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Hydrological Response of Semi-Arid River Catchment to Rainfall and Temperature Fluctuations

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ABSTRACT

Determining the response of basin water resources to rainfall and temperature fluctuations is a crucial source of information for basins water resources planning and management. The study used a descriptive, Mann-Kendall trend test (M-K) and Multiple Linear Regression (MLR). The mean, standard deviations and variations were spatially interpolated using the geostatistical technique. The trend results showed an increase in both rainfall and temperature series. However, the only statistically significant trends were in June and September for rainfall series and in February, May, and April for the temperature series. Rainfall exhibited high temporal variability whereas temperature showed high spatial variability. The intra-annual variability was higher than the inter-annual variability, suggesting that the local climate is largely controlled by natural force. The result of the multiple linear regression (R^2 =0.431), indicates that the hydrology and water resources of the basin are impacted largely by factors not considered in this study such as land use changes, infiltration, and rate of evaporation among others. However, among the factor considered, rainfall (Beta = 0.505; P = 001) has the highest impacts on the river discharge behavior and should be given preference while addressing water resources predicaments in the catchment.

Keywords: Climate variability, geostatistical methods, multiple linear regression, river catchment, semi-arid region

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INTRODUCTION

Global advances in standard of living and increased economic development have resulted in an increasing demand and dependency on water resources. Many countries are projected to face water stress in the foreseeable future (Daniel et al., 2011). This forecasted water scarcity is associated with climate change and variability, increased human and animal population, urbanization and industrial development (Falkenmark, 2013). However, in semi-arid regions of the world, climate change and variability are identified as the most influential factor affecting water resources availability (Daniel et al., 2011). In these regions, our ability to clearly comprehend the current and future water resources availability depends largely on our understanding of the connections between climate variability in the form of rainfall and temperature fluctuations and the hydrological response of the basin ecosystem. This will help to appreciate surface water resources availability in response to climate variability.

Besides, rainfall and temperature changes, extreme weather events such as floods and droughts play an important role in the understanding of climatic changes. The historical beginning of the decrease in river discharge in Hadejia river catchment is dated back to 1970s and 1980s in response to the historical droughts that swept Sub-Saharan Africa (Umar et al., 2017). The consequence was the drastic effect incurred on the wet season flood/inundation used for flood recession agriculture in the area. The basin has experienced a decreasing trend in flood extent at the downstream areas from about 962 km^2 in 1991 to 525km^2 and 413 km^2 in 1992 and 1993 respectively (Adams & Thomas, 1996). Thus, from the foregoing, the need to assess the hydrological response of Hadejia river catchment to rainfall and temperature changes has arisen in a way to provide crucial information for effective planning and management of the basin's water resources.

MATERIALS AND METHODS

Study Area

Hadejia River Basin is a sub-catchment of the Hadejia-Jama'are river basin in the Northern Nigeria (Figure 1).

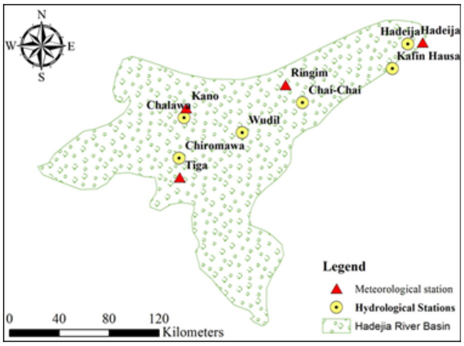


Figure 1. Hydrological and meteorological stations in the basin (Modified after IUCN 2003)

The Hadejia River was formed by the confluence of the Challawa and Kano Rivers at Tamburawa and it passed through two distinct geological formations, Basement Complex and Chad Formation. The elevation of the area reduces northward from over 600 m above sea level in the south to less than 300 m in the northern part of the basin (Adakayi, 2012).

Two wind systems control the climate of the area, the South West (SW) and North East (NE) trade winds. The SW trade winds come along with moisture from the Gulf of Gunue and stay in the North between May to September (summer), while the NE trade wind comes along with dry cold winds from the Sahara Desert and stays between Octobers to April (winter).

The mean annual rainfall varies from 1,100mm in the most southern locations of the basin (Tiga and Kano) to less than 300 mm in the extreme northeast (Hadejia). Temperatures reach as high as 35°C before the arrival of the rains (April/May) and drop as low as 18°C in December/January (Akinsanola & Ogunjobi, 2014).

Data

Rainfall, temperature and river discharge data for thirty-six years were obtained from Nigerian Meteorological Agency (NIMET), Hadejia Jama'are River Basin Development Authority (HJRBDA) and Jigawa State Ministry of Water Resources (JSMWR) respectively. These data were used for the analysis of hydroclimatic relationships and responses and only stations within the basin perimeters were used.

Prior to the application of suitable statistics, the data was subjected to QA/QC analysis (Duhan & Pandey, 2013), checked for irregularities such as missing data and outliers. The QA/QC scrutiny revealed that the data was statistically clean and normality distributed except for few missing data constituting less than 10% of the whole dataset and were replaced with the means of the last two recorded observations that binds the missing observations (Mwangi et al., 2016). For the normality test, the Shapiro-Wilk test was used to establish the normality status of data. The least square regression (LSR) test was, however, applied on only the rainfall and river discharge time series.

