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Rainfall Irregularities, Trends and Variations Intropical Semi-Arid River Catchment

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Rainfall Irregularities, Trends and Variations Intropical Semi-Arid River Catchment

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Keywords: rainfall, climate variability, mann-kendall, cluster analysis, semi-arid, Nigeria.

I. Introduction

There have been reported studies and some are currently ongoing on impact of climate variability on hydrology and water resources worldwide (Pachauri et al., 2014; Pervez and Henebry 2015; Hoque et al., 2016; Li et al 2016). The variability in climate system is basically investigated using rainfall and temperature fluctuations. However, in arid and semi-arid areas the inter-annual and intra-annual rainfall variability has been more important in the study of climatic changes. This is due to the sensitivity of these areas to minor climatic fluctuation, especially the rainfall irregularities. Although climate variability in the form of rainfall irregularity occur at all spatial scales (Elsanabary and Gan 2015), currently interest have been shifted to regional and basin scales studies, that provide suitable location for details hydro climatic studies which will provide crucial information for planning and management of regional and local activities such as farming and water supply (Pervez and Henebry 2015), and for the preparation against extreme events such as floods and drought (sangaya et al., 2014).

Rainfall dynamics have been used as representative in the study of climate change and variability (Kusangaya et al., 2014; Mohammed et al., 2015), particularly in drier areas. Besides rainfall variability, temperature fluctuation and increased manifestation of extreme weather events such as heavy storms, droughts and floods were mentioned as basic features of climate variability (Ogungbenro and Morakinyo 2014; Suleiman and Ifabiyi 2015).

Although variability is an inherent behaviour of climate, the increase fluctuation of climatic variables particularly rainfall is becoming a major concern and is associated to motivated rise in greenhouse gas (GHG) concentrations and the changes in land uses (Warburton et al., 2005; Reason 2007), which consequently intensified global warming and the hydrological cycle (Huntington 2006; Pachauri et al., 2014).

In the semi-arid region of Nigeria due to its sensitivity to minor climatic changes, rainfall irregularities was found to aggravate the already existing environmental deprivation and water scarcity (Ogungbenro and Morakinyo 2014; Balogun et al., 2016). Consequently, there is increasing fear of food insecurity, human health challenges and slowing down of environmental flow (Balogun et al., 2016) and of course conflict over available natural resources particularly the water(Roma 2008; Audu 2013; Umar and Ankidawa 2016)

Thus, the study area is prone to extreme weather events largely due to rainfall variability, and therefore farming and water supply in the area is

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subjected to the tyranny of climate variability, particularly the rainfall irregularities. Considering the importance of rainfall to agriculture and water supply in particular and to all aspects of human existence in Hadejia River Catchment (HRC), the need to understand the nature and pattern of rainfall irregularities from trends and variations of the rainfall series has arisen.

II. Materials and Method

a) Study area

Hadejia River Basin is sub-catchment of the Lake Chad Basin. This sub-catchment has an area of 24,680 km^2 (Adakayi 2012). The basin is climatically control by two air masses, the south west and the north east trade winds. The south west trade wind is rainfall bearing from the Gulf of Genue, thus, precipitation over a particular location is in the area is by the dominance of the south west air masses. This south west air masses usually stayed between May to September (summer). The north east trade wind, however come along with dryness and coldness from the Sahara Desert between Octobers to April (winter). The interphase of these air masses is known as the Inter-tropical convergence zone (ITCZ) and its pendulum north to south of the region in particular control the onset and cessation of rainfall in the entire basin perimeter (Ebele and Emodi 2016).Precipitation is very variable with time temporal and with space spatial, however temporal variability is more discernible. Mean annual rainfall varies from 987 mm in the south of the basin (Tiga station) to less than 400 mm in the extreme north east of the basin (Hadejia station) (fig 2). Temperature reaches as high as 35°C before the onset of the rains (April/May) and drop as low as 18° C in December/January (Abdul Kadir et al 2015). Mean annual maximum temperature varies from 33°C at the north-eastern part of the basin (Hadejia station) to 31°C at the southern part of the basin (Tiga stations). Similarly, mean annual minimum temperature varies from 20°C at the north-eastern part of the basin (Hadejia station) to 19°C at the southern part of the basin (Tiga stations). Temperature increases north to south, unlike rainfall which decreases with increasing altitude.

