Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

Homogeneity Analysis of Precipitation Series in Northern Nigeria

Chukwu, S. Emeka*
Otache, Y. Martins *
Onemayin, D. Jimoh**
John, J. Musa*
Ikugbiyi, S. Olushola*
**Department of Agricultural & Bioresources Engineering,*
***Department of Civil Engineering, Federal University of Technology, Minna, Nigeria.*
Email: sechukwu6@gmail.com,

ABSTRACT

This study offers a viable insight into the prevailing homogenous characteristics of rainfall phenomena in northern Nigeria. The derived results and concomitant implication are important for policy making, especially for water resources management, planning and agriculture productivity. Three applied approaches explored were Bayesian, Cumulative Deviations and Normality tests for homogeneity analysis. Based on the results of the Bayesian and Normality tests, the annual precipitation time series are homogeneous at each HA, thereby lending credence to hydrological based classification by Federal Ministry of Water Resources (FMWR). In addition, recognising the fact that each HA is homogenous within it confines, it is important to infer that in the present of dearth of century data a composite station in a given HA may give a realistic estimate of rainfall characteristics; for instance, in line with Bayesian computation algorithms, in HA3 Gombe shows a very insignificant inhomogeneity of 2.08%, HA2 Abuja, Kaduna, Zaira, Lokoja, Ilorin, Bida and Minna had inhomogeneity of 4.2% only in 2018 and 2019, HA1 Tatamarfara and Jibyia (2019, 2017, 2012, 2013, 2005, 2006, 2001 and 1995) which stood at 16.66% inhomogeneity, HA4, Jos, Lafia and Makurdi recorded 27% inhomogeneity while HA8 only Kano shows deviation in 1991, 2015, 2019 and 1999 which accounted for 10.42% inhomogeneity, at such the alternative hypothesis of the present of homogeneity of HAs data are not rejected at a significance level of 0.05. In all studied instances, inhomogeneity reported were lesser than 50%, therefore may not significantly condition the significant of any quantitative findings or submission. Though, with the application of the cumulative test, inhomogeneity was detected in the annual series at seven stations as opposed to normality test where the test statistics employed confirms all the stations homogenous within the confines of respective HAs. It is recommended that admixture of approaches that strongly embrace element of soft computing techniques like artificial neuron network, Fuzzy and Genetic algorithms should be harness, as well as exploring lengthier dataset.

Keywords: *Rainfall, Northern, Nigeria, inhomogeneity, Significant and Hydrological area*

1.0 INTRODUCTION

Climate has changed significantly in the last hundred years. One of the challenges posed by climate change or climate variability is ascertainment, identification and quantification of pattern of rainfall and their implications in food security. Hence, the formulation, adaptation measures via appropriate strategies for water resources management is *a sin qua non* in climate variability. Suffices to note, that long-term systematic climatic observations are of great importance in order to understand the natural variability of climate, determine human impacts on the climate system, parameterise the main processes required in models, and verify model simulations. One of the ways to examine natural variability and changes in the climate system as well as all the ecological responses to them is time series analysis of paleoclimatic historical data (Türkes *et al*. 2002).

Precipitation is considered important because changes in precipitation patterns may lead to floods or droughts in different areas, which has a direct impact on agricultural productivity, hydroelectric power generation, and sustainable economy (Ologunorisa 2004; Odekunle 2001; Folland *et al*. 1986; Omotosho and Abiodun 2007). Therefore, information about time and spatial variability of precipitation time series has become indispensable from both the scientific and practical points of view. Hence, precipitation trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community. In addition, homogeneity analysis in precipitation time series is one of the interesting research areas in climatology though seldom researched thus, perceived by many scholars as grey area. As noted by Yue *et al*. (2003) that the changes in precipitation are not globally uniformly distributed therefore, regional variations can be much larger, and considerable spatial and temporal variations may exist between precipitation of different regions or within the same region as a function of composite stations (Yue *et al*., 2003).

Consequently, homogeneity tests of time series could be classified in two groups: absolute tests and relative tests. In absolute tests, the statistical tests are applied to each station data separately. While in the relative tests, the testing procedures use records from neighboring stations (named reference stations) which presumably are homogeneous (Peterson *et al*. 1998). The relative tests assume that within a geographical region, climatic patterns will be identical and that observations from all sites within the region will reflect this identical pattern (Costa *et al*. 2009). If there are sufficiently high correlations between the candidate station and its neighboring stations, the relative tests might be a useful method Costa *et al.* (2009). However, there is always a possibility that neighbouring stations may be inhomogeneous or otherwise (Tayanc *et al.* 1998). In addition, different statistical test methods have been used to detect trends and homogeneity in hydro-meteorological time series; these are classified as parametric and nonparametric tests (Dahmen and Hall 1990; Zhang *et al.* 2006; Chen *et al.* 2007). Parametric tests are more powerful but require that data be independent and normally distributed, which is rarely true for hydrological time series data. For nonparametric tests, data must be independent, but outliers are better tolerated.

