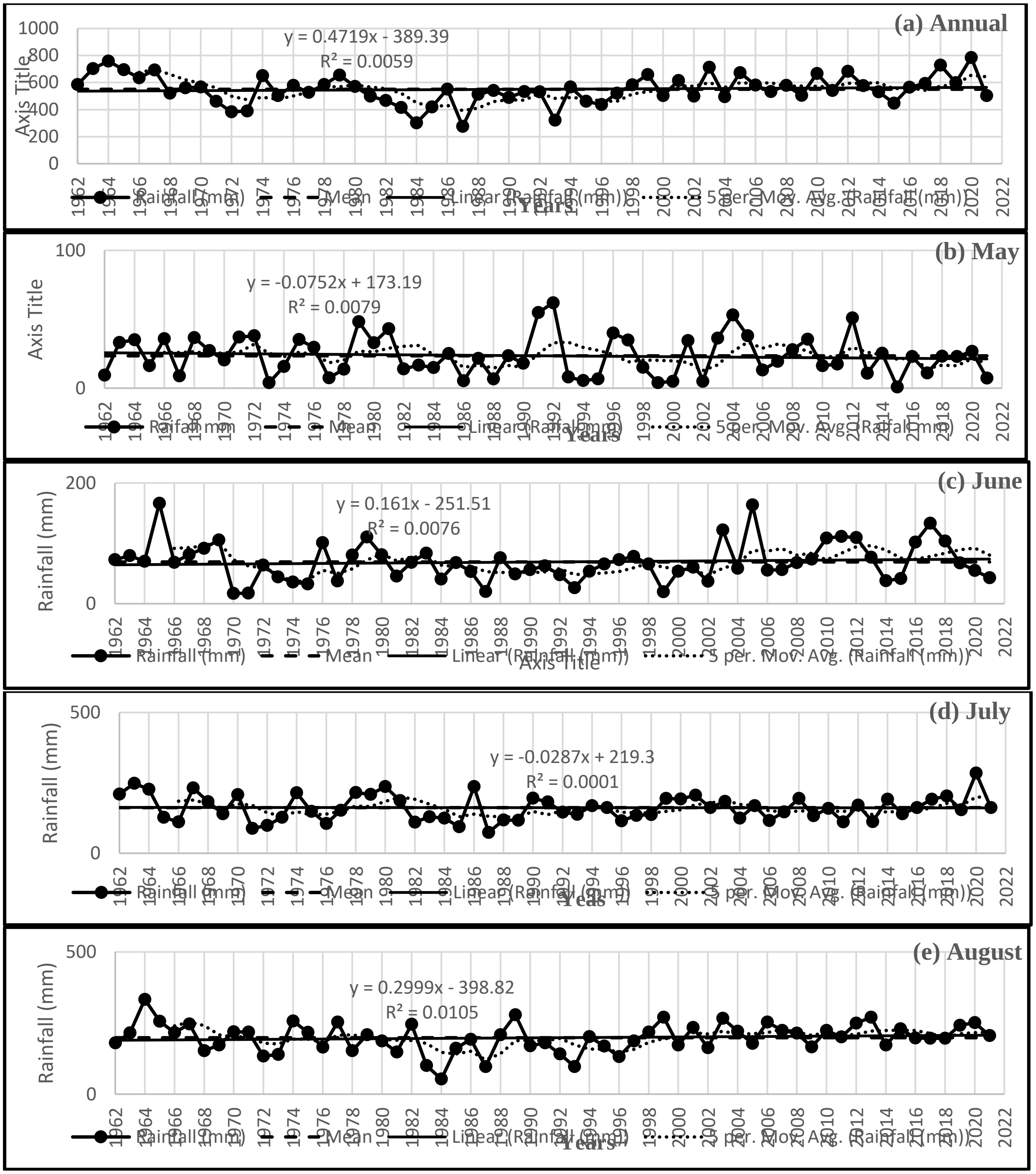
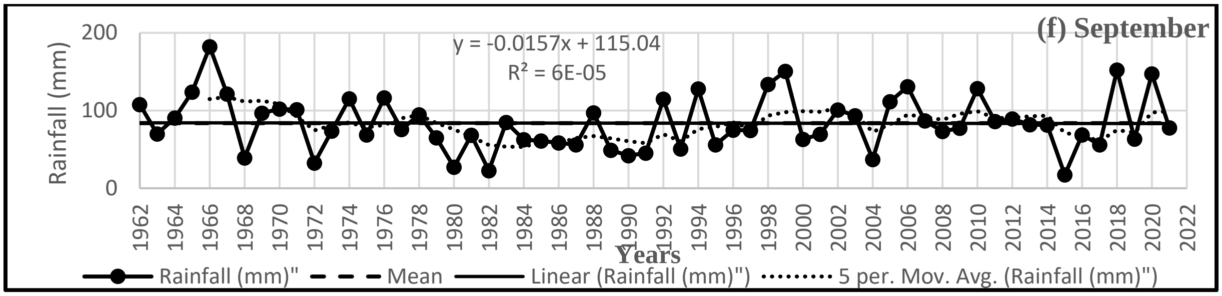
APPENDIX II: Rainfall Trends for Kaita





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