



ORIGINAL RESEARCH ARTICLE

RAINFALL AND STREAMFLOW DYNAMICS IN THE BORNO REGION OF THE
LAKE CHAD BASIN: A HYDROLOGICAL ASSESSMENT

B. O. Sanyaolu^{1*}, U. A. Ibrahim¹ and A. N. Alkali¹

¹Department of Civil and Water Resources Engineering, University of Maiduguri, Maiduguri, Borno
State

*Corresponding author's email: femisanyaolu@rocketmail.com

ARTICLE INFORMATION

Received: 24th March 2025

Revised: 30th April 2025

Accepted: 30th April 2025

Keywords:

Lake Chad Basin

Ngadda river

Maiduguri

Rainfall

Streamflow

Hydrological

ABSTRACT

This study assesses the water resources potential within the Maiduguri catchment of the Lake Chad Basin by analyzing a 20-year using rainfall data between 1999 to 2018 and streamflow data between 1981 to 2000 (each over a 20 year period). The results indicates that monthly rainfall was generally higher between 1999 and 2011, followed by a significant decline from 2012 to 2018. This shift suggests a progressive extension of aridity from the Lake Chad region into the Sudan Savannah, likely influenced by the effects of climate change. Flooding events were recorded in 16 of the 20 years analyzed. Streamflow analysis of River Ngadda, which traverses Maiduguri, revealed an average discharge of 6,201.2 m³/s over the study period, with a 7-year span of flooding. Additionally, storage apportionment data were evaluated to inform water resource management in the region.

© 2025 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

1.0 Introduction

One of the biggest problems facing the Lake Chad basin is the variability of its hydrological regime and freshwater availability. Lake Chad shrank by 90% as a result of recurrent droughts in the period from 1970 to 2008 and the declining discharge of the rivers that feed it (Ross, 2018). Over this period, groundwater levels followed the same trend as surface water levels, showing a significant decline. Since the 1990s, however, rainfall has remained relatively stable, close to its yearly average. This has led to a slight improvement in the situation. Many of the world's river basins are either 'closed' or 'are closing' as water use within them exceeds or is approaching the amount of renewable water available (Jedwab et al., 2023). The Lake Chad Basin being one of these closed basins poses complex water management since there is interconnection between the water cycle, aquatic systems and water users. Population growth increases the demand for food, land and water also increasing the stress on available water resources (Mahmood and Jia, 2018; Odada et al., 2011; Romero et al., 2014). The resultant effects of these actions have been drastic changes in the natural environment with notable implications on the climatic water distribution. Findings from various climatic models as they relate to climate change predict increased evapotranspiration in the presence of water. However, in the absence of precipitation, this will result in increased risk of drought due to enhanced surface dryness (Westerling and Swatnam, 2003), heat wave (Lyon, 2009; Lau and Nath, 2012) and wildfires (Whitman et al., 2015). This is true of the Sudan-Sahelian region of Nigeria which is characterized by acute rainfall variability and in the last 40 years has witnessed dramatic reductions in mean annual rainfall (Thompson and Amos, 2010; Ekpoh and Nsa, 2011). The Chad basin is the largest basin of interior drainage in Africa occupying an area of 600,000 square miles in the southern Sahara and in the Sudan region. The basin is named for its most conspicuous feature, the Lake Chad.