However, in Nigeria, Oguntunde *et al.* (2011) analysed the spatial and temporal patterns of monthly and annual rainfall between 1901 and 2000 and reported that 1950s and 1980s are the wettest and driest decades, respectively; negative trends in about 90 % of the entire landscape with only 22 % showing significant changes at 5 % level. Findings revealed a sharp difference between changes in rainfalls in 1931–1960 and 1961–1990 periods. Fasona *et al*. (2011) investigated the influence of ecogeographic factors on local climate over the western Nigeria using geographic information system and principal component analysis (PCA), findings indicated the major drivers of local climate to be coupling of terrain, rainfall, and temperature in all seasons. Ati *et al*. (2002) also analysed rainfall data covering a period of 50 years over northern Nigeria and found the annual trend and increasing annual rainfall amount of precipitation between 1993 and 2002.

It is pertinent to know, that there is complete absent of documented studies or evident on homogeneity analysis for the entire Northern Nigeria on hydrological areas (HAs) basis nor related studies that hinges on cumulative deviations test, Bayesian test and normality test (Anderson-Darling (A), Kolmogorov-Smirnov (D) and Kolmogorov-Smirnov (D)) with precipitation dataset that ran into 2019.Therefore, this research sought to filled in this identified knowledge gap. Thus, taking into cognisance, that reliable estimate of rainfall characteristics vis-à-vis homogeneity formulation as well as accurate determination of the magnitude of climatic fluctuations is necessary segments of the time series analysis for supposed water resource planning and management. It is on that basis this study presents homogeneity analysis of precipitation series in northern Nigeria.

.

Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

2.0 MATERIALS AND METHOD

2.1 Study Location and Data Assembly

The study location Northern Nigeria is located between 10°N - 14°N and 4°E - 7°5' E. It belongs to arid and semi-arid region of the country, precisely of a predominantly Sudan vegetation. It is characterised by a distinct bi-seasonal weather pattern; i.e., wet and dry. The wet season starts in April and ends in October, while the dry season starts in November and ends in March (Sombroek and Zonneveld, 1971). Figure 1 shows the map of HAs in Northern Nigeria. For this study, historical rainfall time series of over 48years (1971-2019) from the region was used. To do this, mean monthly rain gauge rainfall values (i.e., point rainfall) for substantial decadal time period were collected from NIMET and River Basin Development Authority Zonal offices across the catchment States of Katsina, Kano, Minna and Sokoto respectively.

Figure 1: Hydrological areas in Northern Nigeria

2.2.1 Cumulative Deviations Test:

A test for homogeneity was based on the adjusted partial sums or cumulative deviations from the mean (Buishand 1982):

$$S^{*}_{k} = \sum_{i=1}^{k}\left(x_i - \bar{x}\right), \text{ k = 1, 2, . . ., n} \qquad (3.1a)$$

where x_i are observed values of the climatic parameter, $\bar{x}$ is the sample mean, and n is the number of records in the time series. Rescaled adjusted partial sums S^{**}_{k} was obtained by dividing S^{*}_{k} 's by the sample standard deviation (D_x) as:

$$S^{**}_{k} = \frac{S^{*}_{k}}{D_x} \quad \text{k = 1, 2, . . ., n} \qquad (3.1b)$$

in which

$$D_x = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \qquad (3.1c)$$

statistic which is sensitive to departures from homogeneity is:

$$Q = \max|S^{**}_{k}|, 0 \leq k \leq n \qquad (3.1d)$$

High values of Q was an indication for non-homogeneity in the time series.

2.2.2 Bayesian Test:

The test was developed by Chernoff and Zacks (1964) and was modified later by Gardner (1969) as expressed below:

$$A = \sum_{k=1}^{n-1}(Z^{**}_{k})^2 \quad \text{k = 1,2, ..., n} \qquad (3.2a)$$

where Z^{**}_{k} was weighted rescaled partial sums, which can be computed using the following equation:

$$Z^{**}_{k} = \left[\left\{\text{k(n} - \text{k)}\right\}^{-0.5}\right]/D_x \qquad (3.2b)$$

where S^{*}_{k} is given in Eq. 3.1a and D_x in Eq. 3.1c

2.2.3 Normality Test:

Assessment of normality of data is a prerequisite for many statistical tests because normal data underlying assumption in parametric test (Ghasemi, *et al.,* 2012) at such done via:

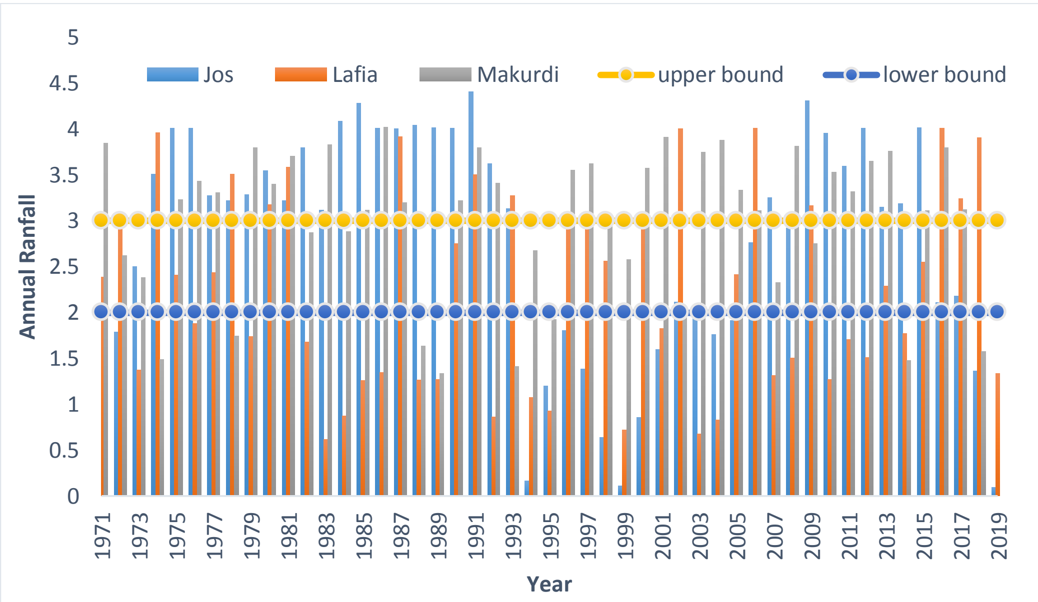
i. Anderson-Darling (A)
ii. Kolmogorov-Smirnov (D)
iii. Shapiro-Wilks (W)

3.0 RESULTS AND DISCUSSION

3.1 Cumulative Deviations Test

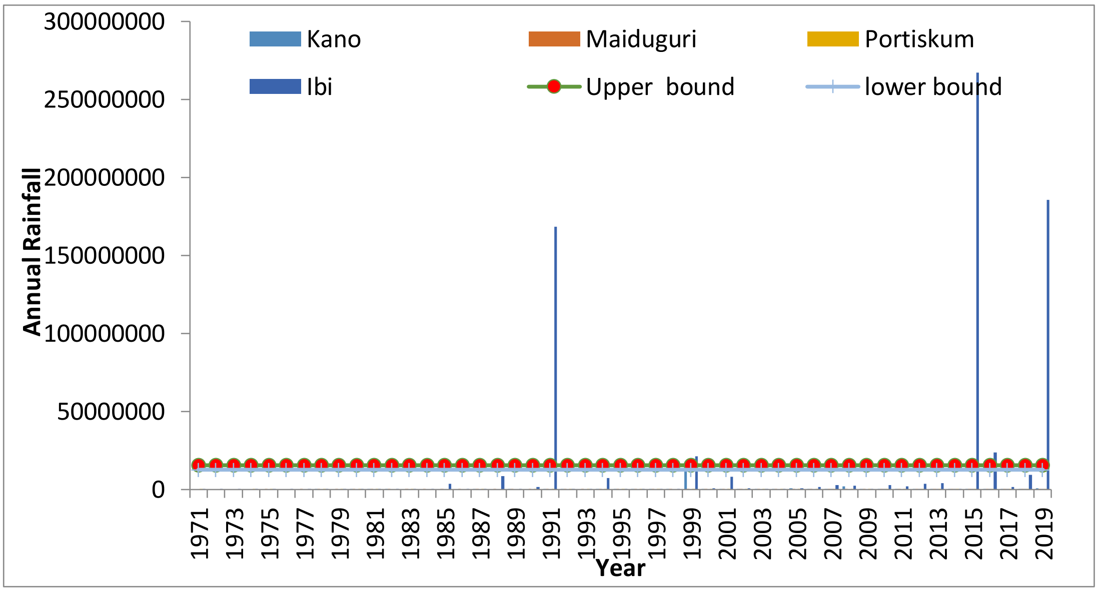
Figure 1 shows HA 8 and HA 1 as the most homogeneous regions with 78% and 67.56% homogeneous criteria respectively, of the total years considered. Hence, exhibits high level of homogeneity and felled within the confident bound at 95% significant level, based on this, the alternative hypothesis of no significant deviation was rejected at 5% for the considered HAs as opposed to HA 4 and 2, that exhibited excessive deviation that accounted for 34% and 43% inhomogeneity and mild homogeneity was observed in HA 3 attributable to 50% of the reckoning year. Wijngaard et al. (2003) noted that inhomogeneities in station data records are often caused by changes in observational routines, among which are station relocations, changes in instrumentation, changes of the surroundings, instrumental inaccuracies, and changes of observational and calculation procedures. This probably may have caused high variability in precipitation of the composite HAs.

(a)

