

IMPACT OF CLIMATE CHANGE ON SURFACE WATER RESOURCES IN KADUNA RIVER BASIN, NIGERIA

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ABSTRACT

Climate change impact on surface water resources of Kaduna River basin (KRB) were investigated from 1984 to 2021. To achieve the aim, the study set out the following objectives: assess the spatial distribution of water balance and assess the hydrological characterization of Kaduna River basin. The meteorological data for the study were sourced from twelve remotely sensed stations around Kaduna State for 37 years, from National Aeronautics and Space Administration (NASA), the Thornthwaite and Mather (TM) Model, runoff coefficient, analysis of variance (ANOVA) and correlation were used to discern the pattern and distribution of climatic elements and testing hypothesis considered in the study. The result indicated that: Rainfall intensities interpolated revealed an increasing length of return periods for all the stations. The temporal differences between P-PET have shown a similar pattern in the State, whereby there was an increase from May to October which indicates a positive value that reveals excess water because of the rainy season while November to April indicate negative values because of the dry season which implies water deficit. Only the month of March in Kaduna Central Catchment Area has a positive value of 77.72mm in the dry months. There was fluctuation of water bodies throughout the period under study and is attributable to increase in population and anthropogenic activities that has resulted in climate variability instead of climate change. The work recommends an awareness programme on climate variation challenges in various States and regions of Nigeria.

Keywords: *Climate Change, Surface water, Water balance, Trend, KRB*

1. INTRODUCTION

Climate change is the latest challenge to sustainable human development in the 21st century and the scientific evidence is clear where the globe is facing a real and serious long-term threat from climate change (Shah, 2018). It is known and established in literature that there is an inherent relationship between climate change and water resources. This is even more so as empirical studies in recent times have shown the impact of the former on the later (Hagemann *et.al.* 2013). Water resources of the world in general are under heavy stress due to increased impact of climate change but the severity of the impact varies from one region to another (Adam *et al.*, 2019).

According to the Intergovernmental Panel on Climate Change (IPCC) (2014c), climate change is defined as “change in the state of the climate that can be identified by changes in the mean or the

variability of its properties, and that persists for an extended period of time, typically decades or longer”. It refers to any change in climate over time, whether due to natural variability or because of human activity. This usage differs from that of the United Nations Framework Convention on Climate Change (UNFCCC) (2012), where climate change refers to a “change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable periods of time”. However, this study adopts the IPCC (2014c) definition. Additionally, Ifeanyi-obi *et al.*, (2012), refers to climate change as the changes in modern climate, including the rise in average surface temperature known as global warming.

Climate change is likely to have negative impacts on the targets set out by United Nation on achieving Sustainable Development Goals (SDG) (Goal 6, ensure available and sustainable management of water resources) in combating climate change impacts on availability and sustainable water resources (UN, 2018; Guterres, 2018a; FGN, 2016). Climate change will affect the nature and characteristics of the freshwater resources on which people depend on. The impacts will vary between eco-zones, exacerbating existing problems of too much water (floods), inadequate water (droughts) and reduced water quality (salt-water intrusion). Climate change impacts, including sea level rise and extreme weather, will also affect coastal, marine areas and water resources will also affect fisheries, the main source of livelihoods and protein for riverside and coastal rural communities. Climate change in recent decades have impacted on natural and human systems in all continents including water resources (IPCC, 2014a; Guterres, 2018b). IPCC (2014a) also revealed that evidence of climate change impacts is strongest and most comprehensive for natural systems. In many regions, changes in precipitation or melting snow and ice are altering hydrological systems, affecting both quantity and quality of water resources. In high latitude and high elevation regions, climate change is also causing permafrost warming and thawing. Climate change impacts according to the IPCC (2014a) report refer to the effects of extreme weather and climate events and of climate change on natural and human systems. Climate change can have positive as well as negative impacts, but negative or adverse impacts are projected to predominate for much of the world. For example, IPCC (2014a) reported that the negative impacts of climate change on water resources affects crop yield more than the positive impacts. The positive impacts mainly to high-latitude regions.