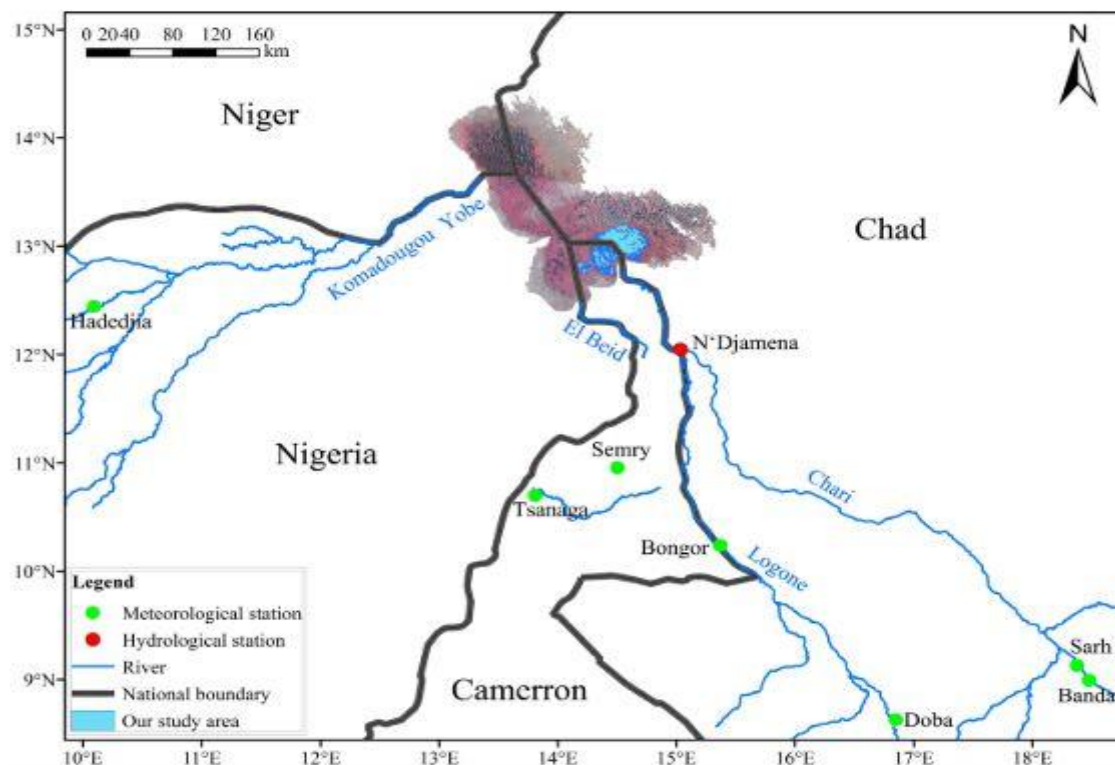


Figure 1: Map of Lake Chad with its tributaries and the four riparian countries

(Source: Zhu *et al.*, 2017)

The sector of the Lake Chad Basin in Nigeria covers an area of 6,074km² which is one tenths of the total area of the basin (Ndehedehe *et al.*, 2016). Out of this, the part situated in Borno State covers 2,258km² (Darnhofer *et al.*, 1988). Because the lake is shallow, the shoreline fluctuates markedly with high and low stages corresponding to the wet and dry seasons. None of the rivers in the Borno area is perennial and most of them flow into marshy areas on the plain and disappear by evapotranspiration before reaching lake Chad. However, the Komadugu-Yobe in the north and the Yedseram river to the south, flowing through Bama are relatively large streams that discharge into lake Chad during the rainy season. The Ebeji river is by far the largest river flowing into lake Chad, but part of its relatively large catchment extends into Cameroon (NNJCC report, 1985). The Ngadda river which flows through Maiduguri has a relatively small catchment basin and like other rivers mentioned above is seasonal in character. The river flows from August to February and usually reaches peak discharge in September. Upstream from Maiduguri, the Ngadda passes through lakes Yare and Alau. Both of which are perennial. At high water, the surface area of lake Yare is about 10 sq. miles while that of Alau is 2 and a half miles (Buma *et al.*, 2018). The Ngadda enters lake Yare and leaves by twin channels, one of which flows into lake Alau. The outlet from lake Alau joins the bypass channel 12 miles south of Maiduguri (Irvboje and Kimingar, 1988). This investigation is concerned primarily with the hydrological analysis of rainfall and streamflow data of river Ngadda with a view to determining the magnitude, distribution, storage and deficit for the period of record.

2. Materials and methods

Mean monthly rainfall data was collected for the period 1999-2018 from the Nigerian meteorological agency (NIMET), Maiduguri. Streamflow data was obtained from the hydrology section of the Borno State water board for the limited period 1981- 2000 that was available. The rainfall data had some missing data and this was filled by interpolation using a rating curve. Thereafter the data was processed into mean annual values. A hyetograph of the annual totals against the years was plotted to show rainfall variation across the period of record. In analysing the rainfall trend, the moving average method of time series was used. This was done by creating a series of averages of different subsets of the full data set. The average for the year was estimated and given in equation 1:

$$Average = \frac{A + 2b + C}{4} \quad |$$

Where: A= rainfall value of the preceding year, B=rainfall value of the year under consideration, C= rainfall value of the preceding year