Data Analysis

Mann-Kendall (M-K) was used after the preliminary descriptive analysis. After assessing the temporal behavior of the data sets, multiple regression was conducted using rainfall, minimum and maximum temperature as independent variables (IV) and river discharge as the dependent variable (DV). The mean, SD and CV was interpolated using Inverse Distance Weighted (IDW), a geostatistical tool used for spatial analysis in the GIS environment

RESULTS AND DISCUSSIONS

Descriptive Statistics (DS) and Exploratory Data Analysis (EDA) of Rainfall Series

Prior to the statistical application normality test was conducted using Shapiro-Wilk normality test, the normality results for all the three sets of data (rainfall, temperature, and river discharge) was $p = 0.490$; $p = 0.319$; $p = 0.080$ respectively. Indicating that all the data set were normally distributed as represented in the Q-Q and Box plots in Figure 2a and 2f.

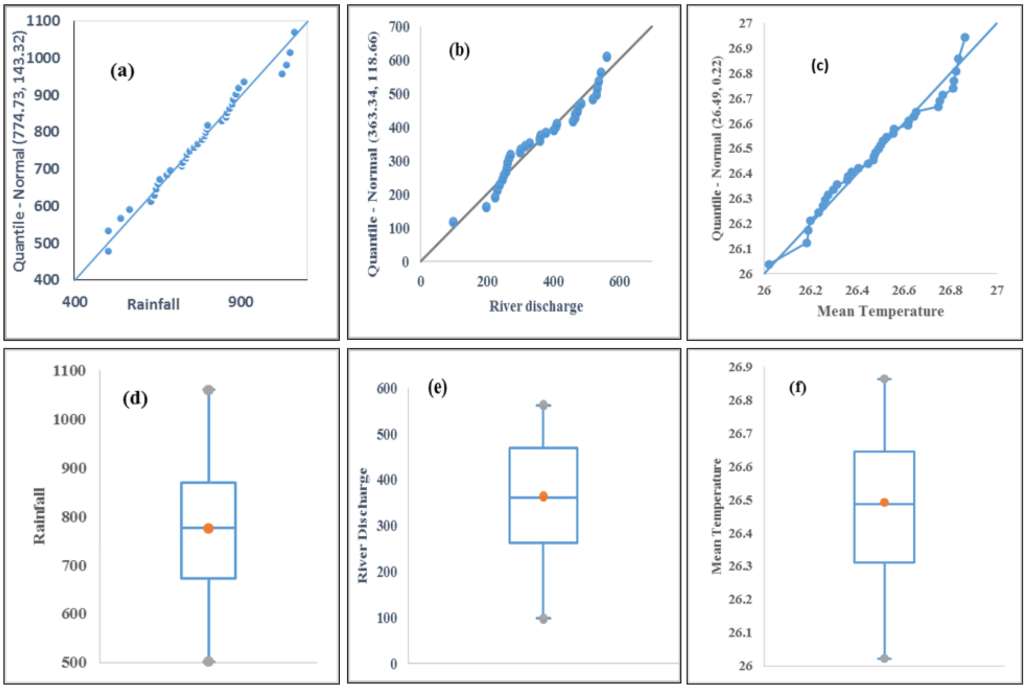


Figure 2. Normality distribution of annual mean rainfall (a) river discharge (b) temperature (c) and Q-Q plot of rainfall (d) river discharge (e) and temperature (f)

Additionally, the distribution of the rainfall, temperature and river discharge mean, SD and CV were spatially interpolated using IDW spatial interpolation tool (Figure 3(a) and 3(l)). Rainfall and river discharge shows a relatively similar pattern. The mean (Figure 3(a) and 3(d)) and standard deviation (Figure 3(e) and 3(h)) were found to be higher in the southern part of the basin and lower in the northern part. Meanwhile, the river discharge was slightly higher in the middle of the basin where the two rivers (Tiga and Challawa) converged to form the Hadejia river system at Wudil. However, the coefficient of variation exhibited a different pattern, where the higher CV was in the south-eastern part of the basin and the lowest CV was in the south-western part (Figure 3(i) and 3(l)).

In the case of temperature (Tmin and Tmax), the mean was higher in the northern part of the basin and decreased southward (Figure 3(b) and 3(c)). Meanwhile, SD and CV for Tmax were higher in the southern part of the basin (Figure 3(g) and 3(k)), while that of Tmin exhibited contrary pattern where SD and CV were higher in two different positions, extreme north and south of the basin (Figure 3(f) and 3(j)).