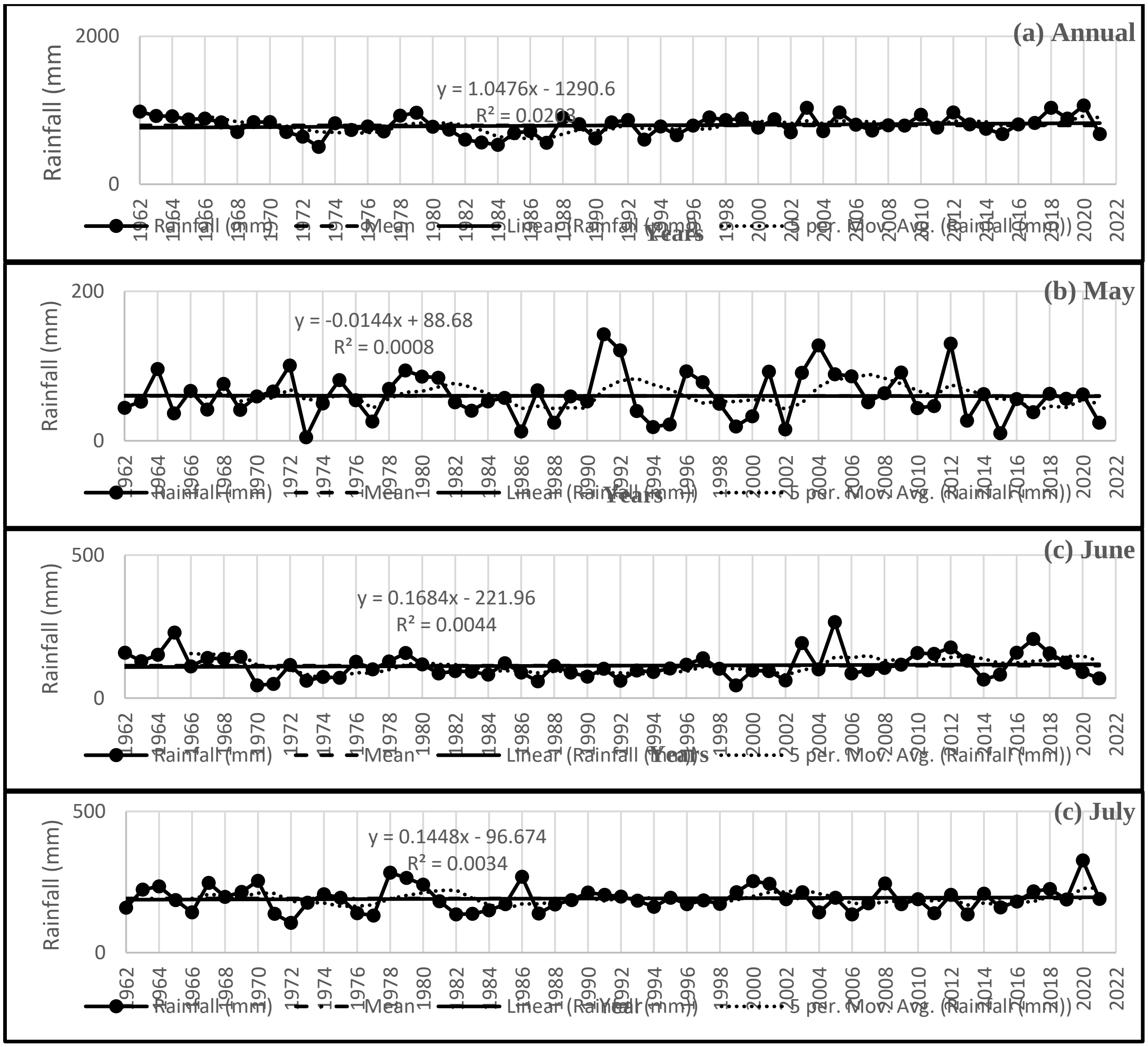
APPENDIX III: Rainfall Trends for Kusada



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