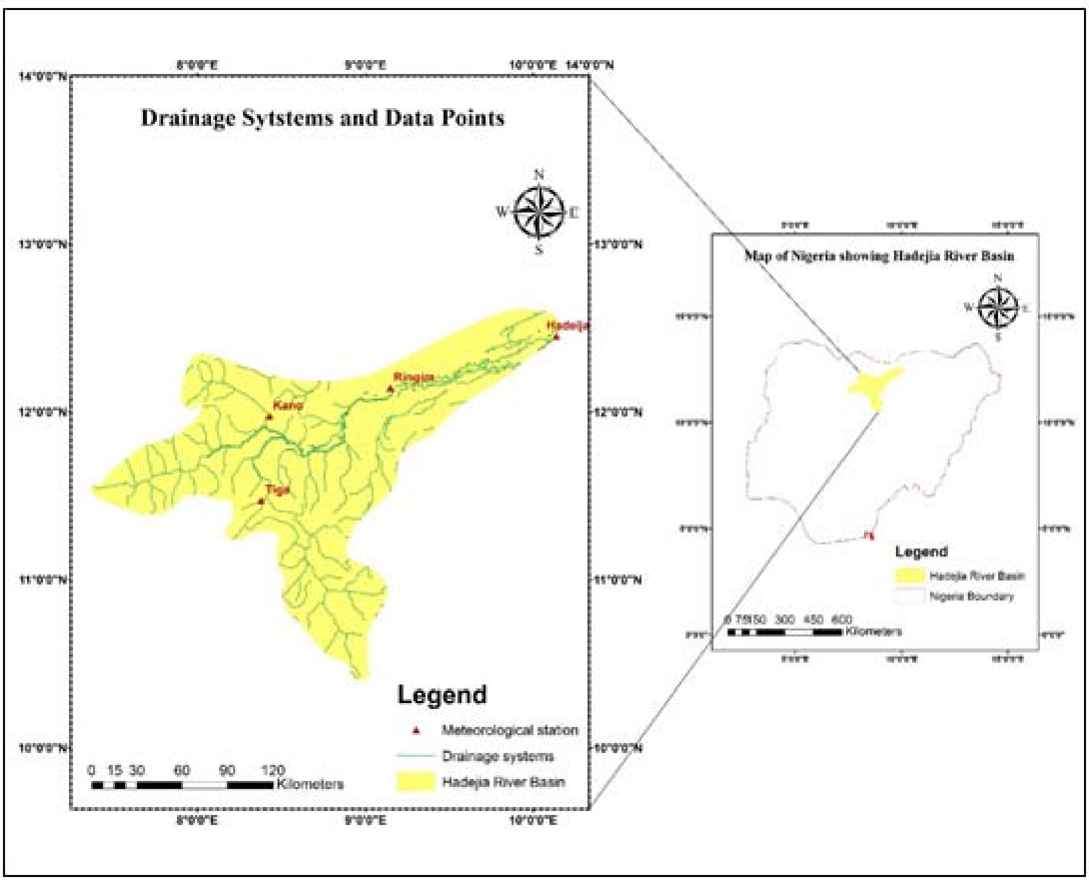

Figure 1: Drainage and meteorological stations within the basin. *Modified after IUCN 2003*

b) Data for the study

Rainfall data for thirty six years were obtained from Nigerian Meteorological Agency (NIMET). The data contained monthly records, which was used in depicted rainfall irregularities in Hadejia River.

The first data treatment applied to the data was the quality assurance and quality control (QA/QC) as prerequisite to the application of suitable statistics (Duhan and Pandey 2013). The data were crisscross for anomalies such as missing data and outliers. The result of QA/QC analysis revealed that the data were statistically clean except for few missing data which is found less than 10% of the whole dataset. They were supplanted with the means of the last two recorded observations that bound the missing observations (Chatterjee and Hadi 2015)

c) Data analysis

Rainfall and river discharge variations were analysed analysis of variance (ANOVA), cluster analysis (CA) and Mann-Kendall trend test. Cluster analysis was also conducted to strengthen the ANOVA and Tukey HSD Test results. However, the relationship between rainfall and river discharge was quantified using correlation statistics and hydrograph analysis. Prior to the application multivariate statistic the data was subjected to descriptive analysis to understand the nature of the dataset. The mean, SD and CV as well as the trend results were interpolated via inverse distance weight age (IDW) technique within the GIS environment.

d) Descriptive statistics

Descriptive statistics are used to label the basic features of the data in a study. They offer simple summaries about the sample and the measures. They are brief coefficients that summarize a given data set. Descriptive statistics discloses the measures of central tendency, and variation/spread in data (Bluman 2008). They are the underpinning procedures for quantitative analysis of a dataset.

e) Analysis of Variance (ANOVA)

Aanalysis of variance (ANOVA) is one of the most renowned statistical tool used in determining the existence of variation between two or more groups of observations. It is used to test whether the means of two or more independent groups are equal. This statistical tool tests the null hypothesis that samples in two or more groups were drawn from the same population (Chatterjee and Hadi 2015).

