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Periodic Assessment of Trend and Climatic Variability in the LCB

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Abstract

Periodic assessment of trend and climatic variability is important for better planning and water resource management in the LCB catchment. This study assessed the impact of climatic variables on the LCB (LCB) using rainfall data derived from TAMSAT, run off and evapotranspiration data derived from climate engine over a period of twenty years (2001-2020). Non-parametric Mann Kendall (MK) and Spearman rho tests were applied to detect the presence of rainfall trends and trend magnitude was calculated using Sen's Slope Estimator (SSE). With an average annual rainfall of 523.62mm, trend analysis showed an annual positive trend for precipitation at 5% significance level. Analysis of seasonal rainfall using both tests revealed an increasing trend during the dry season. However, the late dry season experienced a slight increasing trend and for wet seasons. There was 2.7% runoff and 4.6% evapotranspiration which are the lowest for the time series.

Keywords: Rainfall; Precipitation; Mann Kendal; Trend; Sen's Slope; Evapotranspiration; Runoff.

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1. Introduction

The LCB (LCB) is characterized by high temperatures throughout the year with low humidity. Intense solar radiation and strong winds which results into a high annual potential evapotranspiration of around 2,200 mm for Central Chad [1]. There has been precipitation variability across the basin in the 1960s and 1970s leading to decrease in the quantity of precipitation which made it the driest decades [2, 3]. The reduction in precipitation in LCB is about 100mm for each 100km of distance northwards [4]. Afterwards, rainfall began to recover at a very slow rate from the 1990s onwards [5, 6]. There is a close interaction between rainfall, evaporation, the generation of lateral inflow, groundwater leakage under the body of the Lake and human abstraction [7]. The LCB consists of an arid dominated Northern part and the wet Southern part which belongs to the monsoon climate, with widely spread precipitation falling during the months of June, July and August [8]. Some studies have attributed the recent greening in the Sahel region in part to increasing rainfall in the past decade, global warming [9], and sea-surface temperature variability [9,10]. A recent study on hydrologic variability using land-surface models found run-off to be extremely sensitive to rainfall fluctuation and variability, higher in the dry period than in the wet period for rainfall, evapotranspiration, run-off, and river discharge [11]. These fluctuations have direct impact on Lake Chad level and size; due to the fact that Lake Chad is a closed lake, decreased precipitation in the basin ultimately results in a net decrease inflow from the tributaries and subsequent reduction in lake level and size. Logone Rainfall variability can be affected by many factors; it can be attributed to global sea surface temperature (SST) anomalies over the rest of Africa [12]. Lake Chad has been experiencing shrinkage in size over the years due to factors including climate change and human activities; hence research on climate variability over the LCB cannot be overemphasized [13]. Okonkwo used gridded gauge monthly time series (1970-2010) to show an increasing trend in annual rainfall over the LCB [14], while Niel, analyzed rainfall data from rain gauges covering the period 1950-2002 and reported a significant drop in annual rainfall in the central part of the basin (11° - 13°N)[15]. Nkiaka also analyzed rainfall data unevenly distributed across the Logone catchment in the LCB over a fifty-year period (1951-2000) using homogeneity tests, non-parametric Mann Kendall (MK) and Spearman rho tests to detect the presence of trends revealed homogeneity and presence of negative trends for annual rainfall [16], Temperature was predicted to increase by 0.65–1.6 °C and precipitation was predicted to decrease by 13–11% in the next two decades 2016–2025 and 2026–2035) relative to 1961–1990 in the most active part of the LCB, Africa,[17]. In the LCB region, the rainfall variability is strongly influenced by seasonal regime changes. The continuous increase of humid air from the Atlantic Ocean characterized the monsoonal regime and it flows into the continent up to about 11°N in May, this is associated with seasonal migration of the Intertropical Convergence Zone (ITCZ) from its southern position in the boreal winter to its northern position in the boreal summer [18]. Paleo-climate records from the LCB was used to back up the fact that the African monsoon responds to insolation forcing in no definite pattern and that Lake Mega-Chad influenced biogeochemical cycles on a global scale[19]. According to Jury, decade-long rainfall variability in the region has been attributed to the interaction of Hadley Walker cells over Africa at decade-long frequency through anomalous north-south displacement of the near-equatorial trough[20], while Chaminade linked it to atmospheric variability [5], Paeth attributed it to global warming [21] while Zeng attributed it to processes related to vegetation feedback [22] .Time series of river discharge incorporates some important hydrological parameters such as precipitation, temperature, and changes in land cover [23]. There is a relationship between variability in water level of continental lakes and global climate change [24]. The large variations in water levels and landscapes are directly dependent on rainfall in the Chari basin and possible to indicate the agricultural production, access to food in the years to come, be seriously compromised by climate change resulting in wide variability in the availability of water resources [25]. Provision of water for agriculture, pastoral purposes and ecosystem sustainability is threatened by unpredictable rainfall thus the LCB has experienced prolonged periods of water shortage, food shortage and loss of livelihoods with consequent increase in insecurity. Several studies have been conducted with claims of shrinkage of the Lake Chad, which is the main source of freshwater in the region, being the cause of the socioeconomic problems. The purpose of this study is to access the periodic trend and climatic variability within the period under review for the study area, while the objectives are: Identify changing patterns of precipitation variability across the basin between 2001 and 2020, access the implication of precipitation on runoff and evapotranspiration.