A Comparative assessment of freshwater resources by the World Meteorological Organization cited by Babatolu and Akinnubi (2014) estimated that up to two-thirds of the world’s population would be living in water-stressed countries by 2025 because of climate change impact. In addition, another estimate shows the proportion of the African population at risk of water stress and scarcity increasing from 47% in 2000 to 65% in 2025 (Arnell, 2004). Hulme *et al.* (2001), observed the past Africa climate change scenarios from (1900 -2000) as well as possible future (2000 – 2100) continent-wide changes in temperature and rainfall for Africa and concluded that the climate was warmer in the year 2000 than it was in 1900. This has occurred at the rate of about 0.5°C and the 6 warmest years have occurred since 1987 with 1998 being the warmest year. The 21st century picture remains almost the same with predicted annual warming across Africa of slightly below 0.2°C per decade to over 0.5°C per decade (Hulme *et. al*, 2001).

Water is an indispensable element of life; the water resources of river basins are highly dependable and sensitive to climate variability and change; due to interconnection between the climate system and hydrological cycle. Thus, if the trends in climate contexts that took place over the last three decades continue to prevail unabatedly, West Africa will no doubt experience decreased freshwater availability and will negatively affect food production (Ayansina *et al.*,

2018). Also, compared to previous decades, it is observed that since the early 1970s, the mean annual rainfall has decreased by 10% in the wet tropical zone to more than 30% in the Sahelian zone while the average discharge of the region's major river system dropped by 40 to 60% (Yunana, *et al.*, 2017). This sharp decrease in water availability will be complicated by greater uncertainty in the spatial and temporal distribution of rainfall and surface water resources (Guoyong *et al.*, 2016).

With the warm increase across Africa, Nigeria inclusive because of climate change, the achievement of universal and equitable access to safe and affordable drinking water for all and increase water use efficiency across all sectors with sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity by 2030 in other to attain the SDGs in Nigeria will be a challenge. Being largely endowed with surface and groundwater resources, Nigeria is well drained with a close network of streams and rivers (Muta'a, 2012). But the task of providing water for the citizens has been quite elusive for over three decades now (Okeola, 2014). Moreover, degradation of water quality remains most severe in the four states (Lagos, Rivers, Kano and Kaduna) containing 80% of the nation's industries (Ebiare, 2010; Taiwo, 2012). As a result, Nigeria (Kaduna State precisely) has failed to attain the Millennium Development Goals (MDGs) set target of 75% for improved water access in 2015 (Bademosi, 2015; Merem *et al.*, 2017). This is compounded by the drying of rivers, lakes and streams due to droughts and climate change impacts that negatively contribute to water resources decline.

Based on the studies carried out by (Attah, 2013; Abaje *et al.*, 2016; Chinwendu *et al.*, 2017; Okafor and Ogbu, 2018; Ologunorisa *et al.*, 2021; Danbaba, 2023). There is no study that link changes in climate on surface water resources and the validation of these detected changes in the GIS environment. There is still a gap between hydrological changes in KRB as result of climate variability and the tremendous importance of water for both societal needs which will be considered in the context of the local Agro-ecological and production conditions present for any area in Kaduna River basin. Moreover, the linkage between climatic changes and surface water fluctuations is poorly documented in this area.

2. MATERIAL AND METHODS

Description of the Study Area

The study area is the Kaduna River Basin (KRB) located between latitudes, 8°45'15"N and 11°40'5"N and longitudes 5°25'48"E and 8°45'36"E in the Guinea and Sudan savannah ecological zone of North-West Nigeria (Oladipo, 1993; KDBS, 2019). KRB has two segments of upstream and downstream and a total catchment area of approximately 65,878km² with its headwater near the north-eastern edge of the Jos Plateau at Sherri Hills. The larger parts of upstream of KRB are found in Kaduna State which is bordered by Katsina and Kano States to the north; Bauchi State to the east; Plateau State to the southeast and this study is mainly in the upstream of the basin while the downstream is found in Niger State (Figure 1).