The null hypothesis (Ho) stated that; all sample means are equal (Ho: $\mu_1 = \mu_2 = \mu_3$)

The alternative hypothesis (Ha) stated that; at least one mean is different

So if the decision is to reject the null hypothesis base on the outcome of the analysis, then at least one of the means is different. However, the omnibus one-way ANOVA does not shows where the difference are, thus you may need to conduct a post-hoc tests for pairwise analysis (Chatterjee and Hadi 2015). The reliability of this statistical tool is tied to some basic assumptions; assumption of normality, homogeneity and independence.

f) Mann-Kendall Trend Test and Sen Slope Estimator

The nonparametric tests have been the most widely used tests for establishing the temporal variations in hydro meteorological variables (Zhang et al., 2014; Li et al 2016). Mann–Kendall (MK) trend test is the most encouraged approach (Jaagus 2006; Yürekli 2015), perhaps for its ability to accommodates missing values and outliers, and data with skewed distributions (AbRazak et al., 2016)

The null hypothesis (Ho) of the MK test is that, *time series values have no trend* while alternative hypothesis (H1) states that, *there is trend in the data set*. In this study 95% confidence level is used, thus a significant trend is indicated in the test when *P* value is less than 0.05.

The test is establish on the statistic that;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(xj - xk). \quad (1)$$

Where S is the Man-Kendall test values, xj and xk are the sequential data values, j, k and n are the length of the data.

Sign $(xj - xk)$ is a pointer function which assumes any of the values 1, 0, and -1, subject to the sign of $(xj - xk)$; i.e.

$$sgn\ (xj - xk) = 1 \text{ if } xj - xk > 0 \quad (2)$$

$$= 0 \text{ if } xj - xk = 0 \quad (3)$$

$$= -1 \text{ if } xj - xk < 0 \quad (4)$$

The Sen Slope estimator is used to estimate the true slope of Man-Kendall's trend analysis. It is a simple nonparametric test developed by Sen. (Sen 1968) and later presented by Gilbert (Gilbert 1987; Dorigo et al., 2012). This test calculates the magnitude of any significant trend detected in the Mann-Kendall test. Sen. (Karpouzos et al., 2010; Gocic and Trajkovic 2013). The Sen Slope estimator can be calculated using this equation

$$Q = \frac{xj}{j} - \frac{xk}{k} \quad (5)$$

where $\boldsymbol{Q}$ is the value of Sen Slope estimator, $\boldsymbol{xj}$ and $\boldsymbol{xk}$ are data values at time j and k.

III. Results and Discussion

a) Descriptive statistics

The result of normality statistics chosen (Skewness and kurtosis) were found to be within the range of -2 to +2 and -3 to +3 respectively, indicating that the data were from normal population distribution (George and Mallery 2003) (figure 2 a and b). Rainfall mean was slightly higher in Kano than Tiga stations and the least rainfall mean was at Hadejia station (Figure 3a). Furthermore, rainfall variability is much higher than that of temperature and the highest coefficient of variation (CV) and standard deviation (SD) of rainfall was at Tiga station. It is also the station with higher rainfall range (Figure 3b and sc).