A frequency analysis of the rainfall data was done to determine the probability of occurrence of flow that would be equaled or exceeded in any given year. In doing this, the rainfall annual totals were arranged in ascending order and the probability of each occurrence ranked. The Weibull equation in equation 2 was used

as plotting formula:

$$P = \frac{m}{n + 1} \quad 2$$

Where: P=probability in % of the occurrence m, m=the rank of the observation, n=the total number of observations

2.1 Mass curve analysis

Mass curve plot was used to investigate reservoir storage requirements along the river. This was obtained using monthly streamflow data. The cumulative inflow values were plotted against time. The storage required at maximum deficiency was then determined.

3. Results and Discussion

3.1 Rainfall Analysis

The mean annual rainfall across Maiduguri shown in Figure. 2 is generally random with a significant decrease in amount between 2012-2018. However, the catchment experienced relatively high rainfall between 1999-2011.

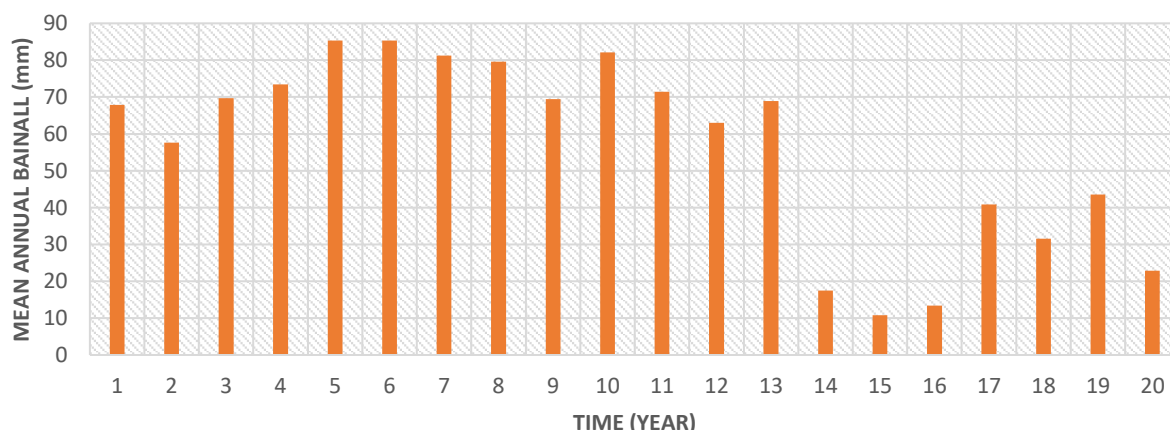


Figure 2: Mean annual rainfall distribution in Maiduguri over a 20 year period (1999-2018)

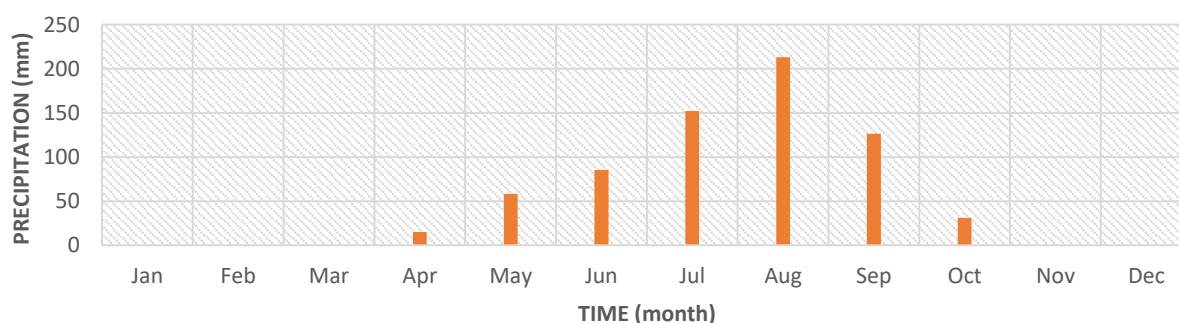


Figure 3: Mean monthly rainfall distribution over Maiduguri (1999-2018)

The mean monthly rainfall hyetograph in Figure 3 indicated that the Maiduguri catchment experienced rainfall between May and October with increased amounts between July and August with dry spells occurring between January and April as well as October to December. The moving average smoothing technique was used to eliminate the random fluctuations with the results converging to a description of the flooding trend. From the total annual rainfall data, the mean annual total was calculated as 681.5mm. The moving average values exceeding the mean annual indicated flood events occurring from 2001-2011 and 2017-2018.