1.1 Study Area

LCB extends between Latitudes 6^0N and 24^0N; Longitudes 7^0E and 24^0E, a part of the semiarid Sahel that is prone to drought [26]. It stretches over an area of 2,400,000Km^2. The basin is named for its most prominent feature, Lake Chad, a closed lake at the center of the LCB, which is highly sensitive to hydroclimatic events [27]. Factors including precipitation, river discharge, climate indices and anthropogenic activities influence the LCB hydro climatic system [28]. The total population of the entire LCB is estimated at about 47 million in 2013. The main activities of the people are agriculture, nomadic and semi-nomadic animal husbandry and fisheries. The basin is classified into different swamp regions. They are known as the Grand Yaéré in Extreme north of Cameroon, Lake Chad, Lake Fiti, Massénya and Salamat to the south-east, and Komadugu-Yobé to the North-east of Nigeria [29].. Precipitation recharges the lake through either surface flows (tributaries) or ground water recharge. There was a dramatic decrease in the lake size from about 24,000 km^2 in the 1950s (Large Lake Chad) to about 18,000 km^2 in the early 1970s (Normal Lake Chad); and the splitting of the Lake around 1975 into northern (Sahara-arid) and southern (Savanna-humid) pool by drought during the late 1960s and early 1970s [30].

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Figure 1: Study Area Map showing the Lake Chad Sub -Basins

2. Materials and Methods

Table 1: Dataset for Climate Variables

	Variable	Sensor/ Dataset	Temporal	Spatial	Extent
1	Precipitation/ Rainfall	CHIRPS/ TAMSAT	2001- 2020	4km	Basin Extent
2	Evapotranspiration	FLDAS (Climate Engine)	2001- 2020	1km	Basin Extent
	Surface Runoff	FLDAS (Climate Engine)	2001- 2020	1km	Basin Extent

The methodology used in this study involves the trend analysis using the Mann-Kendal (Z_{mk}) and Sen's slope estimator test at 0.05 significance level (p-value) on time series. The rainfall variability on time series was performed monthly, annually and seasonally. The four seasons used for this study namely Dry, Late dry, wet and late wet were categorized based on the rainfall patterns of the LCB [31, 8]. Mann Kendal is a non-parametric test which allows to accept the alternative hypothesis (Ha) that states the presence of a monotonic trend or reject (Ho), which states that no monotonic trend occurred. The Z-Value represents significant trend in the rainfall data while the Sen's slope estimator (m) shows a magnitude of trend. If the Z_{mk} is greater than zero ($Z_{mk} > 0$) trend is increasing, if Zmk < 0, trend is decreasing and if Z is zero, no trend occurred [32,33]. The positive value of (m) indicates an upward trend on the other hand, a negative value indicates a downward trend. Spatial precipitation data gotten from **T**ropical Applications of **M**eteorology using **SAT**ellite data and ground-based observations (TAMSAT). Monthly total Evapotranspiration (ET) and Surface Runoff value derived using a Variable Infiltration Capacity hydrology model from Laing and his colleagues1994.