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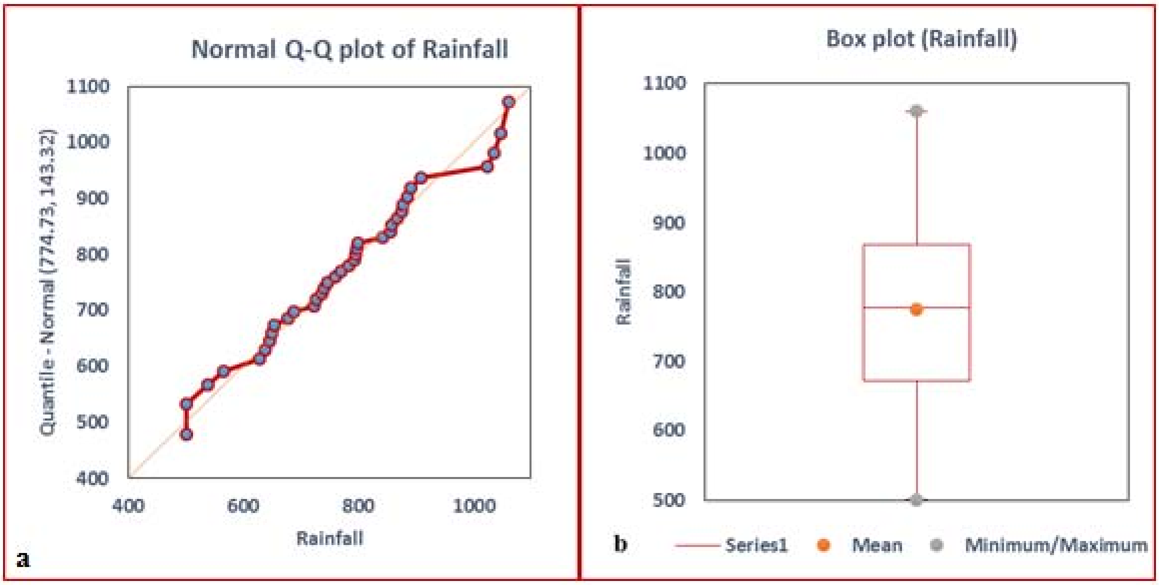

Figure 2: Rainfaoo normality (a)and box plot rainfall centrality(b)

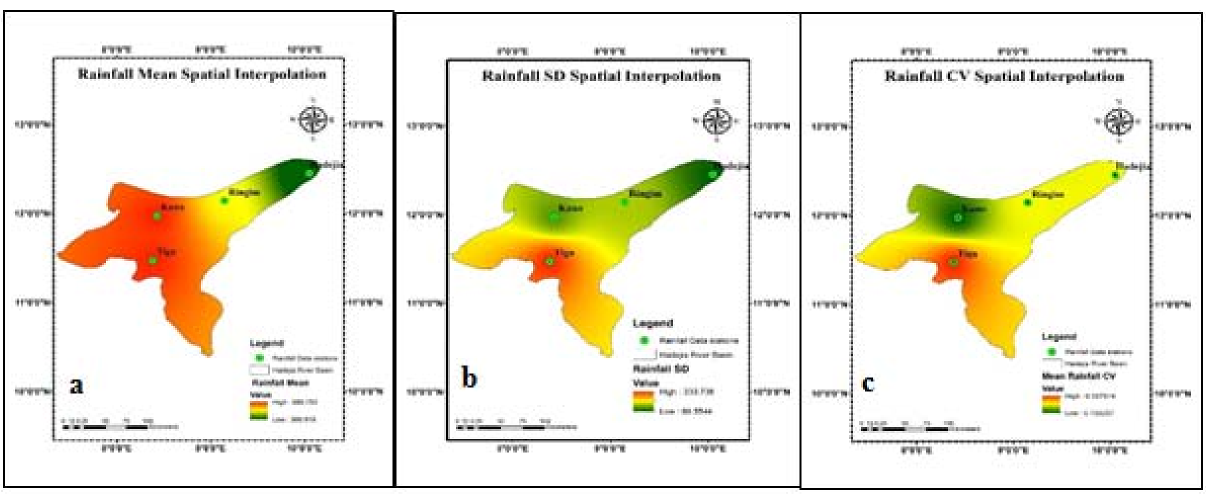

Figure 3: Spatial interpolation of rainfall (a)mean (b) SD and (c)CV

b) *One way Analysis of Variance (ANOVA)*

A one way analysis of variance (ANOVA) was conducted to compare the difference between six meteorological stations on annual mean rainfall. The result shows significant difference in annual mean rainfall based on meteorological stations computed [F (3, 140) = 67.012, $P < .05$] (Table 1).

Multiple comparisons test using Tukey HSD further revealed that, there was a significant difference between all the stations except between Tiga and Kano (Table 1).