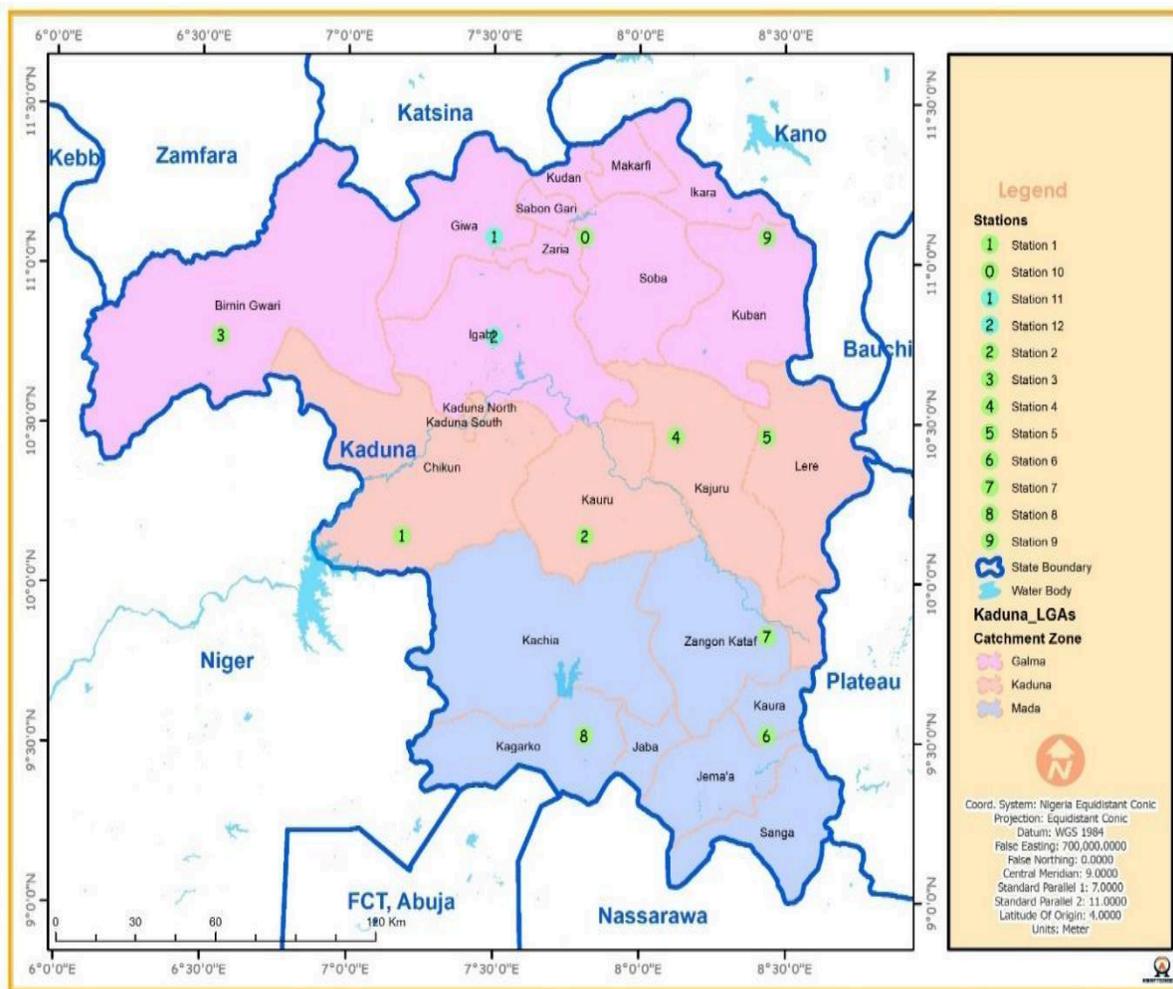


Figure 1: Map of Catchment Areas/ Remotely Sensed Stations within Kaduna State.

The basin's general climatic condition is similar to tropical continental (Aw) characterized by a well-defined wet and dry season climate, strong seasonality in rainfall and temperature distributions (Koppen, 1928). The mean annual rainfall can be as high as 2000 mm in wet years and as low as 500 mm in drought years but with a long-term average of 1000 mm and average annual temperature of 27.48°C (NiMET, 2020). The 550km² long River Kaduna is the third-longest river in the country after Rivers Niger and Benue. Most of River Kaduna's course passes through open savanna woodland but its lower section cuts several gorges above its entrance into the extensive Niger floodplains. The KRB is an important food-producing region, responsible for more than half of Nigeria maize production, among other crops (Agronews, 2019; KDBS, 2019). Additionally, users of the KRB depend on the system for irrigation farming, fishing, industrial uses, drinking water, recreation, navigation, hydro-electricity generation and wildlife habitat. Although its highest headwater is free-flowing and is the only river feeding Shiroro Dam (Chinwendu *et al.*, 2017).