3. Results

3.1. Annual Rainfall

Results below were obtained from statistical trend tests and are explained in these sub-divisions; annual and seasonal. From figure 2, time series and trend analysis of the LCB for the period studied shows rainfall value for the months of July to be 2159.19 mm while August is 2583.48mm. These periods (July and August) experienced higher rainfall in the time series which indicates the wet seasons. This can be due to the continuous increase in flow of moist air from the Atlantic Ocean which is in agreement with the work of Lebel [18]. However, lower rainfall was experienced between December and January with rainfall values of 28.54mm and 26.77 mm respectively but generally the temporal trend shows steady increase during this period of review (figure 3)

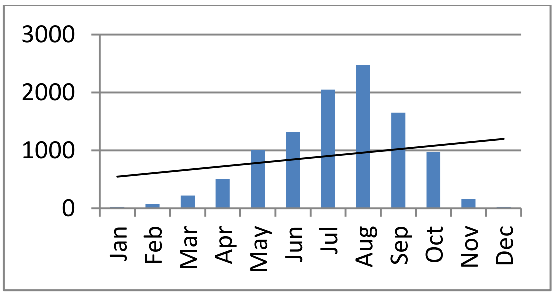

Figure 2: Average monthly rainfall (mm) at *LCB* for the period 2001-2020

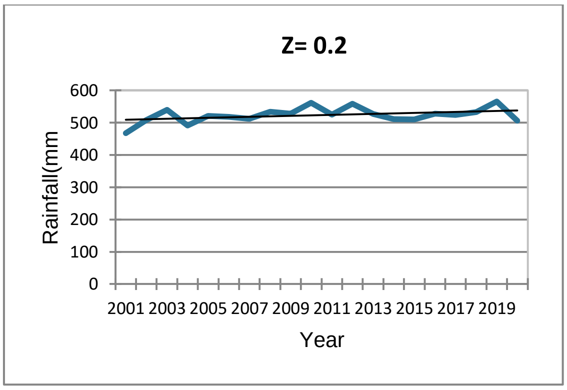

Figure 3: Temporal characteristics (trends) of annual rainfall in the LCB between 2001 and 2020

3.2. Seasonal rainfall

The seasonal rainfall was analyzed using both Mann Kendall and Sen's slope tests and the result had a positive trend for three seasons namely dry, late dry and wet, but had a negative trend for the late wet season. The amount of rainfall for each season is quite slightly different as shown in table 2. Analysis revealed an increasing trend during the dry to wet seasons but shows decrease rainfall in late wet season (Table 2). The figures 4,5,6, shows that the trend of dry to wet seasons were generally positive even though the late wet seasonal rainfall is negative because the rainfall period in receding toward dry season in the LCB. Table 2 shows the results of MK and Sen's Slope tests at 5% (0.05) significance level (means the result is 95% acceptable). The negative trend might be suggesting the decline of rainfall for this season, meanwhile further analysis can be carried out using ground-based data for validating this result.

Table 2: Seasonal and Annual Trend analysis of LCB (Mann Kendall and Sen's slope)

Time Series	Min Rainfall (mm)	Max Rainfall (mm)	Mean	Std Dev	Sen's Slope(m)	Signific. (p)	Mann Kendall (Z)	Rainfall Trend
Dry	1.27	10.9	6.173	3.03	0.14	0.38	0.15	positive
Late Dry	73.70	103.77	86.63	8.75	0.59	0.07	0.29	positive
Wet	268.64	318.67	291.97	14.95	0.93	0.3	0.16	positive
LateWet	111.82	167.55	138.87	13.81	-0.41	0.58	-0.10	Negative
Annual	467.92	566.1	523.62	23.15	1.12	0.2	0.20	positive