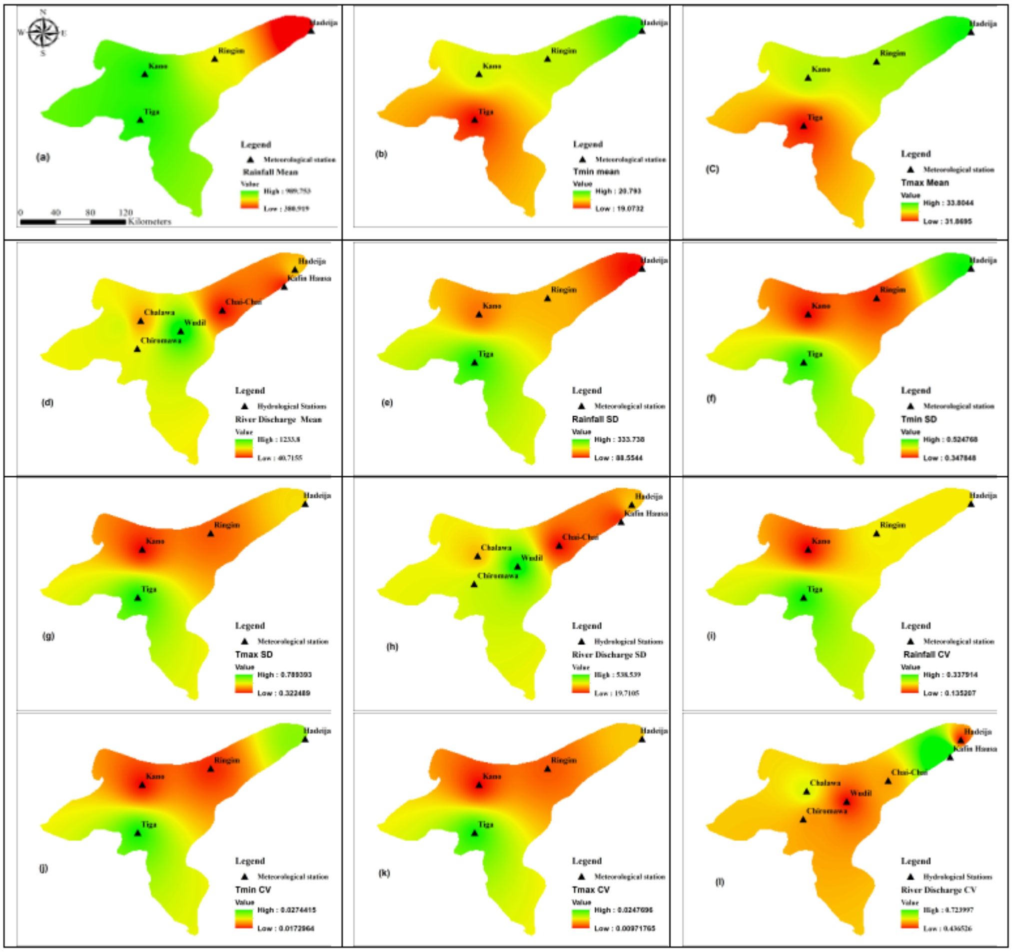


Figure 3. Spatial interpolation of mean (a) rainfall, (b) T_{min} (c) T_{max} and (d) river discharge; (e) rainfall SD (f) T_{min} SD (g) T_{max} and (h) river discharge; (i) rainfall CV (j) Tmin (k)T_{max} and (l) river discharge CV

The time series plots of rainfall, temperature, and river discharge showed that the mean annual rainfall and temperature were increasing over the entire basin (Table 1, 2, 3 and Figure 4). Meanwhile, mean annual river discharge was decreasing.

Table 1

Descriptive statistics and trend analysis (M-K) of rainfall for the entire basin

Stations	Minimum (mm/yr)	Maximum (mm/yr)	Mean (mm/yr)	SD (mm/yr)	CV (%)	Z (mm/yr)	Q (mm/yr)
Tiga	477.6	1789.2	987.6	333.7	33.0	1.51	0.746
Kano	700.8	1266.0	989.8	133.8	13.0	0.67	1.637
Ringim	398.4	1137.6	740.6	174.4	23.0	1.48	4.436
Hadejia	225.6	544.8	380.9	88.6	23.0	1.65	0.175
Basin	450.6	1184.4	774.7	182.6	20.0	1.32	1.74

Table 2

Descriptive statistics of monthly, seasonal and annual temperature

Series		T_{mean}			T_{max}			T_{min}	
	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)
Jan	21.9	0.9	3.9	29.7	1.1	3.6	14.2	0.9	6.4
Feb	24.7	1.1	1.1	32.6	1.3	3.9	16.8	1.3	7.5
Mar	28.6	0.9	3.2	36.2	1.1	3.9	21.0	1.0	4.8
Apr	29.5	0.3	1.1	38.2	0.6	1.6	20.9	0.3	1.3
May	30.7	0.7	2.1	37.2	1.0	2.5	24.1	0.6	2.3
Jun	28.8	0.5	1.6	34.5	0.6	1.6	23.2	0.5	2.2
Jul	27.4	0.5	1.7	32.6	0.8	2.4	22.1	0.5	2.4
Aug	26.5	0.5	1.9	31.4	0.9	2.7	21.6	0.5	2.1
Sept	26.9	0.4	1.6	32.1	0.6	1.9	21.8	0.5	2.3
Oct	26.5	0.6	2.1	32.2	0.7	2.2	20.8	0.7	3.1
Nov	24.3	0.5	1.9	31.5	0.7	2.1	17.2	0.5	2.9
Dec	22.0	0.5	2.3	29.6	0.7	2.2	14.5	0.6	4.2
DJF	22.9	0.5	2.2	30.6	0.6	2.1	15.2	0.6	3.8
MAM	29.6	0.4	1.3	37.2	0.6	1.6	22.0	0.4	1.6
JJA	27.6	0.4	1.3	32.8	0.5	1.8	22.4	0.2	1.0
SON	25.9	0.4	1.4	31.9	0.4	1.4	19.8	0.4	1.9
Annual	26.5	0.2	0.8	33.1	0.3	0.9	19.8	0.2	1.0

Note: SD and CV are deviation and standard coefficient of variability, respectively

Table 3

Descriptive statistics and trend analysis (M-K) of river discharge for the entire basin

Stations	**Minimum (mm/yr)**	**Maximum (mm/yr)**	**Mean (mm/yr)**	**SD (mm/yr)**	**CV (%)**	**Z (mm/yr)**	**Q (mm/yr)**
Chiromawa	205.0	788.4	473.1	187.9	40.0	0.50	1.558
Challawa	200.6	324.4	248.4	34.8	14.0	0.86	0.450
Wudil	348.8	1790.0	1085.6	440.8	41.0	0.11	0.236
Hadejia	172.5	877.0	412.4	195.9	47.0	-2.33	-7.087
Basin	218.2	682.4	483.6	188.8	25.0	-1.02	-1.356