Table 1: ANOVA Test of Meteorological stations on Mean Annual Rainfall

Variable	*n*	Mean ± SD	*df*	F	*P*
Rainfall			3	67.012	.000
Tiga	36	987.64 ± 338.48			
Kano	36	989.77 ± 135.70			
Ringim	36	743.36 ± 183.11	140		
Hadejia	36	383.74 ± 96.34			

The overall rainfall spatial behaviour via ANOVA and Tukey HSD statistics has unveiled the spatial changes in rainfall mean in the area. The highest rainfall mean was in Kano (989.77 mm) and the least was in Hadejia stations (383.74 mm), probably due to their locational disparity (Figure 1). Thus, there was significant difference between all the stations except between Kano and Tiga, meanwhile Kano station has the highest rainfall mean though the difference with Tiga station was very slight likely natural rainfall variability. It is thus indicated as previously established (Adakayi 2012) that rainfall is higher in the southern locations and low in the northern part of the basin (Figure 3a).

Table 2: Turkey HSD Test of Mean Annual Rainfall between stations

Significant Difference Between stations	Mean Difference (Md)	*P*-value.	Std. Erro
Tiga station			Std. Error = 49.41
Kano	-2.12222 (NSD)	1.000	
Ringim	244.27778*	.000	
Hadejia	603.90000*	.000	
Kano station			
Ringim	246.40000*	.000	
Hadejia	606.02222*	.000	
Ringimstation			
Hadejia	359.62222*	.000	
Hadejia station			
See above			

The mean difference is significant at the 0.05 level; NSD= no significant difference

The movement of these two air masses is regulated by the migration of the ITCZ or ITD north to south and vice versa (Oyekale et al 2010). Thus, the seasonal characteristics of the basin and the country at large was dictated and shared by the ITD's migration north to south and vice versa (Thelma 2015). This might be one of the reason for high rainfall mean in Kano and Tiga stations relative to Hadejia station. Moreover, the altitudinal/topographic differences is also another reason for this visible disparity. For instance, Tiga and Kano stations were located in the higher elevation topography relative to Hadejia. This, may occasionally influence the formation of orographic precipitation (Odjugo 2010).

c) *Spatial pattern of rainfall and temperature using cluster analysis (CA)*

Agglomerated hierarchical clustering (AHC) using XLSTART was used to find out the homogeneity between the studied stations based on their dissimilarities characteristics. In respect of rainfall characteristics, the stations were grouped into three classes; class 1(Tiga, and Kano stations), class 2 (Ringim) and class 3 Hadejia stations (Figure 8).

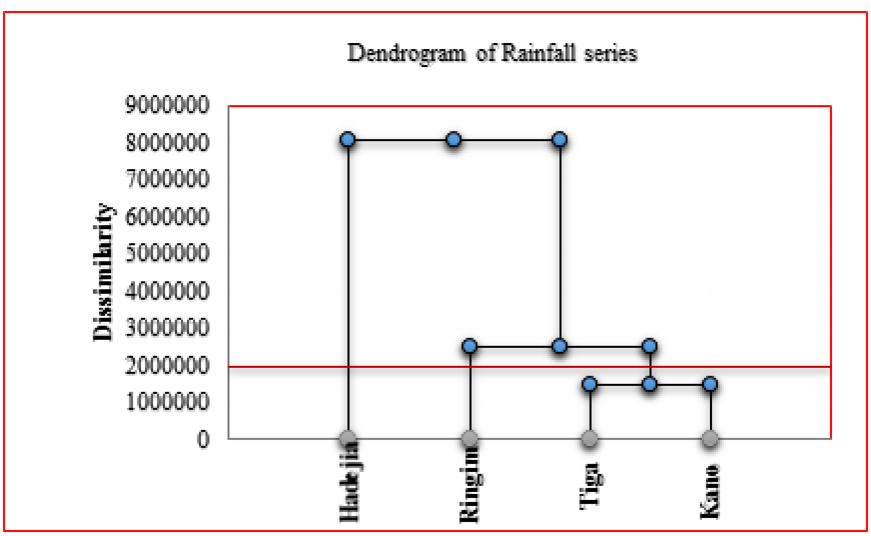

Figure 4: Rainfall clusters across the catchment

Hadejia was independent of all other stations, probably because of its location in the extreme north eastern part of the catchment. The pattern of rainfall clustering seems incline more to the temporal dynamics than to spatial fluctuations. Moreover, there is marked differences in topographical alignment between the locations, reflected by differences in elevation, vegetation and other physiographic factors which contributesto the spatial disparities in the occurrence and distribution of rainfall in the area (Medugu et al 2011; Adewole and Serifat 2015; Balogun et al., 2016).