Types and Source of Data

Secondary sourced data records were taken for thirty-seven years (1984-2021) temperature, rainfall, relative humidity, solar radiation and Kaduna State boundary map was also obtained. The climatic data were obtained from NASA (National Aeronautics and Space Administration) through the net, <http://power.larc.nasa.gov/data-access-viewer/> this is because the climatic data were only available till the end of 2021. The Data were collected from twelve (12) remotely sensed stations around Kaduna State (Figure 1).

This study utilizes land use data from remotely sensed Satellite Imageries that covered 37 years (1984 – 2021) from United States Geological Survey (USGS).

Table 1: Source of Data Sets

S/N	Data Type	Resolution (m)/Scale	Date	Sources
Satellite Imageries				
1.	Landsat TM imagery	30m	25/10/1984	United States Geological Survey USGS
2.	Landsat TM imagery	30m	5/11/1994	USGS
3.	Landsat TM imagery	30m	21/12/2004	USGS
4.	Landsat ETM imagery	30m	12/11/2014	USGS
5.	Landsat8 imagery	30m	12/12/2021	USGS
6.	Kaduna State Boundary map	1:50,000		NCRS

(Source: Field Survey, 2024)

The Thornthwaite and Mather (TM) Model

Monthly potential evapotranspiration (PET) was computed using the following equation to compute the climatic water balance using the Thornthwaite and Mather (TM) model (Thornthwaite and Mather, 1955):

$$PET = 16 \times C \times \left(10 \times \frac{T}{I}\right)^a \dots\dots\dots \text{Eq. 1}$$

Were.

PET = the potential evapotranspiration (mm month¹);

T = the mean monthly temperature (°C).

I = the annual heat index for the 12 months in year ($I = \sum i$).

i = the monthly heat index $\left(i = \left[\frac{T}{5}\right]^{1.514}\right)$;

a = $6.75 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1.792 \times 10^{-2} \times I + 0.49239$

C = a correction factor for each month ($C = [m/30] \times [d/12]$),

Where *M* is the number of days in the month and *d* is the monthly mean daily duration (i.e., number of hours between sunrise and sunset were expressed as the average for the month).

P – PET, which is an estimation of the quantitative water excess (+) or deficit (–) with *P* as precipitation was calculated. Then the accumulated values of (*P – PET*), i.e., the accumulated potential water loss (*APWL*) for each month, were calculated. This will be zero for months having positive (*P – PET*) and starting with the first month having a negative value after the rainy season (Thornthwaite and Mather, 1957). At that point, the actual storage of soil moisture (*STOR*) for each month was determined as follows:

$$STOR = AWC \times e^{\left(\frac{APWL}{AWC}\right)} \dots\dots\dots \text{Eq. 2}$$

Where *AWC* is the moisture storage capacity (i.e., the available water capacity) of the soil. This was calculated based upon the land cover, soil texture and rooting depth as suggested by Thornthwaite and Mather (1955, 1957). The results are summarized in Table 2. Changes of actual storage (ΔSM) for all the months were calculated as:

$$\Delta SM_{\text{month}} = STOR_{\text{month}} - STOR_{\text{previous month}} \dots\dots\dots \text{Eq. 3}$$

A negative value of ΔSM implies subtraction of water from the storage to be used for evapotranspiration, whereas a positive value of ΔSM implies infiltration of water into the soil and its addition to the soil moisture storage.