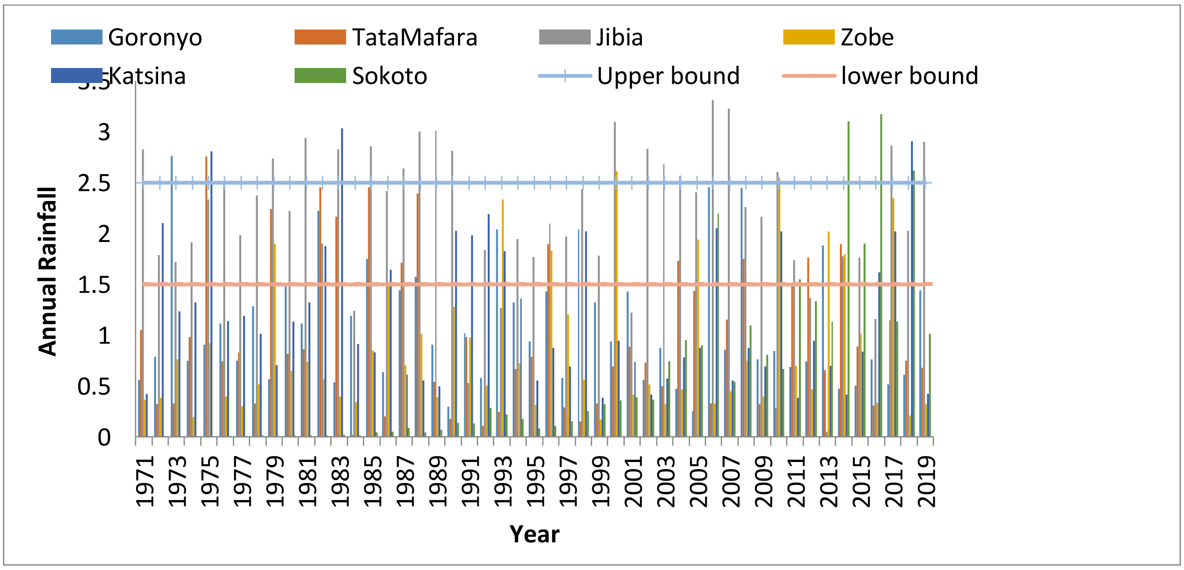


Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

(b)

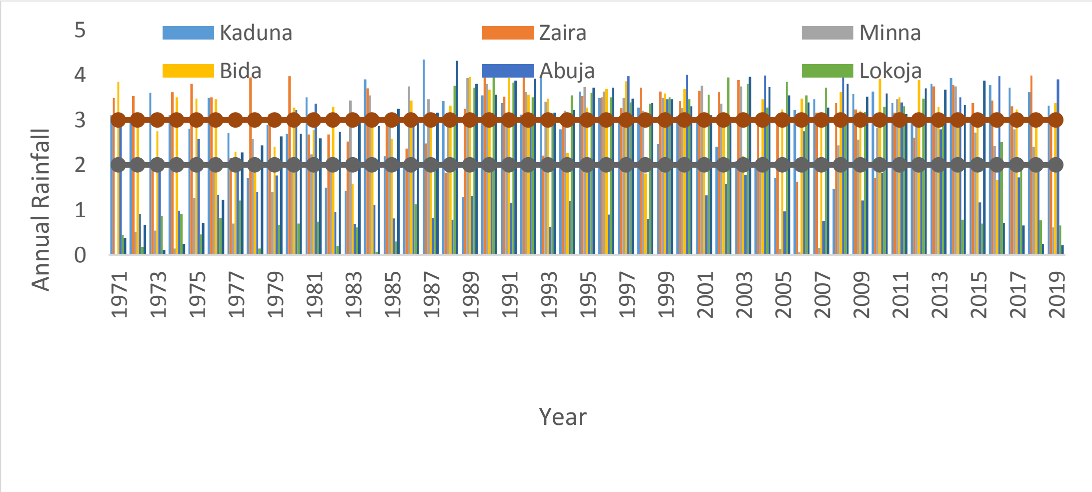


(c)



Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

(d)



(e)