d) Trend analysis

Man-Kendall trend test was conducted to detect temporal behaviour of rainfall and temperature in the area (Table 8). The monthly rainfall trend test result in all the stations shows an increasing trend except for some few months (e.g. in August at Tiga; in April, May and July at Kano; in April, May, August and October at Ringim station), there is no decreasing trend observe at Hadejia station. However, the only statistically significant increasing trends was in October atTiga; June and September at Ringim and lastly in October at Hadejia stations respectively (see table 8; Figure 11 a, b, c and d). The statistically significant increasing trend in June, September and October, especially the October increased at Hadejia station is an indication of increasing rainfall/climate variability in the area.

Table 3: Mann–Kendall test statistic for monthly precipitation by stations (1980-2015)

Month	Tiga			Kano			Ringim			Hadejia		
	Z	*Q*	*P*	*Z*	*Q*	*P*	*Z*	*Q*	*P*	*Z*	*Q*	*P*
April	0.19	0.000	0.846	-0.01	-0.020	0.989	-1.39	-0.077	0.163	0.0 0	0.000	0.970
May	0.90	0.644	0.369	-0.50	-0.225	0.617	-1.09	-0.413	0.276	1.3 6	0.221	0.173
Jun	0.10	0.220	0.925	1.59	0.903	0.112	2.33	2.279	**0.019**	1.2 5	0.757	0.210
Jul	1.74	3.917	0.081	-0.18	-0.131	0.861	1.59	2.243	0.112	0.1 5	1.058	0.882
Aug	-0.04	-0.130	0.968	0.56	0.800	0.579	-0.44	-1.298	0.663	0.3 0	1.782	0.764
Sept.	1.78	2.180	0.074	1.02	1.312	0.310	2.56	2.342	**0.010**	1.5 3	0.870	0.127
Oct.	2.51	0.660	**0.012**	-0.49	-0.208	0.623	-0.54	0.000	0.589	1.0 1	0.213	**0.044***
Annual	1.51	0.746	0.130	0.67	1.637	0.507	1.48	4.436	0.139	1.6 5	0.175	0.099

**The bold values are mean difference significant at 0.05 level*

Meanwhile, the overall annual trend was increasing from all stations, but were not statistically significant (Table 3). However, spatial interpolation showed that rainfall increasing trends was higher around Hadejia station (Figure 5 and 6a) even though it is the station with lower rainfall mean. Similar findings was previously established in the area (e.g. Mohammed et al., 2015; Suleiman and Ifabiyi 2016), where a noticeable increase in rainfall condition was reported.