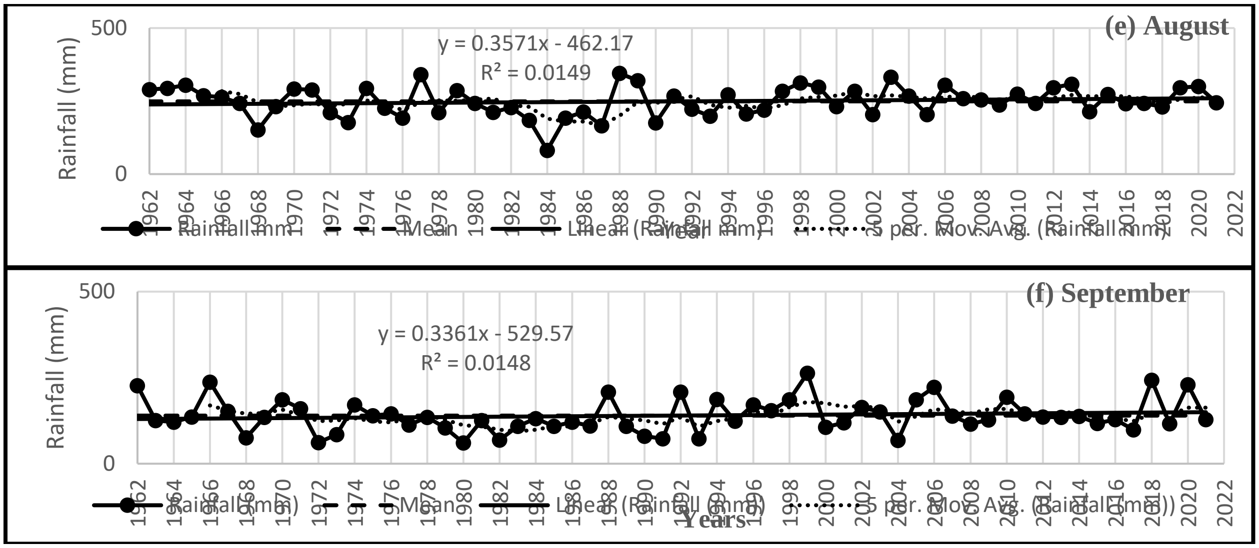

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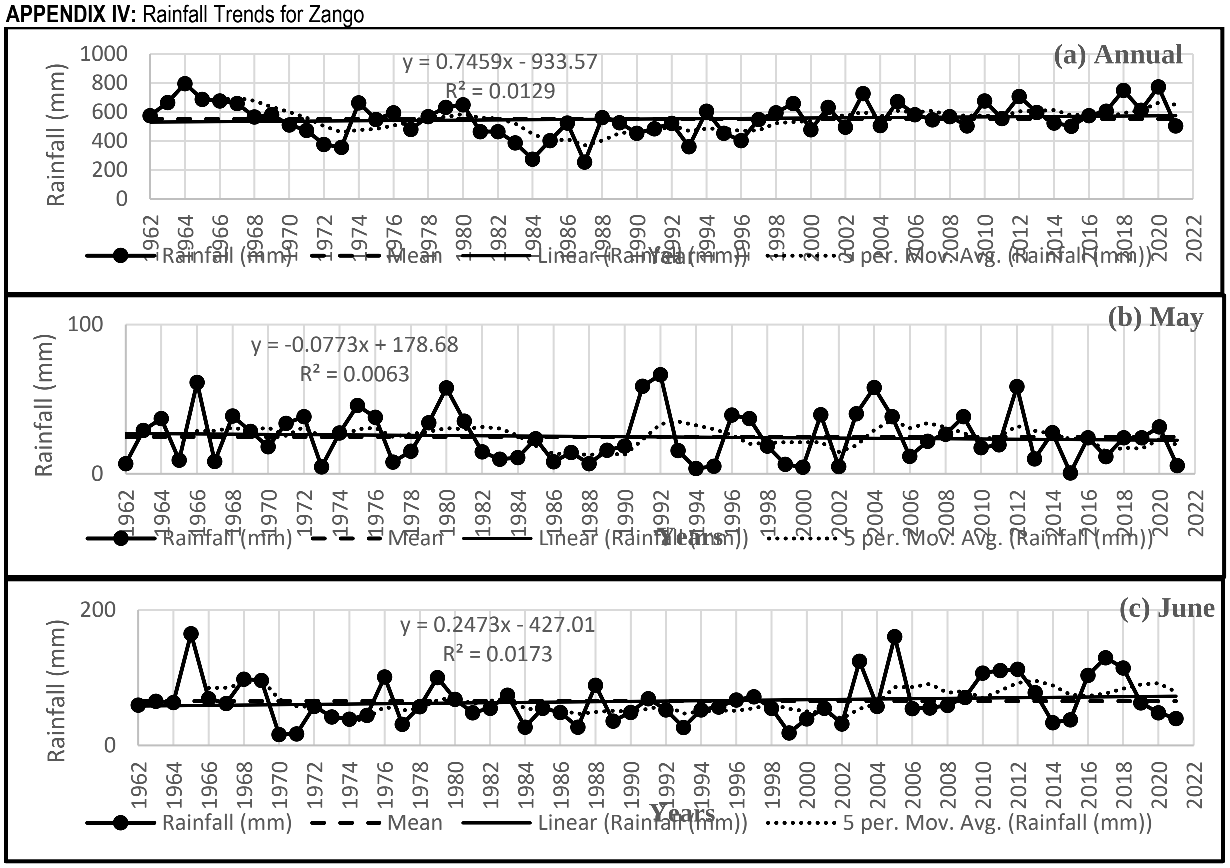
APPENDIX IV: Rainfall Trends for Zango