Figure 4 indicated that the rainfall pattern was generally similar from 1999-2011, but a sharp decline is noticeable between 2014 and 2016. These observations indicate that Maiduguri and its environment and populations are under a growing risk of water scarcity, food insecurity, wetland loss and shoreline retreat.

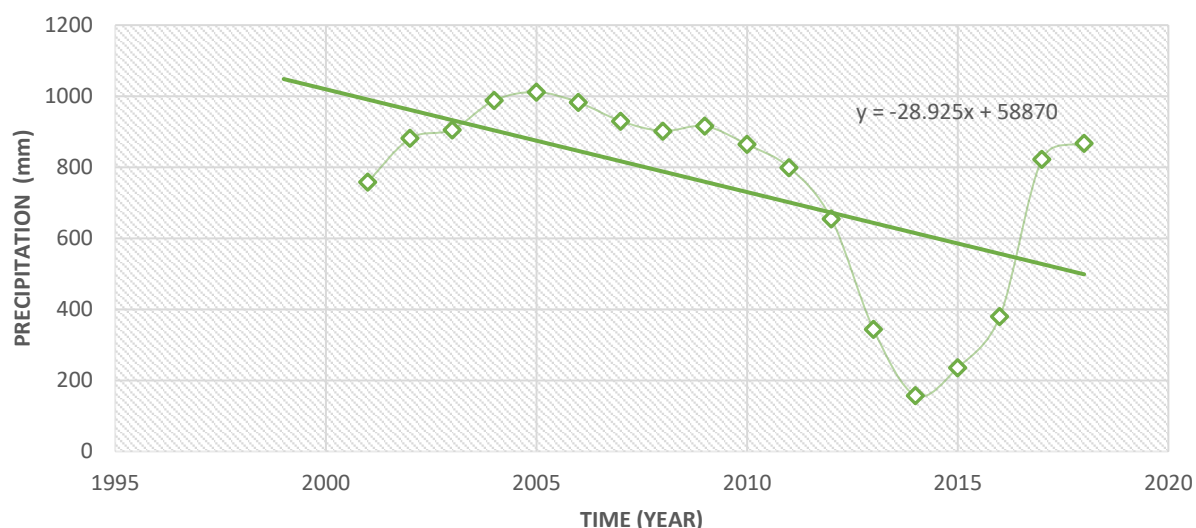


Figure 4: Rainfall moving average pattern over the 20 year study period (1999-2018)

The National Action programme to combat desertification in Nigeria estimates that about 50% of Borno State is seriously affected by desertification (Butu and Emeribe, 2019). A hydrologic frequency analysis of the total annual rainfall data was carried out in order to obtain the cumulative distribution which provides a rapid means of determining the probability of a flood event occurring or exceeded in any given year. A normal distribution function was fitted to the total annual rainfall data and a probability plot drawn to show the exceedance frequencies and recurrence interval for the 20 year period.

From Figure 5(probability plot), the 50% chance (100 yr.) of the total annual rainfall occurring or exceeded is 780mm, while the probability of 95% (100 yr.) total annual rainfall occurring is about 150mm. Table I shows that the highest precipitation value, 1023.8mm has a calculated recurrence interval of 21.278years while the lowest value 129.86mm has a recurrence interval of 1.1 years.