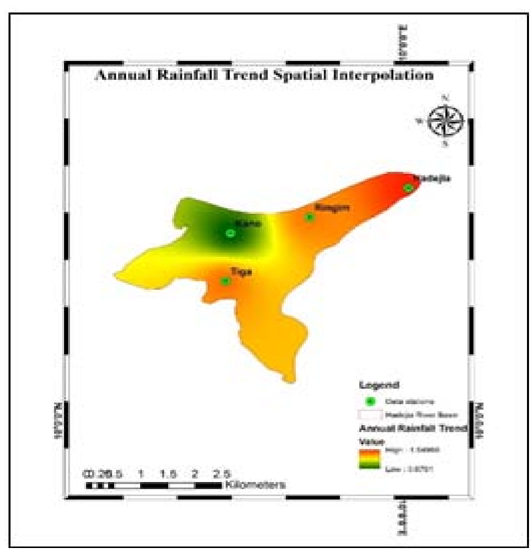

Figure 5: Interpolated annual rainfall trend

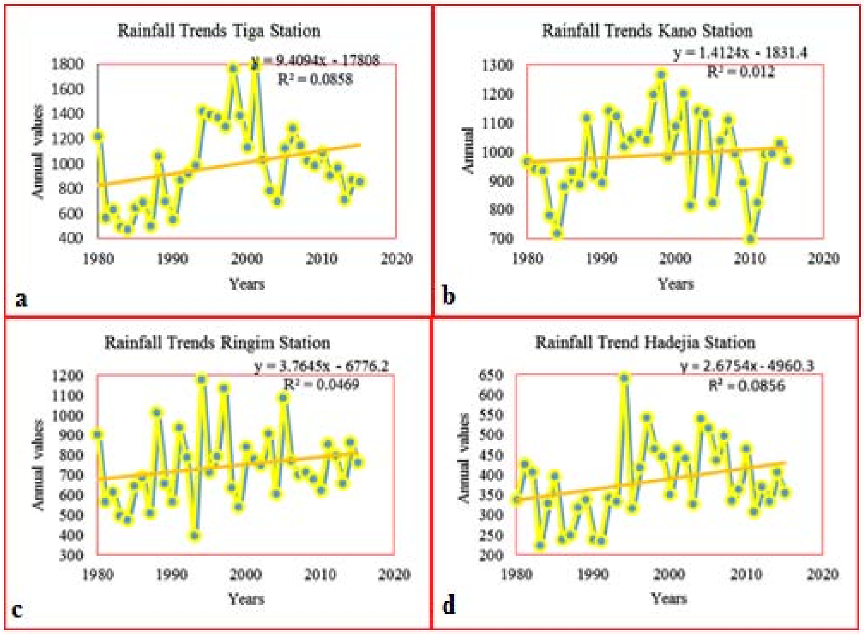

Figure 6: Trend for Individual Stations (a) Tiga (b) Kano (c) Ringim (d) Hadejia

e) Occurrence of extreme weather events

The occurrence of extreme weather events such as floods and droughts are considered important evidences of climate variability in the area. Of all the climatic parameters, rainfall is the most variable parameter in the region (Medugu 2011; Ekpoh and Nsa 2010). The pattern of rainfall behaviour and the increased inter-annual rainfall variability has long been associated to climate change and variability (Medugu et al 2011; Adakayi 2012; Muhammad et al 2015) as demonstrated by the current study. Although rainfall and do vary with time and space, however the temporal variabilityis more visible than the spatial changes. Thus, rainfall extreme (high and low) values were given precedence in the discussion of weather related extremes in this study. In terms of drought disasters, the downstream areas of the basin are the most affected, perhaps due to low rainfall and high temperature north-eastward. Whereas, the severity of flood disaster was more pronounced in upstream areas, this is not surprising because rainfall increases southwest ward and temperature decreases in the similar direction(Figure Table 12). Furthermore, all the representative stations in the area shows corresponding coincidence between some years of high and low rainfall records and some years of floods and drought occurrences (Table 12).Some of these recurrent climatic events have been reported to cause untold consequences to over 15 million inhabitants living and depending on Hadejia river catchment for their livelihoods (Sobawole et al 2010; Medugu et al 2011).

Table 4: Rainfall extremes and corresponding year of floods/droughts in the studied stations

Stations	Parameter	Extremes		Historical Records		Droughts Magnitude	Floods Magnitude	Source
		High Years	Low Years	Droughts Years	Floods Years			
Tiga Kano	*Rainfall*	1999 2009 2010	1983 1985 1987	1983/84 1986/87	1999/ 2010	Moderate Moderate	Moderate Severe	(Adefolalu 1985) *(Olagunju 2015)* (Olaniran, and Summer 1989)
Ringim	*Rainfall*	1998 2001 2003	1983 1984 1987	1983/84 1986/87	2001 2003	Severe Moderate	Severe Severe	*(Olagunju 2015)* (Olaniran, 1991)
Hadejia	*Rainfall*	1994 2005 2010	1983 1986 1991	1983/84 1986/87 1991/92	1994 2005 2010	Severe Severe Severe	Severe Severe Moderate	(Ekpoh and Nsa 2010) *(Medugu et al 2011)*

Source of the extreme values are from the data

IV. Discussion

The overall findings was that, rainfall varied significantly between stations and that the temporal variation is more discernible than spatial variation. The statistically significant annual increasing trend in rainfall at 50% of the stations, have suggested the presence of increasing climate variability, considering thatthe variations were reversible within few years to few decades shorter than the climatic averaging period. Thus, we cannot yet conclude the full existence of climate change, as the time span of the data is not enough to draw such a critical conclusion. Since climate change connotes variations longer than the standard climatic averaging period with significant impacts on man and the general ecosystem. (Ayeode 2003).

The spatial variability of rainfall and temperature was assessed using one way ANOVA, Tukey HSD test and cluster analysis. ANOVA results showed that there was a statistically significant difference between the meteorological stations on mean annual rainfall [F (3, 140) = 67.012, $P < .05$]. The multiple comparison test using Tukey HSD has confirmed the ANOVA results, that there was significant variation between the studied stations.