Note: Confidence level at 95%

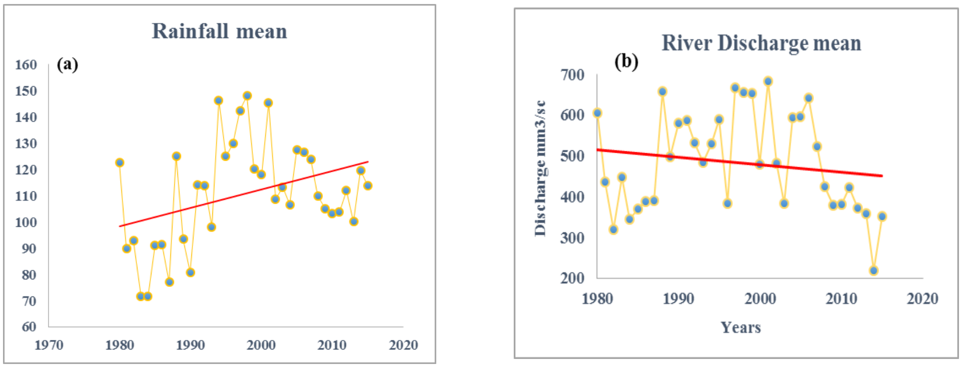


Figure 4. Time series plot of mean (a) rainfall (b) river discharge

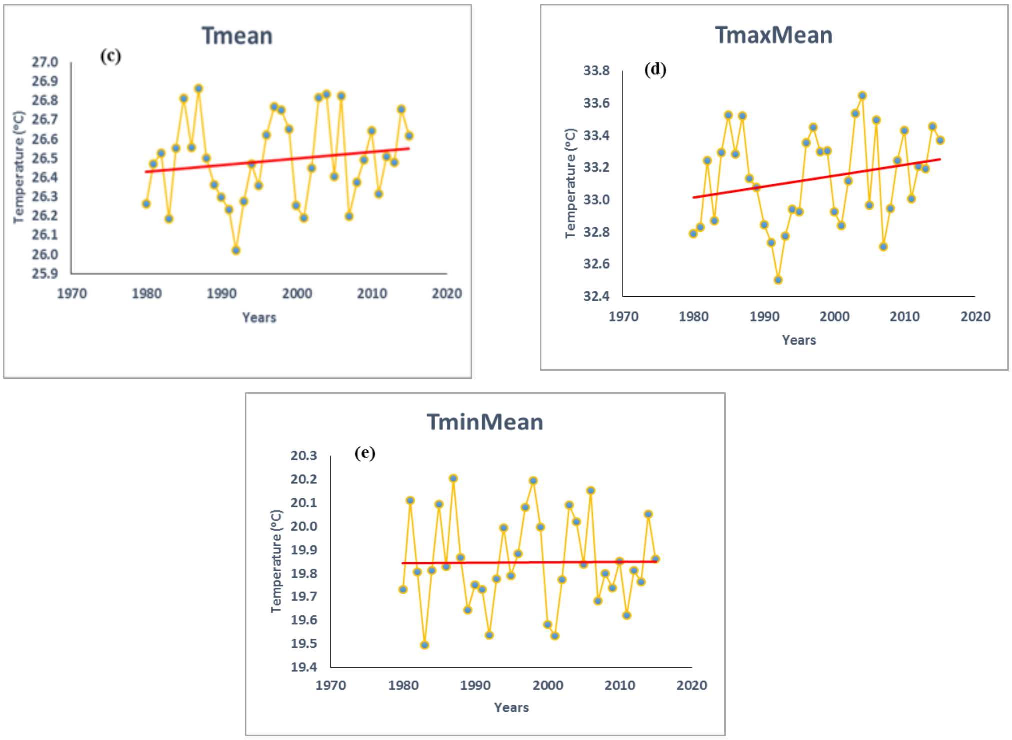


Figure 4. Time series plot of mean (c) temperature mean (d) maximum and (e) minimum temperature

The monthly rainfall, temperature, and river discharge trend analysis shows varied results of increasing and decreasing trends. For instance, noticeable increase in rainfall trend was detected except for the months of April and August, however, the statistically significant increasing trends were in June and September (Table 4).

Table 4

Descriptive statistics of monthly (mm/month) and annual rainfall series (mm/year)

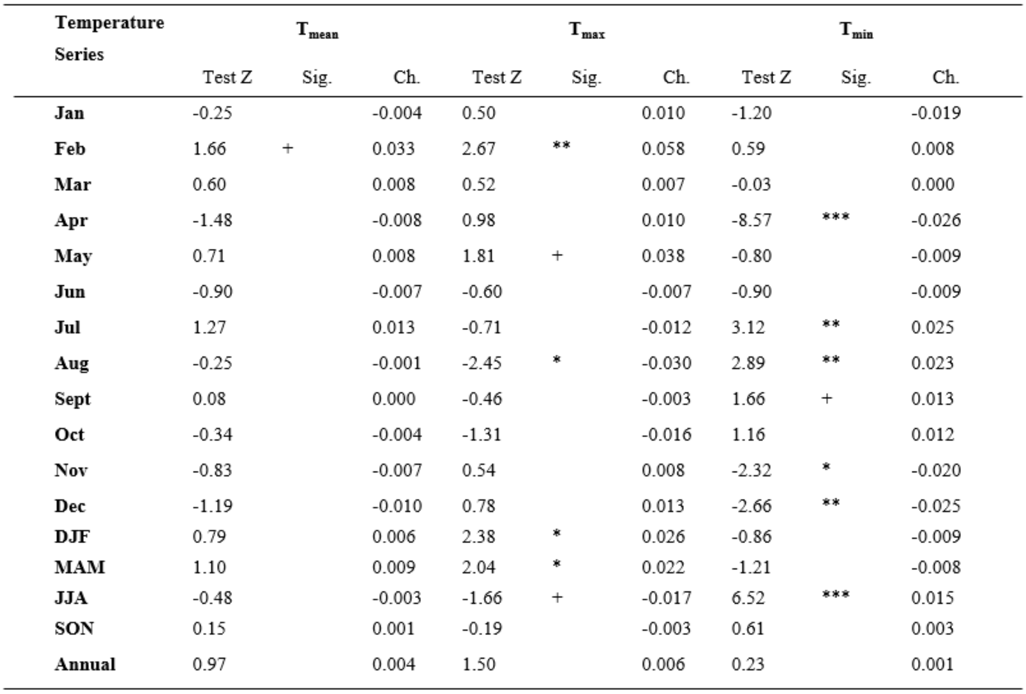
Series	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
April	0.0	38.9	17.3	11.1	63.4	-0.12	-0.042
May	21.0	109.7	57.4	24.0	41.2	0.75	0.234
June	57.0	158.9	114.4	27.4	23.6	**1.98**	0.933
July	102.5	333.1	207.4	49.3	23.5	1.73	1.367
Aug.	74.7	372.9	237.1	65.6	27.3	-0.20	-0.308
Sept.	38.5	243.7	124.7	43.6	34.5	**2.66**	1.563
Oct.	0.0	39.8	16.1	10.4	63.4	1.57	0.208
Annual	71.6	148.0	110.6	20.1	17.9	1.62	0.618