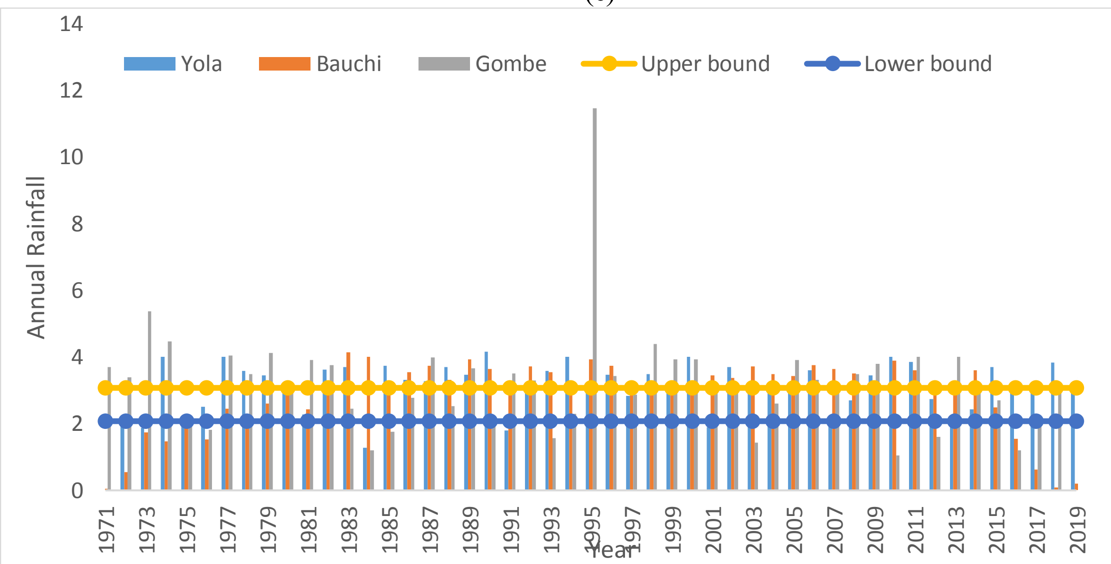
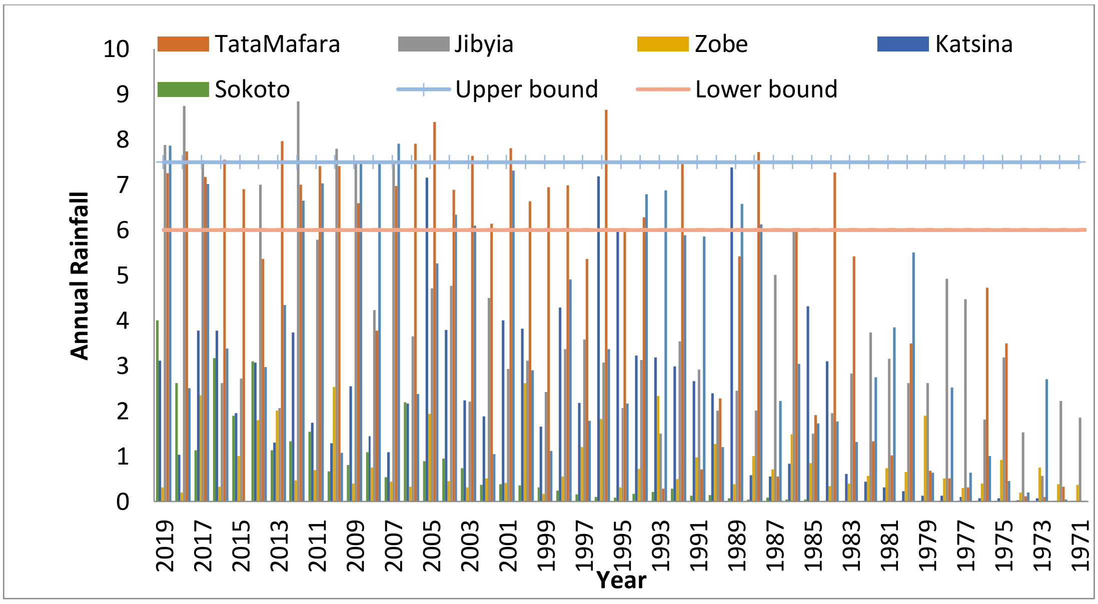


Figure 1: Cumulative deviation test HAs: (a) Four (b) Eight (c) one (d) Two (e) Three

3.2 Bayesian Test

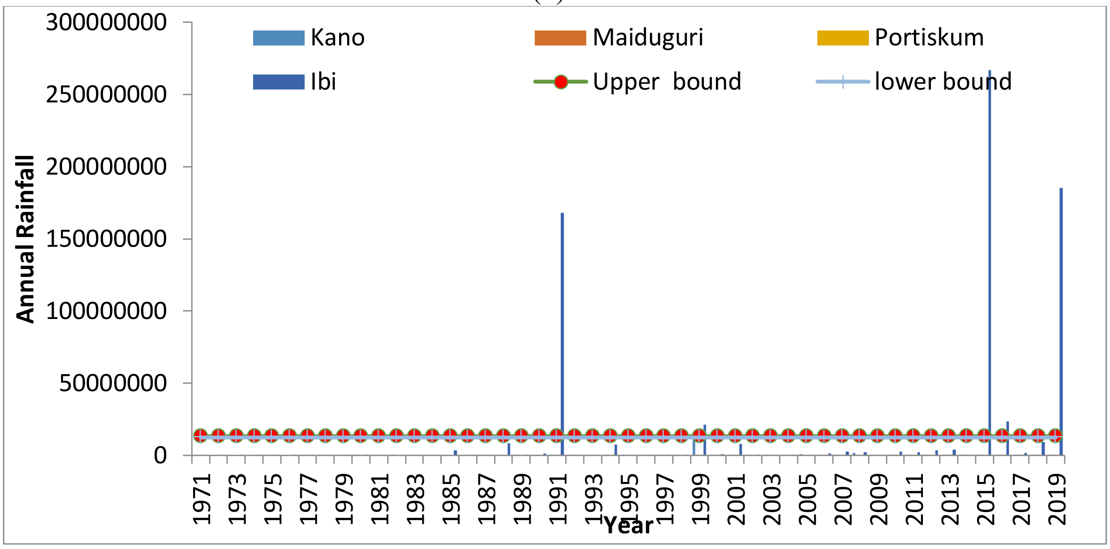
Figure 2 shows that stations in each candidate HAs had a significant level of homogeneity with a slightest inhomogeneity or variability which corresponds to 2.08%, 8.33%, 16.33%, 2.08%, 8.33% 29.16% of the total year computed for HAs, 1, 2, 3, 4 and 8 respectively, thus, indicating precipitation characteristics within the defined HAs tend to experience less perturbation, consequences of hydro-climatic similarity prevalence common in a particular zone of related in interest. The slight degree of inhomogeneity observed in the HAs are attributable to low-frequency oscillatory movement induced by climatic factors or through changes in land use and catchment characteristics. In line with the thought of Costa *et al.* (2009) confirms that homogeneous tests observes within a geographical region or areas, may likely exhibit similar climatic patterns and may differ from neighbouring observations. This assertion probably informed the classification of Nigerian into hydrological areas by Federal Ministry of Water Resources FMWR (2016) based on seemingly similar hydroclimatic characteristics.