Both results (ANOVA and Turkey test) have sustained the earlier findings that, the southern part of the basin has higher rainfall and lower temperatures compared to the northern frontier of the basin (Adakayi 2012 and Mohammed et al 2015) and that, rainfall is less variable spatially (Thelma 2015). Cluster analysis have further distinguished the spatial characteristics between the stations. These stations were grouped based on their associated attributes.

The apparent spatial variations between the stations were attributed to many factors such as the influence of topographical alignment, the movement and how longITDZ stayedin given location.

The result of temporal evaluation via Mann-Kendall trend test have shown a general increasing annual trends for all stations. Although the annual result was statistically insignificant, it is still crucial for the understanding of climatic behaviour of the region particularly that the region is fragile and very sensitive to minor climatic changes. Moreover, the increasing and decreasing trends in monthly series have further confirmed the variability in climate of the region. In this area, the annual and monthly increased in precipitation significant or insignificant possessed the potential incur serious impacts on the activities (rain-fed and irrigation agriculture) and programmes (water supply) of the region as well as other socio-economic activities such as fishing and recreation. The findings obtained is consistent with the proceeding studies, which have confirmed the uncertainty and irregularities of rainfall behaviour and is associated to increased climate variability (Ekpoh and Nsa 2011; Ifabiyi and Ojoye 2013; Suleiman and Ifabiyi 2015).

Additionally, Adakayi (2012) used 36 years of meteorological data to assess the extent of climate change and variability in the region and part of his findings was that rainfall and temperature does not deviate from the climatic normal and that rainfall was the most variable parameter in the area. Similarly, Mohammed et al (2015) used 100 years of rainfall data to assess rainfall dynamics over the region, found that there was a noticeable improvement in rainfall/moisture condition in the area. Thus, their major conclusion was that the climate of the area have not significantly deviate from the normal trend. Therefore, the observed changes were just an increasing climate variability.

The spatial and temporal fluctuations and the presence of extreme observations in climatic parameters and the corresponding occurrences of extreme climatic events (floods and droughts) are some of the major evidences of increased rainfall irregularities linked to climate variability in the area (Sawa et al 2015) Moreover, besides increased rainfall irregularities and its potential impacts in the area, it is feared that the effects of other factors such as increased temperature, land use changes and increased human and livestock population expansion may perhaps aggravates the effects of rainfall irregularities. These other factors are liable to increase the sensitivity of the region and thus the vulnerability of inhabitants and their societal resources, particularly water resources and agriculture will be amplified.

V. Conclusion

Generally, rainfall annual trend displayed an insignificant increasing trends, suggesting gradual rainfall recovery in the area as reported by Adakayi (2012) and Muhammad et al (2015). However, the monthly trends showed varied results consisting of statistically significant increasing and decreasing trends portrayingintra-annual rainfall variability and has further accentuate the temporal behaviour of rainfall in the catchment.

It is concluded that, the semi-arid region of northern Nigeria within which Hadejia River Catchment is located faces challenges of increased rainfall irregularities associated to increased climate variability. Evidences were manifested from the statistically significant spatial variations in the rainfall series and in the increasing and decreasing trends depicted from the annual and monthly rainfall trend results. Even though theannual trends was not statistically significant, the results is still crucial for the understanding of rainfall behaviour in the area and for planning and management of activities and program related to water resources in the area such as agriculture and water supply. In the whole, the results displayed the magnitude of spatial and temporal inclination of rainfall, thus temporal variability is more discernible than the spatial changes, but that does not suggest overlooking the spatial variations, since spatial variations will accordingly affect the distribution of water related activities spatially across the river catchment. This suggest careful consideration in the apportionment of priorities to these variations in the area. For instance the spatial variability might constraints the water resource planning and management across the spatial extent of the catchment as more water will be where it is not even needed the most.

Furthermore, the study presented the ability and robustness of the used statistical and envirometric techniques; ANOVA, cluster analysis and the Mann-Kendall trend test. The findings will also assist the local climate and river basin management authorities with valuable information crucial for proper planning and management of climate related events (floods and droughts) and activities (agriculture and water supply). Finally, the study will hopefully assist the scientific research community in stimulating further research efforts on simulations and predictions of future climate behaviour.

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"Conflict of interest-None"

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