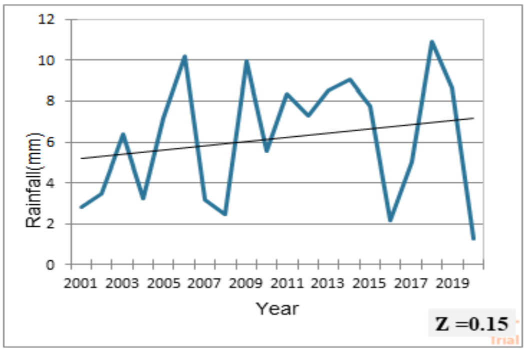

Figure 4: Trend of dry season (2001- 2020)

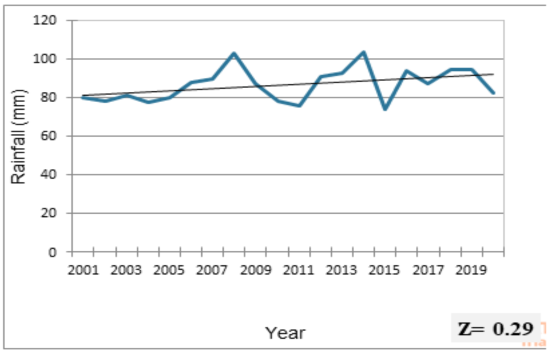

Figure 5: Trend of dry season (2001-2020)

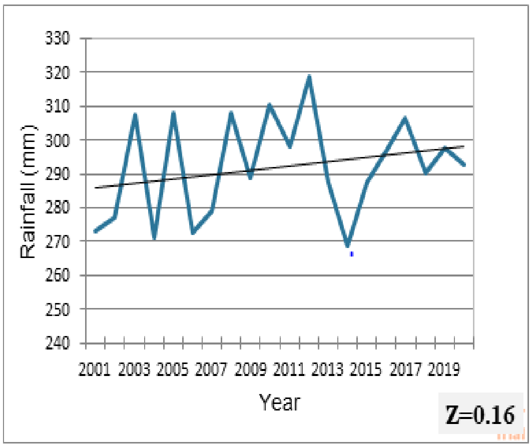

Figure 6: Trend of wet season (2001- 2020)

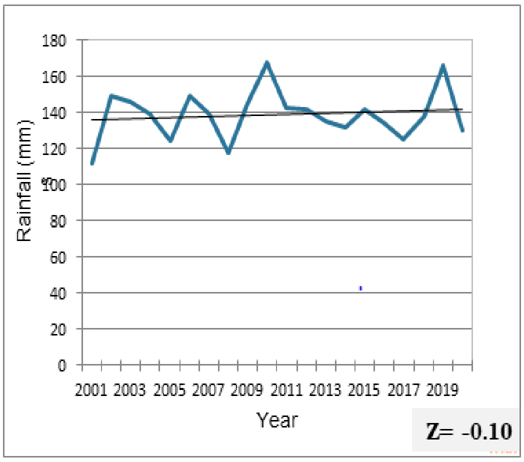

Figure 7: Trend of late wet season (2001- 2020)

3.3. Rainfall Variation, Evapotranspiration and Run Off

Recent study on hydrologic variability model found run-off and evapotranspiration to be extremely sensitive to rainfall variation and these fluctuations have direct impact on Lake Chad level and size [11]. The maps in figures 8 and 9 shows how rainfall reduces towards the northern part of the LCB as revealed in Beauvilain's work [4], that there is a reduction in precipitation of about 100mm for each 100km of distance northwards. The northern part of the LCB showed low rainfall volume and low evapotranspiration while the southern part of LCB has higher precipitation and subsequent high evapotranspiration (figures 8-11). The maximum rainfall for the years under review was in 2019 (566.1mm) and evapotranspiration was highest (355.80mm) in the same year 2019. Runoff was highest in the year 2012 with 3.20mm. Over 60% of the total rainfall in the period review (2001-2020) goes to evapotranspiration while less than 1% goes to runoff as shown in Table 3. This result shows that most of the water coming into the basin disappears reducing the lake inflows which an evidence of climate variability impact on the lake.