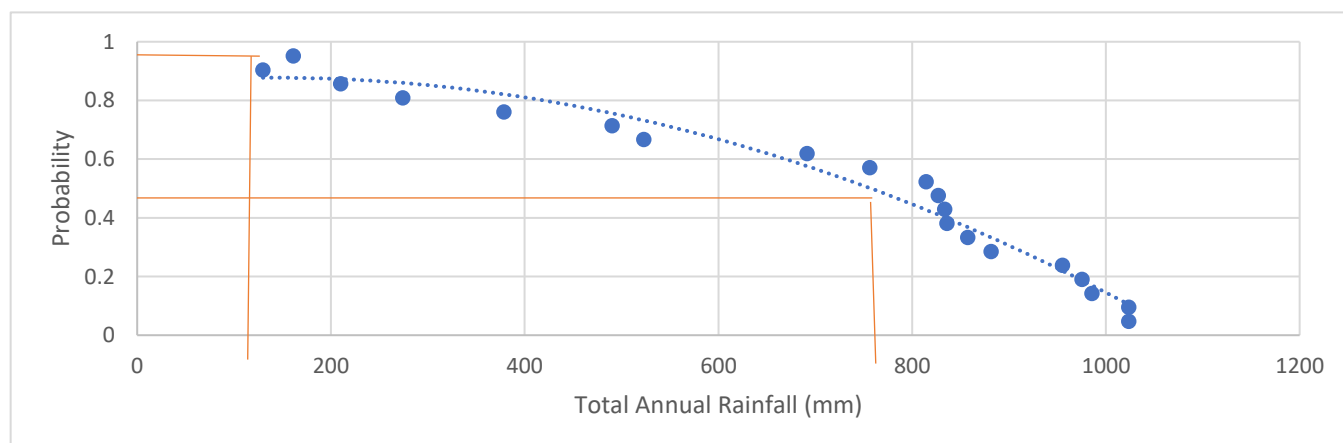


Figure 5: Probability vs. Total Annual Rainfall Plot

Table 1: Exceedance frequencies and recurrence intervals for total annual precipitation (1999-2018).

YEAR	Total annual rainfall (mm)	RANK(m)	$P=\frac{m}{n+1}$	$T(yr)=1/p$
2003	1023.8	1	0.047	21.276
2004	1023.6	2	0.095	10.526
2008	985.9	3	0.142	7.042
2005	975.5	4	0.19	5.263
2006	955.4	5	0.238	4.201
2002	881.6	6	0.285	3.508
2009	857.4	7	0.333	3.003
2001	835.9	8	0.381	2.624
2007	833.6	9	0.429	2.331
2011	827.1	10	0.476	2.101
1999	814.6	11	0.523	1.912
2010	756.5	12	0.571	1.751
2000	691.8	13	0.619	1.615
2017	523.01	14	0.667	1.499
2015	490.29	15	0.714	1.401
2016	378.70	16	0.761	1.314
2018	274.32	17	0.809	1.236
2012	210.06	18	0.857	1.166
2013	129.86	19	0.904	1.106
2014	161.15	20	0.952	0.952

3.2 Streamflow analysis

The magnitude of total annual flow along the river Ngadda was used to study some of its flow characteristics. However, due to paucity of reliable data from 2001-2020, only available data for the period 1981-2000 was used. Based on this, the average streamflow was 6201.20m³/s. Moving average values exceeding this average would result in flooding as shown in Table 2.

Table 2: Annual Streamflow data with moving average values and flood events

Time (year)	Total Annual Streamflow (m ³ /s)			Moving average(m ³ /s)	Flooding (m ³ /s)
1981	6325.28	-	-	-	
1982	8302.2	14627.5	-	-	
1983	1620.44	9922.64	24550.1	6137.53	
1984	7399.5	9019.94	18942.6	4735.645	
1985	6640.23	14039.7	23059.7	5764.92	
1986	5349.88	11990.1	26029.8	6507.46	•
1987	4981.35	10331.2	22321.3	5580.34	
1988	7436.24	12417.6	22748.8	5687.21	
1989	9345.11	16181.4	28598.9	7299.735	•
1990	6333.51	15678.6	31860	8114.99	•
1991	5392.63	11726.1	27404.8	6373.97	•
1992	7425.87	12818.5	24544.6	6136.16	
1993	6584.94	14010.8	26829.3	6707.33	•
1994	9046.39	15631.6	29642.4	7410.54	•
1995	6339.11	15385.5	31017.1	7753.97	•
1996	5709.3	12048.4	27433.9	6858.48	•
1997	4965.65	10675	22723.4	5680.84	
1998	4900.44	9866.09	20541	5135.26	
1999	5222.14	10122.6	19988.7	4997.17	
2000	4703.87	9926.01	20048.6	5012.15	

The highest monthly stream discharge for the period was 3214.05m³/s recorded in December 1989 while the lowest flow was 2.62m³/s recorded in May, 2000. The flow trend observed from the moving average plot (Fig.6) indicated an increase in flow between 1989-1990 as well as between 1993-1994.