Note: Bold font is significant at 95%

However, the monthly temperature trends shows that T_{mean} was outweighed by negative trends and among the positively increasing months only February was statistically significant. Similarly, T_{min} displayed more negative trends, but only statistically significant in April, November, and December. However, the statistically significant positive trends in the T_{min} series were in July and August. Meanwhile, the T_{max} series was dominated by positive trends, but only February and May were statistically significant. The only statistically significant negative trends in T_{max} series was in August (Table 5).

Table 5

Trend statistics of monthly, seasonal and annual temperature series



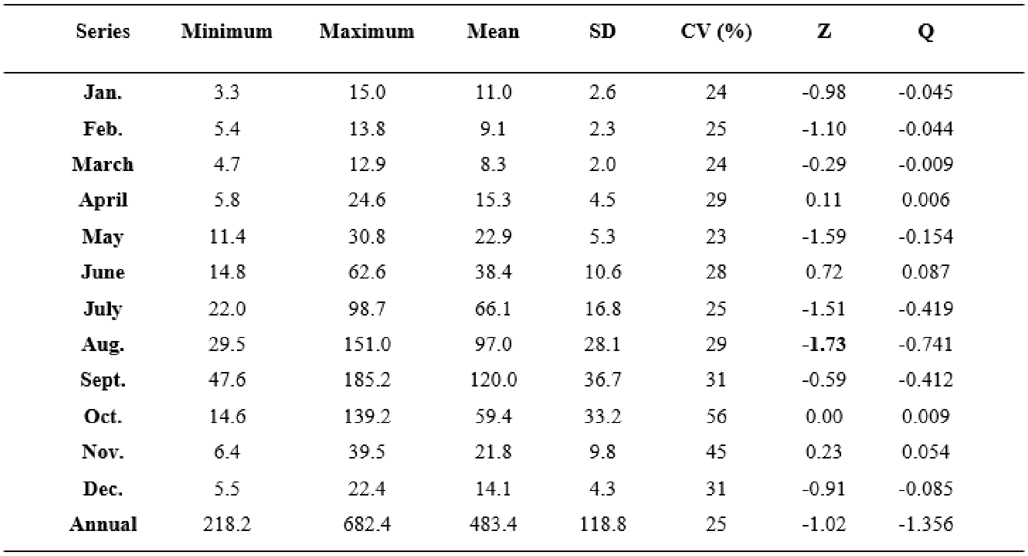
Temperature Series	T_{mean}			T_{max}			T_{min}		
	Test Z	Sig.	Ch.	Test Z	Sig.	Ch.	Test Z	Sig.	Ch.
Jan	-0.25		-0.004	0.50		0.010	-1.20		-0.019
Feb	1.66	+	0.033	2.67	**	0.058	0.59		0.008
Mar	0.60		0.008	0.52		0.007	-0.03		0.000
Apr	-1.48		-0.008	0.98		0.010	-8.57	***	-0.026
May	0.71		0.008	1.81	+	0.038	-0.80		-0.009
Jun	-0.90		-0.007	-0.60		-0.007	-0.90		-0.009
Jul	1.27		0.013	-0.71		-0.012	3.12	**	0.025
Aug	-0.25		-0.001	-2.45	*	-0.030	2.89	**	0.023
Sept	0.08		0.000	-0.46		-0.003	1.66	+	0.013
Oct	-0.34		-0.004	-1.31		-0.016	1.16		0.012
Nov	-0.83		-0.007	0.54		0.008	-2.32	*	-0.020
Dec	-1.19		-0.010	0.78		0.013	-2.66	**	-0.025
DJF	0.79		0.006	2.38	*	0.026	-0.86		-0.009
MAM	1.10		0.009	2.04	*	0.022	-1.21		-0.008
JJA	-0.48		-0.003	-1.66	+	-0.017	6.52	***	0.015
SON	0.15		0.001	-0.19		-0.003	0.61		0.003
Annual	0.97		0.004	1.50		0.006	0.23		0.001

Notes: *** significant at $\alpha = 0.001$, ** significant at $\alpha = 0.01$, * significant at $\alpha = 0.05$, + significant at $\alpha = 0.1$ and - not significant. Ch. and Sig. refer to change and sign, respectively

On the other hand, the monthly river discharge trend results showed a general decreasing trend except for the months of June, November, and October. The statistically significant decreasing trend was in August (Table 6).