Table 3: Annual Rainfall, Evapotranspiration and Runoff (mm) for LCB (2001-2020)

YEAR	Annual RF mm	RF %	Annual ET mm	ET %	Annual RO mm	RO%
2001	467.92	4.47	328.24	5.01	2.43	5.94
2002	508	4.85	315.16	4.81	1.61	3.93
2003	540.31	5.16	346.4	5.28	2.05	5.01
2004	491.34	4.69	317.38	4.84	1.59	3.88
2005	521.06	4.98	334.3	5.10	1.77	4.32
2006	518.14	4.95	331.66	5.06	1.65	4.03
2007	512.14	4.89	320.26	4.88	1.65	4.03
2008	534.2	5.10	303.1	4.62	1.58	3.86
2009	527.55	5.04	304.51	4.64	1.12	2.74
2010	561.48	5.36	322.66	4.92	2.47	6.03
2011	525	5.01	324.9	4.96	2.11	5.15
2012	559.06	5.34	350.15	5.34	3.2	7.82
2013	526.74	5.03	329.83	5.03	2.05	5.01
2014	511.6	4.89	316.66	4.83	1.69	4.13
2015	510.44	4.87	317.26	4.84	1.97	4.81
2016	528.08	5.04	332.05	5.06	1.72	4.20
2017	524.21	5.01	323.44	4.93	2.51	6.13
2018	532.57	5.09	335.3	5.11	2.07	5.06
2019	566.1	5.41	355.8	5.43	3.04	7.43
2020	506.46	4.84	347.45	5.30	2.66	6.50
	10472.4	100.00	6556.51	100.00	40.94	100.00

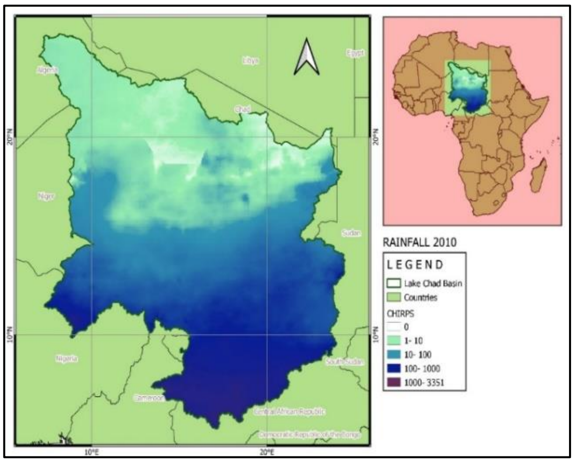

Figure 8: Rainfall Map of LCB for 2010 (climate

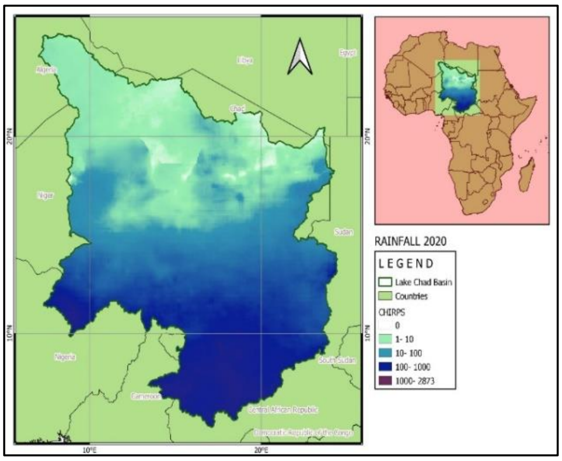

Figure 9: Rainfall Map of LCB for 2020 (climate

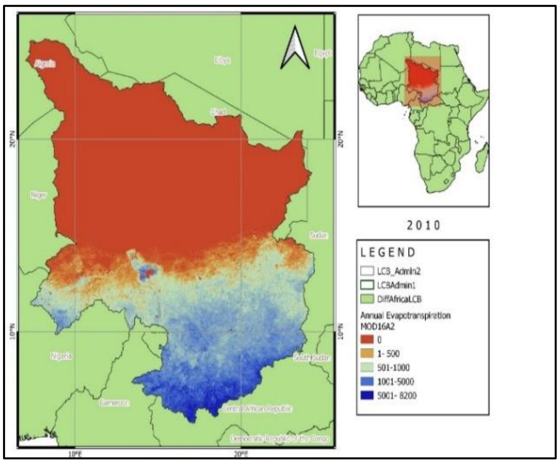

Figure 10: Evapotranspiration Map of LCB for 2010 (climate engine)