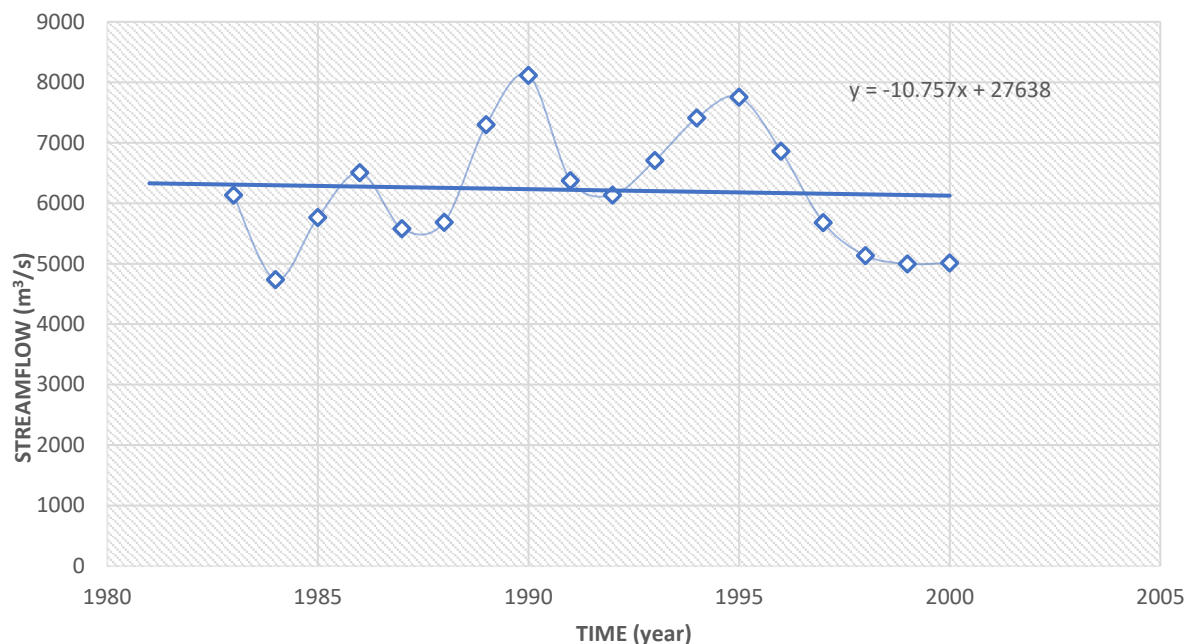


Figure 6: Streamflow moving average pattern over the 20 year study period (1981-2000)

Figure 7 shows the relationship between cumulative flow against monthly flow. The mass curve gives an estimated flow deficit suitable for future water resources planning. The upper limit gives a flow of 62,000,000 while the lower limit gives a flow of 23,000,000 putting the difference at 39,000,000.