(a)

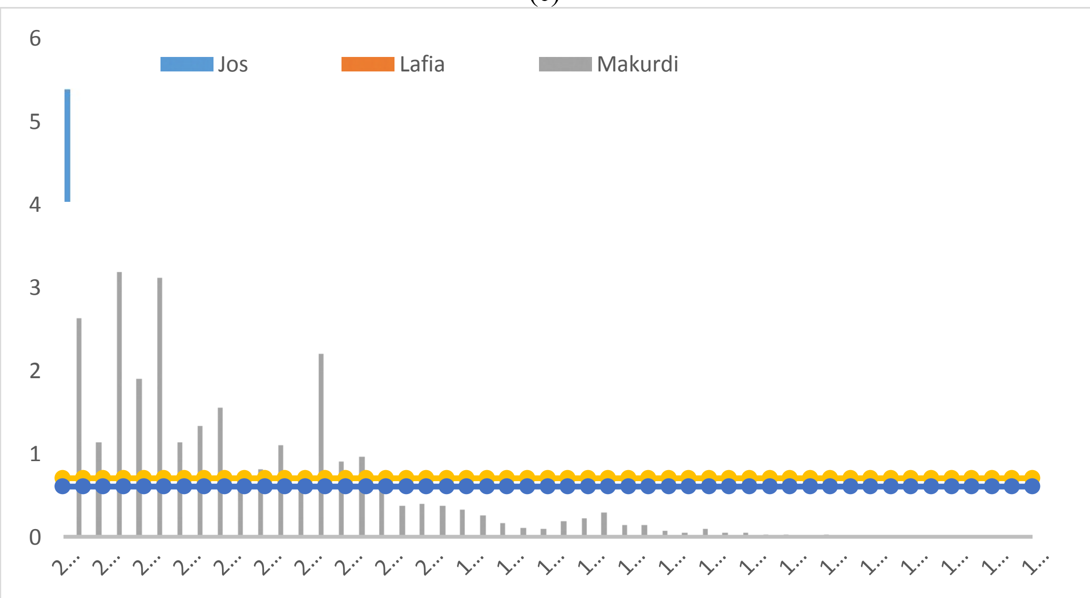


Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

(b)

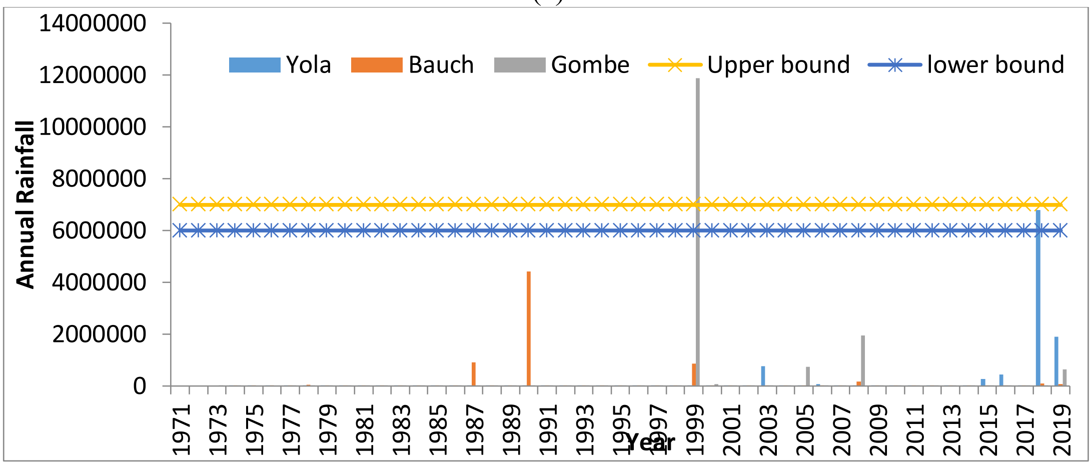


(c)



Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

(d)



(e)