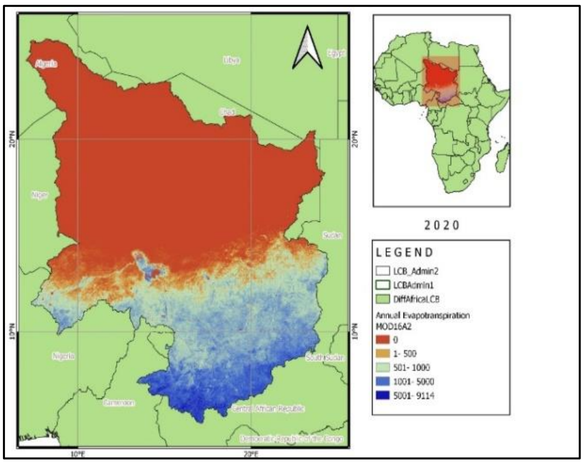

Figure 11: Evapotranspiration Map of LCB for 2020 (climate engine)

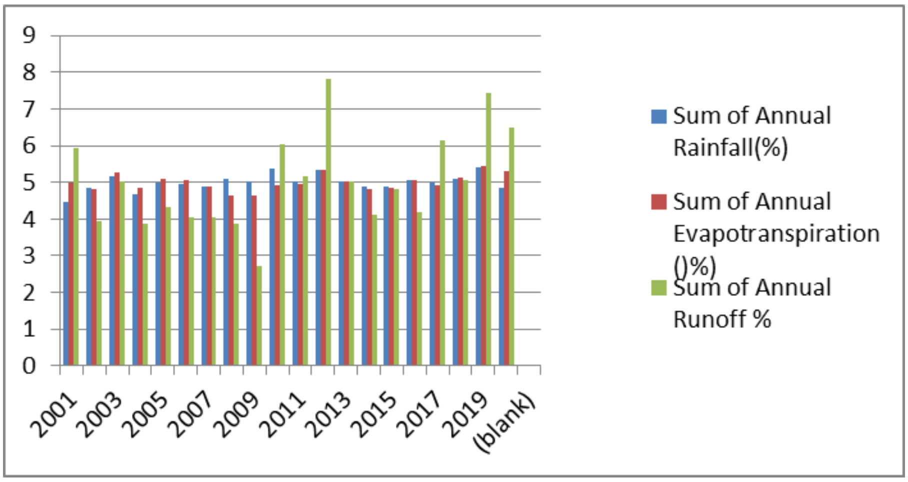

Figure 12: Percentage annual rainfall, evapotranspiration and runoff

4. Conclusion

The result of the study showed yearly and seasonal variability of rainfall pattern. Monthly statistical analysis showed the months of July and August had the highest amount of rainfall while the months of December and January had the lowest amount of rainfall. Analyses showed positive (increasing) trend for annual and seasonal except the late wet season that has a slight negative (deceasing) trend which is an indication of receding rainfall toward dry season. The statistical analysis of the whole series data indicated that the average annual rainfall of the study area is 523.62 mm with maximum average annual as 566.1mm and minimum average annual amount of rainfall as 467.92 mm. Rainfall is significant to evapotranspiration and runoff as statistics shows both variables are dependent on rainfall. The total rainfall during the period under review is 10,472.4mm while the total evapotranspiration for the period is 6556.5mm (above 60% of the rainfall) and less than 1% runoff of the rainfall occurred during the period of review in the LCB. Rainfall is an important hydro climatic factor that contributes greatly to the LCB and the surface water especially the impact it has on the evapotranspiration. Increasing rainfall trend is a positive implication for water management and agricultural practices because changes in basin's water resources are strongly influenced by Precipitation and Evaporation. The limitation of this study is lack of ground-based data. Satellite data was used for this study which allows for coverage over the entire LCB within the desired time but validation of the study could not be a certain because of insecurity and lack insitu climate data. Therefore, Lake Chad's sustainability and water resources management strategy should incorporate the access to ground-based Scientific Measurement Networks according to Charles Ichoku[34]. Further research detailing the direct impact of the climate variability on the lake would be beneficial to understanding the relationship of hydroclimatic condition of the basin.

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