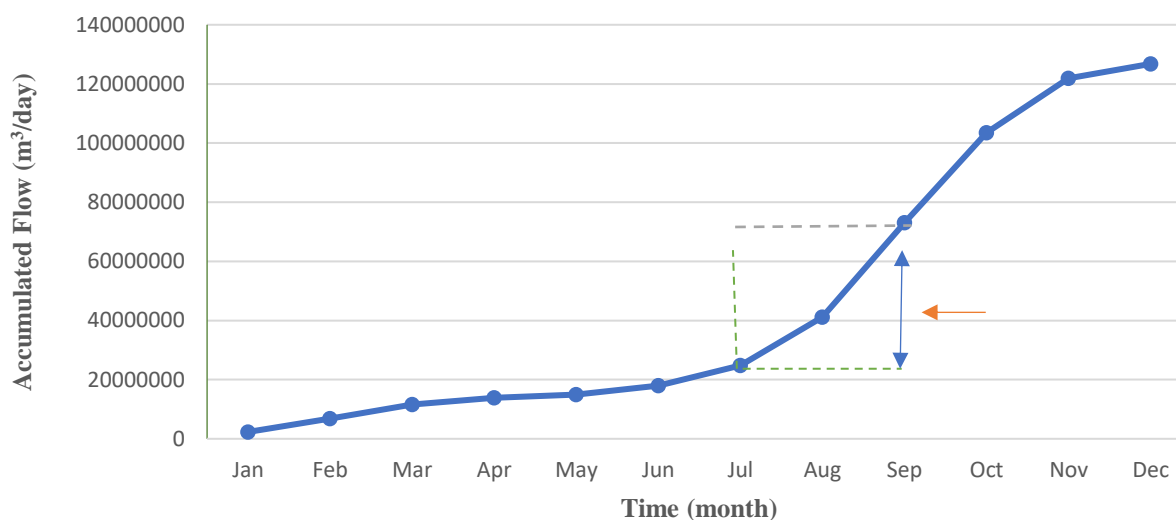


Figure 7: Mass curve of cumulative flow against monthly streamflow

Three main factors would drive the continued growth in demand for water, population, prosperity and climate change. The biggest uncertainty in projecting future demand lies in estimating how much will be needed for agriculture, which currently accounts for about 70% of water withdrawals, mostly for irrigation (UNESCO, 2024). Some forecast a big increase in demand, as food production has to rise to feed a growing population. The impact of climate change is however, still unpredictable as it may exacerbate the trend of wet areas getting wetter and vice versa for the dry areas as well. And rainfall on which much of subcontinental African economic life hinges, will become more erratic. The most extreme short-term effects have been the increasing number of extreme weather events. In the long run, Consequently, however, the bigger problem from climate change will not be too much water but too little. As a report by the World Bank puts it: “The impacts of water scarcity and drought may be even greater, causing long-term harm in ways that are poorly understood and inadequately documented.” Of course, a lot depends on how much the climate changes and how fast.

Approximately 80% of the basin is shown to be prone to erosion. The areas most likely at risk from erosion are Lake Chad, Maroua and Kano, and vulnerable areas include those situated between Maroua, Maiduguri and N'Djamena and between Diffa and Zinder. A possible way forward could involve the LCBC member states

granting Lake Chad and its immediate surroundings special status as an area of great environmental value. A partnership agreement could be signed with UNESCO to make Lake Chad a biosphere reserve. All the environmental problems described are being addressed by the LCBC through projects and programs implemented in collaboration with different international, national organizations, and civil society organizations which are keen to increase their support to the LCBC for the good of the regional and global environment. However, due to the upsurge in violence from non-state actors such as Boko Haram and the Islamic state in West Africa province, many setbacks have ensued. In this regard, there is need to plan and design sustainable water resources management techniques in different sectors – agriculture, irrigation and water supply to adapt to changing patterns of rainfall fluctuation and rising cases of insurgency. Decreasing streamflow is a worldwide phenomenon. Some of it results from declining rainfall. But much is the direct result of human intervention—the damming and diversion of rivers for flood control, water-storage and irrigation. And, where rivers still flow, the water in them is often unsafe to drink or even bathe in. Waterborne diseases recorded within communities around river Ngadda include diarrhea, dysentery, intestinal parasitic diseases, bilharzias, cholera and typhoid fever. The lack of potable water and in particular, the poor hygiene levels are seen as the main causes. Much is being done in this regard, especially on the part of international agencies and civil society groups, but projects still face major constraints: poor health infrastructure, few skilled staff motivated to work in some areas, limited access due to religious and cultural influence.

4. Conclusion

This study provides valuable insight into the variability in rainfall and streamflow pattern in the Borno sector of the Chad Basin. The continuous decrease in rainfall amount between 2012 and 2018 could be as a result of reversible climatic fluctuation and not climate change. This may be attributed to repeated drought cycles in those years caused by large scale shifts in global circulation. Flood events occurred from 2001 to 2010 as well as in 2017 and 2018. From the mass curve analysis of streamflow data from River Ngadda, storage capacity required to hold surplus waters for release during critical periods when inflows fall short of demand was calculated to be $3.8 \times 10^6 \text{ m}^3/\text{s}$. Member states of the Lake Chad basin commission have not efficiently implemented the Lake Chad water charter after its ratification in 2013 which establishes the rights, obligations, duties, restrictions and procedures for the effective management of Lake Chad resources. The stumbling blocks relating to national sovereignty are still present, particularly that of the quantitative management of surface and groundwater resources. Similarly, the charter has failed to tackle the issue of sanctions against those who break the charter. As with all legal documents, the charter is merely a document that can only be effective when it is faithfully implemented and upheld. In other words, its usefulness and effectiveness depend entirely on the capacity and will of the parties to adopt the measures required for its implementation.