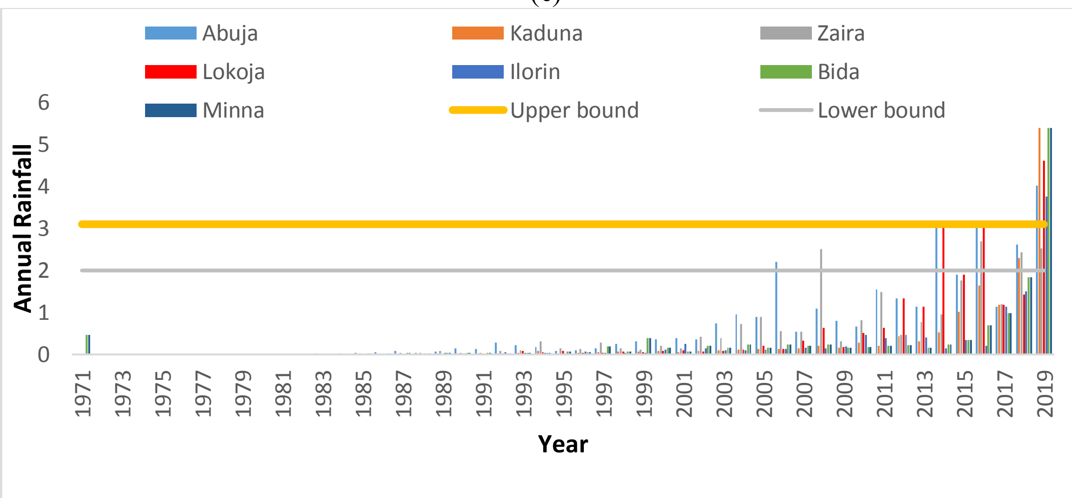


Figure 4. 2: Bayesian Test of HAs: (a) One (b) Eight (c) Four (d) Three (e) Two

3.3 Normality Test

As Inferred from Table 1 Anderson-Darling (A) test, Kolmogorov Smirnov (D) and Shapiro-Wilks(W) confirmed that all HAs data were drawn from normal distribution as resulting p-values in all considered cases is greater than 0.05 significant level. In this instance, the alternative hypothesis that the data follows a normal distribution

Journal of Environmental Issues and Agriculture in Developing Countries
Volume 15, Number 3, December 2023
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

was accepted. The implication of the finding here; are that the mean of the sampled dataset is a true representative of the dataset. In addition, three statistics test confirms the homogeneity of the composite HAs as denoted by uniformity of distributions. In the overall, based on the results of the Bayesian and Normality tests, the annual precipitation time series are homogeneous at each HA at such the alternative hypothesis of the present of homogeneity of HAs data are not rejected at a significance level of 0.05. Though, with the application of the cumulative test, inhomogeneity was detected in the annual series at seven stations. In general, it can be inferred from the analysis that the cumulative deviations test is more sensitive than the Bayesian and normality in the determination of inhomogeneity in the precipitation series. In the light of foregoing, high temporal and spatial variability of precipitation makes it difficult to analyse the homogenisation of precipitation data sets. Thus, identification of the inhomogeneity in the precipitation time series by the application of several statistical tests was used to enhance the chance of rejecting a true null hypothesis.

Table 4.1: Normality Statistical Tests for the Composite Hydrological Areas

Hydrological Areas (HA)	Station	Normality Test					
		Anderson-Darling (A)		Kolmogorov Smirnov (D)		Shapiro-Wilks(W)	
		A	P-value	D	P-value	W value	P-
1	Goronyo	0.74	0.05	0.105	0.648	0.942	0.017
	Gusau	0.549	0.149	0.201	0.051	0.954	0.055
	Katsina	0.78	0.039	0.121	0.474	0.955	0.06
	Sokoto	0.31	0.543	0.079	0.896	0.979	0.508
	Tatamafara	1.576	0.000	0.142	0.271	0.851	0.000
	Jibyia	0.504	0.195	0.103	0.682	0.966	0.159
	Zobe	0.662	0.079	0.109	0.609	0.948	0.031
Regional average		***0.731***	***0.150***	***0.109***	***0.597***	***0.943***	***0.118***
2	Kaduna	0.704	0.063	0.132	0.361	0.955	0.059
	Zaira	0.171	0.927	0.061	0.993	0.989	0.936
	Minna	0.438	0.495	0.097	0.677	0.972	0.498
	Bida	0.213	0.845	0.055	0.996	0.985	0.779
	Abuja	0.297	0.577	0.082	0.869	0.979	0.506

	Ilorin	0.365	0.581	0.085	0.779	0.976	0.556
	Lokoja	0.297	0.685	0.075	0.862	0.980	0.655
Regional average		***0.355***	***0.596***	***0.084***	***0.791***	***0.977***	***0.569***
3	Yola	0.255	0.714	0.059	0.991	0.982	0.635
	Bauchi	0.321	0.589	1.124	0.001	1.713	0.000
	Gombe	1.082	0.007	0.142	0.249	0.938	0.013
Regional average		***0.552***	***0.437***	***0.442***	***0.414***	***1.211***	***0.216***
4	Jos	0.901	0.005	0.121	0.632	0.891	0.070
	Lafia	0.795	0.037	0.112	0.525	0.953	0.05
	Makurdi	0.319	0.085	0.569	0.071	0.514	0.901
Regional average		***0.671***	***0.042***	***0.267***	***0.409***	***0.786***	***0.340***
8	Kano	0.339	0.483333	0.0921	0.759333	0.981	0.617
	Maiduguri	0.357	0.442	0.093	0.754	0.979	0.56
	Ibi	0.364	0.426	0.0823	0.867	0.978	0.473
	Portiskum	0.296	0.582	0.101	0.657	0.986	0.818
Regional average		***0.431***	***0.451`***	***0.081***	***0.913***	***0.813***	***0.717***