However, the spatial variations of river discharge trends across the basin showed varied results, where the upstream (Chiromawa & Challawa) and midstream (Wudil) stations displayed an insignificant increasing trend, while the downstream station (Hadejia) exhibited statistically significant decreasing trend (Table 3).

Table 6
Descriptive statistics of monthly (mm/month) and annual river discharge series (mm/year)



Series	Minimum	Maximum	Mean	SD	CV (%)	Z	Q
Jan.	3.3	15.0	11.0	2.6	24	-0.98	-0.045
Feb.	5.4	13.8	9.1	2.3	25	-1.10	-0.044
March	4.7	12.9	8.3	2.0	24	-0.29	-0.009
April	5.8	24.6	15.3	4.5	29	0.11	0.006
May	11.4	30.8	22.9	5.3	23	-1.59	-0.154
June	14.8	62.6	38.4	10.6	28	0.72	0.087
July	22.0	98.7	66.1	16.8	25	-1.51	-0.419
Aug.	29.5	151.0	97.0	28.1	29	**-1.73**	-0.741
Sept.	47.6	185.2	120.0	36.7	31	-0.59	-0.412
Oct.	14.6	139.2	59.4	33.2	56	0.00	0.009
Nov.	6.4	39.5	21.8	9.8	45	0.23	0.054
Dec.	5.5	22.4	14.1	4.3	31	-0.91	-0.085
Annual	218.2	682.4	483.4	118.8	25	-1.02	-1.356

Note: Bold font is significant at 95%

The summary of the descriptive statistic shows that annual minimum and maximum rainfalls were 450.6 and 1154.4 mm/yr, respectively. Mean rainfall was highest in August (237.1 mm/yr) and lowest in October (16.1 mm/yr) while the annual mean was 774.7 mm/yr. SD was highest in August (65.6 mm/yr) and lowest in October (10.4 mm/yr), with the annual SD obtained, was 20.1 mm/yr; CV was highest in April and October (63.4% each) and lowest in July (23.5%) whereas the annual CV was 17.9% (Table 4). The results show that rainfall variability was higher on intra-annual basis than inter-annual in the basin.

However, temperature descriptive summaries indicate that the spatial mean fluctuates from 21.9 to 30.7°C, SD from 0.3 to 1.1°C, maximum from 29.6°C to 38.2°C and minimum from 14.2 to 24.1°C (Table 5). The resultant warming due to temperature increase over the whole basin was relatively uniform, with CV ranging from 1.0% to 0.8%, but was 0.9% on the average. Higher values of temperature were obtained in the months of March and April (Table 5). However, the seasonal analysis showed that MAM (spring) had been the hottest of all seasons, while SON was the coldest, and monthly scales variability was higher compared to both seasonal and annual scale variability. The temporal plots of the cumulative departure of Tmean, Tmax, and Tmin (Figure 5) also showed similarity in their pattern of cooling and warming. For instance, between 1985 and 2005 there was a random warming in 1995. However, both Tmean and Tmin changed from warming to cooling in 2005, and continued till 2015 though there was an indication of reversal to the warming trend from that year.

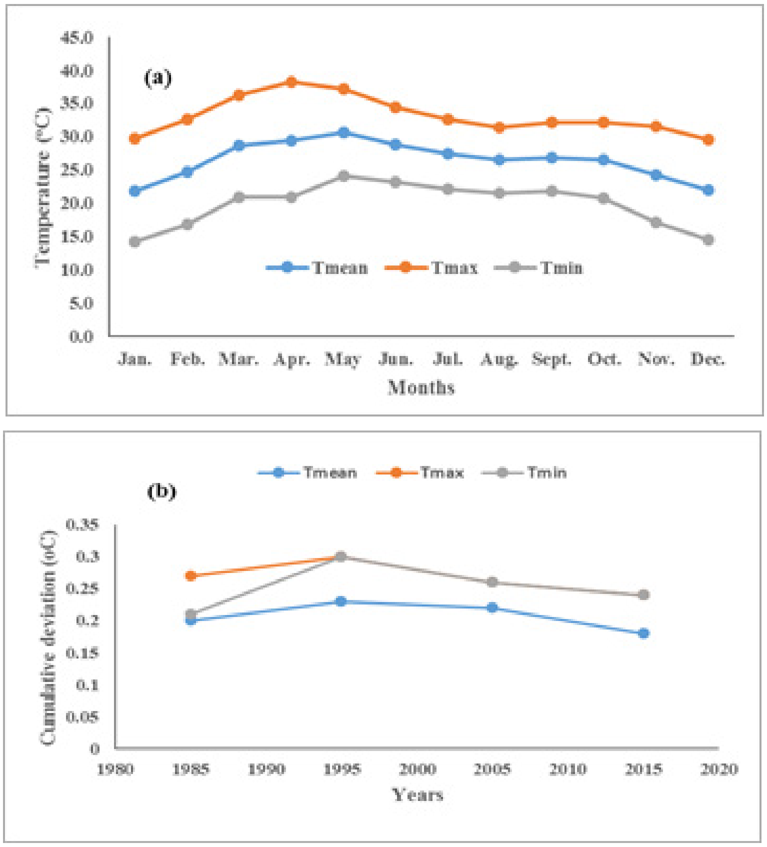


Figure 5. Plots of (a) monthly temperature series and (b) cumulative deviations

While the descriptive summaries of river discharge showed that annual minimum and maximum discharges were 218.2 and 682.4 mm^3/yr, respectively. Mean discharge was highest in September (120.0 mm^3/yr) and lowest in March (8.3 mm/yr) while the annual mean was 483.4 mm3/yr. SD was highest in September (36.7 mm^3/yr) and lowest in March (2.0 mm^3/yr), with the annual SD obtained as 118.8 mm3/yr, however, CV was highest in October (56%) and lowest in May (23%) and the annual CV was 25% (Table 4). The result shows that river discharge variability was higher on inter-annual than intra-annual basis within the basin.