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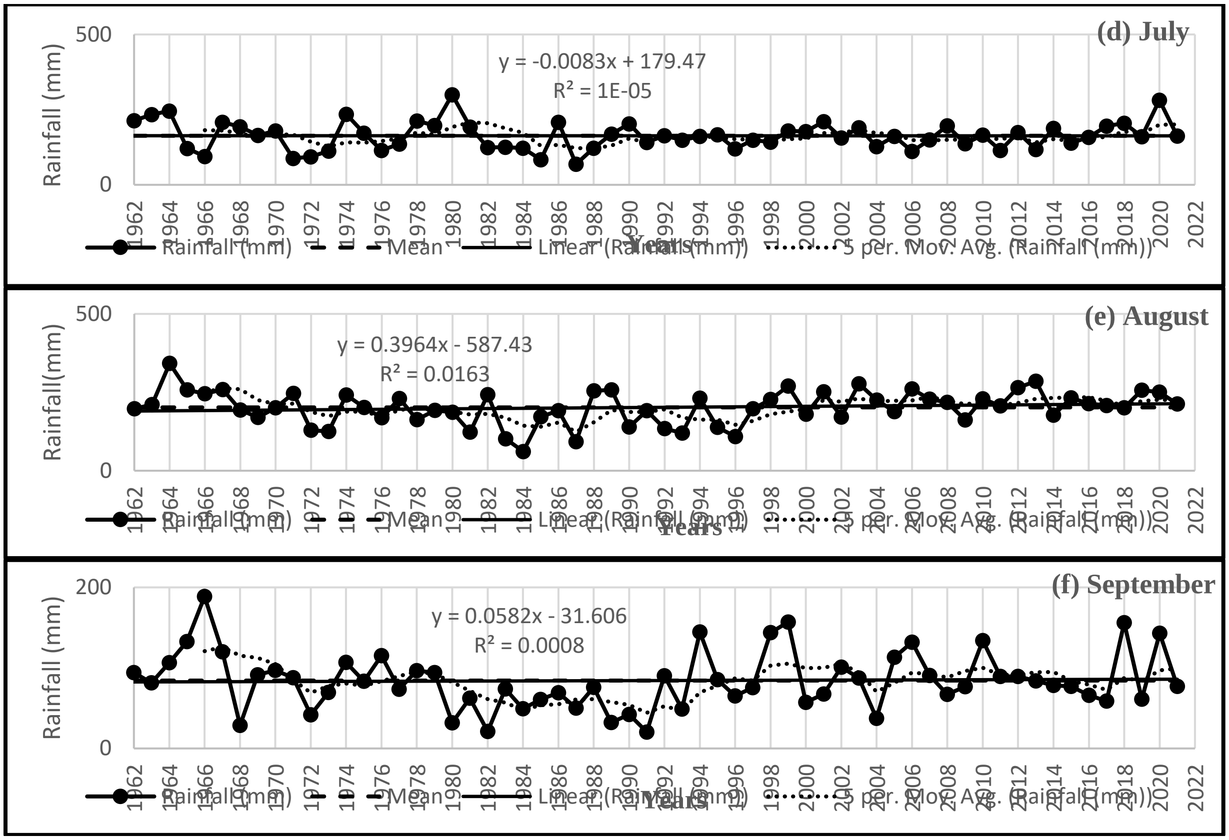

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