References

- Avis CA., Weaver AJ. and Meissner KJ. 2011. Reduction in areal extent of high-latitude wetlands in response to permafrost thaw. *Nature Geoscience*, 4:444-448.
- Buma, WG., Lee, S. and Seo, JY. 2018. Recent Surface Water Extent of Lake Chad from Multispectral Sensors and GRACE. *Sensors*, 18(2082): 1–24. <https://doi.org/10.3390/s18072082>.
- Butu AW. and Emeribe CN. 2019. Spatial patterns of climatic variability and water budget over Sudan Savannah of Nigeria. *African Journal of Environmental Science and Technology*, 13(12): 464-480
- Darnhofer, T. 1988. The agroclimatic and water balance situation of the Chad basin: evaluation of proposed management schemes to improve the water balance of lake Chad.: UNEP mission report Nairobi (KE): UNEP. 51.
- Ekpoh IJ. And Nsa E. 2011. Extreme Climatic Variability in North-western Nigeria: An Analysis of Rainfall Trends and Patterns *Journal of Geography and Geology*. 3(1).
- UNESCO. 2024. United Nations World Water Development Report.
- Irivboje, OC. And Kimingar, N. 1988. Commission du Bassin du Lac Tchad (CBLT) N'Djaména. TD. Le bassin du Chari: évolution depuis la dernière sécheresse (1984-1985 à 1987-1988)

Jedwab, R., Haslop, F. and Zarate RD. 2023. The effects of climate change in the poorest countries: Evidence from the permanent shrinking of Lake Chad. UNDDR Prevention.

Lau, N., Nath, MJ. 2012. A model study of heat waves over north America: Meteorological aspects and projections for the twenty-first century', *Journal of Climate* 25(14): 4761-4784.

Lyon, B. 2009. Southern Africa Summer drought and heat waves: Observations and coupled model behaviour, *Journal of Climate*, 22(22): 6033-6048.

Mahmood, R., and Jia, S. 2018. Analysis of causes of decreasing inflow to the Lake Chad due to climate variability and human activities. *Hydrology and Earth System Sciences Discussion*, 2: 1–42. <https://doi.org/10.5194/hess-139>

Ndehedehe, CE., Agutu, NO., Okwuashi, O., and Ferreira, VG. 2016. Spatio-temporal variability of droughts and terrestrial water storage over Lake Chad Basin using independent component analysis. *Journal of Hydrology*, 540: 106–128. <https://doi.org/https://doi.org/10.1016/j.jhydrol.2016.05.068>

Niger Joint Commission for Cooperation (NNJCC Report) 1985. Study of the water resources in the Komadougou-Yobe basin. Vol. I: general report.

Odada, EO., Oyebande, L., and Oguntola, JA. 2005. Lake Chad: Experience and lessons learned brief. *Lake Vic.*, 92: 72–91.

Romero-Lankao, P, Smith, JB., Davidson, DJ., Diffenbaugh, NS., Kinney, PL., Kirshen, P., Kovacs, P., Villers, LR. 2014. North America. In: *Climate Change: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1439-1498.

Ross, W. 2018. Lake Chad: Can the vanishing lake be saved. BBC

Westerling, AL. and Swetnam, TW. 2003. Interannual to decadal drought and wildfire in the Western United States. *EOS* 84:545-560.

Whitman, E. , Batllori, E., Parisien, MA., Miller, C., Coop, JD., Krawchuk, MA., Chong, GW., Haire, SL. 2015. The climate space of fire regimes in north-western North America. *Journal of Biogeography*, 42(653): 1736-1749.

Zhu, W., Yan, J. and Jia, S. 2017. Monitoring Recent Fluctuations of the Southern Pool of Lake Chad Using Multiple Remote Sensing Data : Implications for Water Balance Analysis. *Remote Sensing*, 9(1032): 1–26. <https://doi.org/10.3390/rs9101032>.