Mann-Kendall (M-K)

The trend analysis test was conducted using the M-K test. The results for all the studied variables and the data points in the entire basin was communicated concurrently with the descriptive statistic results in Table 4, 5 and 6 for rainfall, temperature, and river discharge respectively. Rainfall annual trend showed a statistically insignificant increasing trend

(Table 4). The trend slope ranged from -0.042 to 0.933 mm/yr and for the entire basin it was 0.618 mm/yr. For the monthly analysis, it was also dominantly increasing trends except for April and August which showed insignificant decreasing trends. In all the positive trends only two monthly series (June and September) indicates a statistically significant trend with the slope of 0.933 mm/yr and 1563 mm/yr respectively (Table 4.0). Similarly, there were two other months (April and August) with insignificant decreasing trends, while the rest exhibited insignificant positive trends of varying degrees. The magnitude of change in the series ranged between -0.12 mm/yr (April) and 2.66 mm/yr (September). Although trends were dominantly positive in all the monthly and annual analysis except but in a few months, however, it seemed there was redistribution in the rainfall pattern, particularly in the monthly series.

Temperature trends result was summarized in Table 5. The result showed an annual increasing trend in both maximum and minimum temperature. The trend slope ranged from -0.042 to 0.933 mm/yr and for the entire basin it was 0.618 mm/yr. For the monthly analysis, it was also dominantly increasing trends except for April and August which showed insignificant decreasing trends.

Correlation and Regression analysis

Preliminary analysis via multiple correlation technique had shown that rainfall played positive roles in river discharge as could be inferred from their positive correlation coefficients (Rf; r = 0.539, n = 216, P = .001), while temperature (T_{min}; r = -0.034, n = 216, P = 0.353 and T_{max}; r = -0.315*, n= 216, P = 0.084) (Table 7) played negative role of reducing the river discharge.

Table 7

Correlations between RD (as DV) and Rf, T_{max} and T_{min} (as IDV)

Variables	RD	P-value
Rf	0.539^{**}	0.001
Tmax	-0.315^{*}	0.084
Tmin	-0.034	0.353

*Notes: ** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed); RD=River discharge, T_{min} and T_{max} are the minimum and maximum temperature respectively.*

Accordingly, rainfall, maximum and minimum temperature was chosen for modeling the relationships between climate and river discharge. The relationship between the dependent variable (in this case river discharge) and the independent variables (rainfall and temperature) was examined through the following equation:

$$RD = a + b_1x_1 + b_2x_2 \ldots + b_nx_n + e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

RRD= river discharge;
a = the intercept on the y- axis;
b_1 - b_n = partial regression coefficient of independent variables
x_1-x_n = the independent variable
e = random error of unexplained variables

The model was designed following Ekpoh and Ekpenyong (2011) in their study of the effects of climate variations on Water Yield in the Sokoto Region of Northern Nigeria. The climatic parameters chosen are expected to give details of their impact on river discharge in terms of their regression coefficients, while the P-values serve as the check on the 'goodness-of-fit' or otherwise of the relationships

The multiple regression model with all three predictors produced $R^2 = 0.431$ (Table 8). Rainfall had a statistically significant positive impact on the outcome of the dependent variable (river discharge). Thus, it was found to have significant positive regression weights (Table 8). However, where the maximum temperature contributed negatively to the multiple regression model, the minimum temperature contributed positively to the regression response variable, though statistically insignificant. Generally, the regression output has unveiled the significant role played by rainfall in the determination of river discharge characteristics in the catchments.

Table 8

Result of multiple regression analysis between Rainfall, Maximum and Minimum temperature and river

	a	Rainfall	Tmax	Tmin	R2	Adjusted R2
R Coefficient	0.656	0.505	-0.350	0.182	0.431	0.357
P-value	0.131	0.001	0.084	0.353		

Notes: Predictors: Rainfall, minimum and maximum temperature; Response variable: River discharge

Rainfall Analysis

Prior to the assessment of the individual impact of rainfall and temperature on the river discharge, trend analysis was conducted on both data series covering the period 1980 to 2015 over the HRB. The results showed that rainfall and temperature had increased over the entire basin, while river discharge was decreasing particularly downstream of the basin. Temporal variability was more noticeable than the spatial variability, and it was assumed the low spatial variability displayed might be due to the smaller spatial scope of the current study relative to some previous studies (e.g. Adakayi, 2012; Ifabiyi & Ojoye, 2013). On the other hand, annual rainfall variability does not differ much from the reported studies (Adewole & Serifat, 2015; Mohammed et al., 2015).

Meanwhile, the monthly analysis showed that rainfall was increasing in all the rain-bearing months except in April and August (Table 4), and only June and September were statistically significant. Furthermore, October was the driest month while August the wettest. Thus, peak discharge and flood events witnessed in the study area occured in the months of September largely due to August rainfall contribution and this scenario could continue for sometimes in the future. This result is in line with (Oyewole et al., 2014) who associated the devastating flood events in Nigeria with the increased in August and September rainfall.