4.0 CONCLUSION

This study provides an insight into the prevailing homogenous characteristics of rainfall phenomena in northern Nigeria. The derived results and concomitant implication are important for policy making, especially for water resources management, planning and agriculture productivity. Three applied approaches explored were Bayesian, Cumulative Deviations and Normality test for homogeneity analysis. In the overall, based on the results of the Bayesian and Normality tests, the annual precipitation time series are homogeneous at each HA, thereby lending credence to hydrological based classification by FMWR. In the addition, recognising the fact that each HA is homogenous within it confines, it is important to infer that in the present of dearth of century data a composite station in a given HA may give a realistic estimate of rainfall characteristics; for instance, in line with Bayesian computation algorithms, in HA3 Gombe shows a very insignificant inhomogeneity of 2.08%, HA2 Abuja, Kaduna, Zaira, Lokoja, Ilorin, Bida and Minna had inhomogeneity of 4.2% only in 2018 and 2019, HA1 Tatamarfara and Jibyia (2019, 2017, 2012, 2013, 2005, 2006, 2001 and 1995) which stood at 16.66% inhomogeneity, HA4, Jos, Lafia and Makurdi recorded 27% inhomogeneity while HA8 only Kano shows deviation in 1991, 2015, 2019 and 1999 which accounted for

10.42% inhomogeneity, at such the alternative hypothesis of the present of homogeneity of HAs data are not rejected at a significance level of 0.05. In all studied instances, inhomogeneity reported were lesser than 50%, therefore may not significantly condition the significant of any quantitative findings or submission. Though, with the application of the cumulative test, inhomogeneity was detected in the annual series at seven stations as opposed to normality test where the test statistics employed confirms all the stations homogenous within the confines of respective HAs. It is recommended that admixture of approaches that strongly embrace element of soft computing techniques like artificial neuron network; Fuzzy and Genetic algorithms should be harness, as well as exploring lengthier dataset.

REFERENCES

Ati, O.F., Stitger, C.J. and Oladipo, E.O. (2002). A comparison of methods to determine the onset of the growing eason in northern Nigeria. *International Journal of Climatology,* 22:731–742.

Buishand T.A. (1982) Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology,* 58:11–27

Chen, H., Guo, S., Xu, C.Y. and Singh, V.P. (2007). Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. *Journal of Hydrology,* 344(3–4):171–184.

Chernoff, H. and Zacks, S. (1964). Estimating the current means of a normal distribution which is subjected to change in time. *Ann Math Stat* 35: 999–1018.

Costa, A.C. and Soares, A. (2009) Homogenisation of Climate data: Review and New Perspectives using Geostatistics. *Math Geosci* 41:291–305.

Costa, A.C. and Soares, A. (2009). Homogenisation of Climate Data: Review and New Perspectives using Geoscience. *Math Geoscience* 41: pp291–305.

Dahmen, E.R. Hall, M.J.(1990). Screening of Hydrological Data: Tests for Stationarity and Relative Consistency. Publication 49, ILRI, Wageningen.

Fasona M., Tadros M., Abiodun B. and Omojola A. (2011) Local climate forcing and eco-climatic complexes in the wooded savannah of western Nigeria. *Nat Res* 2:155–166. doi:10.4236/nr.2011.23021.

Federal Minister of Water Resources (FMWR) (2016). National Water Resources Policy.

Folland C.K., Palmer T.N. and Parker D.E. (1986). Sahel rainfall and worldwide sea temperatures 1901–85; observational, modelling and simulation studies. *Nature* 320:602–607.

Gardner, L.A. (1969). On detecting changes in the mean of normal variates. *Ann Math Stat* 40:116 126.

Ghasemi, A. and Zahhedias, S. (2012). Normality tests for statistical analysis A guide for non-statisticians. *Int J Endocrinol* Metab.

Odekunle, T.O. (2001) The magnitude–frequency characteristic of rainfall in Ondo, southwestern Nigeria. *Ife Res Publ Geogr* 8:36–41.

Oguntunde, P.G., Abiodun, B.J. and Lischeid, G. (2011). Rainfall Trends in Nigeria, 1901–2000. *J. Hydrol* 411:207–218. doi:10.1016/j. jhydrol.2011.09.037.

Ologunorisa, E.T. (2004). Rainfall flood prediction in the Niger Delta, Nigeria. *International conference in hydrology*. science and practice for the 21st century. UK, London.

Omotosho, J.B. and Abiodun, B.J.(2007) A numerical study of moisture buildup and rainfall over West Africa. *Meteorol Appl* 14:209–225. doi: 10.1002/met.11.

Peterson, T.C, Easterling, D.R., Karl, T.R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino R, Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Forland, E.J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. and Parker, D. (1998). Homogeneity Adjustments of in situ Atmospheric Climate data: a review. International Journal of Climatology 18(13):1493–1517.

Türkes M, Sümer UM, Kılıç G (2002) Persistence and periodicity in the precipitation series of Turkey and associations with 500 hPa geopotential heights. *Clim Res* 21:59–81.

Wijngaard, J. B., Klein-Tank A. M. G. and Konnen, G. P. (2003). Homogeneity of 20th Century European Daily Temperature and Precipitation Series. *International Journal of Climatology* 23: pp679–692.

Yue, S. and Hashino, M. (2003). Long term trends of annual and monthly precipitation in Japan. *J Am Water Resource Association* 39(3):587–596.

Zhang, Q., Liu, C., Xu, C.Y., Xu, Y. and Jiang, T. (2006). Observed trends of annual maximum water level and stream-flow during past 130 years in the Yangtze River basin, China. *J. Hydrol.,* 324(1–4):255–265.