Similarly, a noticeable increasing trend in rainfall was reported in the region by Adakayi (2012). He applied the M-K trend test to hydro-meteorological variables using 36 years of data in northern Nigeria where the HRB was located. In the same vein, Mertz et al. (2012) reported rainfall recovery in the Sub-Saharan West African beginning from the 1990s. Elsewhere in China, Qin et al. (2010) studied the impacts of climate changes on water resources at Tarim river basin, their results indicated an increasing trend in precipitation as shown by the current study. Similarly, Modarres and Silva (2007) reported an insignificant trend in annual rainfall in the semi-arid region of Iran.

Temperature trends results also showed a rising trend, and the rate of warming is relatively higher in T_{max} than in Tmin but the pattern was basically comparable. However, it appeared that the monthly temperature was highly variable as the CV was as high as 7.5% for T_{min}; while in the Tmax series it reached 3.9°C, SD went up to 1.3°C. This suggests that the monthly temperature behavior in the basin is more temporally inclined, with the highest rate in April and May but the trend is stronger in February and weaker in January and August, this is one of the characteristics of tropical semi-arid climate (Nobre et al., 2016). Consistent with the current findings, Adakayi (2012) reported a higher temperature in April and May. The April-May higher temperature recorded may perhaps be a warming up towards the summer (JJA) storms.

Furthermore, the magnitude of increased warming was found to be higher in Tmax than in both Tmean and Tmin indicating greater warming during the daytime relative to night-time. On the contrary, Oguntunde et al. (2012) discovered a night-time (Tmin) warming stronger than the day-time. A similar stronger significant trend in minimum temperature was reported over Italy (Brunetti et al., 2006), India (Kothawale et al., 2010) and Brazil (Nobre et al., 2016). The daytime increased warming experienced in the area, could be linked to the overriding influences of natural inherent climate variability.

However, the warming trends observed in the seasonal scales was only significant in winter and spring, for T_{mean} and T_{max} and in summer for the T_{min}, whereas there was a significant decreasing trend in summer for the T_{max} series. Moreover, the highest increased warming magnitudes were observed during JJA (summer) in the T_{min} series. Similar findings were reported in other parts of the world (e.g. Kothawale et al., 2010; Nobre et al., 2016). However, Gocic and Trajkovic (2013) reported contrary results where high-temperature trends were observed in autumn and spring seasons in Serbia. Though part of his findings can be sustained herewith since the current study has also observed significant warming trends in the spring season for the T_{mean} and T_{max} series. In the whole, the result could be ascribed to the temperature gradient that is typically created due to season's adjustment from warming to cooling, and that is yet not understood and further investigation is needed to unveil the possible reason(s) in future studies.

However, annual trends in all the temperature series were positively insignificant and magnitudes of change ranged between 0.001°C and 0.006°C concluding that the warming in the basin was not significant within the time span of the study. However, the result is consistent with some previous studies (Adakayi, 2012; Ayinde et al., 2013; Dammo et al., 2015).

Contrary to what was obtainable in both rainfall and temperature results, river discharge shows a decreasing annual trend attributed to many factors such as the climatic variations (rainfall and temperature fluctuations), the nature and the spatial disparity of the geology settings, high temperature and rate of evaporation downstream relative to other part of the basin. Moreover, there exist two non-returning channel (Chai Chai and Kafin Hausa bifurcation streams) before the outlet of the Hadejia river basin which occasionally reduces the volume of water reaching the downstream station.

Additionally, there is the disappearance of sharp channel streams at a certain location along the basin profile due to high erosion and siltation. Moreover, the basin management in itself was blamed for the reduced flow downstream of the basin, though some previous studies had disputed these allegations, stressing that, rainfall variability was the main factor determining the general flow of the river (Adewole & Serifat, 2015). Thus, of all the identified factors associated to decrease streamflow downstream, climate variability was conceived as the most frightening one.

The results of the regression analysis showed that the three predictors variables; rainfall, maximum and minimum temperature are not the only factors affecting the variations of the river discharge in Hadejia river basin, the evidence is the coefficient of determination obtained $R_2 = 0.432$, and the adjusted $R_2 = 0.357$ (Table 8). However, a close scrutiny of the Table reveals that rainfall made the highest contribution to the regression equation with a Beta coefficient of 0.505, which is highly significant at the 0.001 level. This is not surprising as some previous studies indicated rainfall as the most important parameters affecting river discharge variations, particularly in the semi-arid region of the country (Umar et al., 2017). On the other hand, both maximum and minimum temperature shows an inverse relationship with river discharge, however, with the insignificant negative Beta coefficient of -0.350 for Tmax and a positive insignificant Beta coefficient of 0.182 for the Tmin. The inference that could be made from the "cat and mouse" behavior of rainfall and temperature in relation to river discharge variations is that while rainfall increases river discharge also increases, but river discharge decreases with increasing temperature as the river water is subtracted via evaporation.

CONCLUSIONS

The findings showed that there was a strong positive relationship between rainfall and river discharge, suggesting that the river discharge was at the mercy of rainfall behavior. However, besides the predictor variables used in this study, there are other explanations associated with river discharge fluctuations in the basin such as the losses to ground water, evaporation and the water loses to the non-returning river channels (Chai-Chai and Kafin Hausa channels). Additionally, the two major dams constructed; Tiga and Challawa Gorge in 1974 and 1992 also affected the natural pattern of the Hadejia river flow turning the flow regime to perennial from the usual seasonal flows. In consideration of the decreasing trend of the river discharge at the downstream areas of the basin possible strategies are suggested such as the use of point-drop, pitcher or water-can irrigations in place of the sprinkler irrigation, the use of the soil surfaces mulching to reduce the water losses via evapotranspiration. However, water loses from the river surfaces can be reduced via aquifer recharge and recovery (ARR). Finally, massive afforestation exercise should be embarked upon in the HRB and indeed in the entire semi-arid region of Nigeria.

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