Table 2: Computation of water holding capacity of the root zone and available water capacities (*AWC*) for different soil textures and land uses

Sn.	Name	Soil Texture	Area (m)	AWC (%)	Rooting	AWC (mm)
1	Water	Sand	16,679.97	10	0.5	83
2	Vegetation	Sandy Loam	928,504.62	15	1.5	300
3	Built Environment	Loamy Sand	312,072.39	10	0.5	50
4	Farmland	Silty Loam	2,641,563.2	20	0.62	125
5	Bare Land	Loamy Sand	26,821.08	10	1	100
6	Rock Outcrop	Sand	496,421.82	10	0.3	20

(Source: Field Survey, 2024)

The actual evapotranspiration (*AET*) was computed for all the months, as given in equations (4) and (5):

$$AET = \Delta SM + P \quad \text{if} \quad \Delta SM < 0 \quad - \quad - \quad - \quad - \quad \text{Eq. 4}$$

$$AET = PET \quad \Delta SM > 0 \quad - \quad - \quad - \quad - \quad \text{Eq. 5}$$

The water deficit (*DEF*) for crop evapotranspiration in each month was calculated for the months having negative ($P - PET$) as follows:

$$DEF = PET - AET \quad - \quad \text{Eq. 6}$$

The amount of excess water that cannot be stored is

denoted as moisture surplus (*SUR*). When storage reaches its capacity, *SUR* is calculated using equation (7):

$$SUR = P - PET \quad - \quad \text{Eq. 7}$$

When the soil storage is not at its capacity, no surplus exists. In a month in which the soil moisture storage capacity is just satisfied, *SUR* is obtained using equation (8):

$$SUR = P - (AET + \Delta SM) \quad - \quad \text{Eq. 8}$$

where ΔSM is the change in actual soil moisture storage.

The available annual surplus should, by definition, equal the actual runoff. The monthly computed surplus is higher than the monthly runoff (RO) because of the delay between the time of precipitation and the time when water passes the gauging station. For large catchments, it can be expected that in any given month, around 50% of the surplus water that is available for runoff goes off (Thornthwaite and Mather, 1957). The remainder of the excess is stored in the basin's subsurface, groundwater, tiny lakes, and channels and is ready for runoff throughout the course of the following month.

Considering the area used for various land uses and the corresponding values from the monthly water balance table, the annual amount of real evapotranspiration and runoff from the watershed was computed. Area-weighted data represents the monthly real evapotranspiration and runoff from each catchment area.

Runoff Coefficient

The runoff coefficient is the ratio of that portion of the total precipitation which flows on the surface that reaches the stream channel to the catchment total precipitation. The higher the value the higher the runoff expected at a gauge location and the less the infiltration and other losses. The runoff coefficient has been estimated by using the equation.

$$C = R/P \quad \text{Eq. 9}$$

Where:

C = runoff coefficient

R = total runoff (mm)

P = total precipitation (mm)

Analysis of variance (ANOVA) is one such technique that may assess, if there are statistically significant variations between the means of several groups based on a sample of data. ANOVA may also determine the likelihood of getting a result as severe or more extreme than the observed one by chance alone, or the p-value, for each comparison. Assuming there is no difference between the groups, a p-value near to zero suggests strong evidence against the null hypothesis, whereas a p-value close to one implies weak evidence. Pearson Product Moment correlation (r_p) was used to test for the relationship between climatic elements and other derived variables. The SPSS software package was used for the analyses.

3. RESULTS AND DISCUSSION

Accumulated Potential Water Loss (APWL)

From Table 3, Thornthwaite and Mather (TM) Model shown in equations (1,2,3, 4,5,6,7 and 8), the monthly precipitation, potential evapotranspiration (PET), difference between precipitation and potential evapotranspiration (P – PET) and accumulated potential water loss (APWL) from monthly precipitation and temperature was calculated across the three (Galma, Kaduna Central and Amere/Mada) catchment areas in KRB and presented in Table 3.

Table 3: Accumulated Potential Water Loss at catchment area in KRB.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Galma Catchment Area (GCA)												
<i>P</i>	0.00	0.00	39.03	15.90	258.4 3	727.5 8	1378. 21	794.3 1	649.4 0	204.8 4	0.00	0.00
<i>PET</i>	79.21	93.42	113.8 5	132.2 0	126.8 7	87.08	63.08	59.26	64.48	73.34	70.1 9	59.33
<i>P</i> – <i>PET</i>	-79.21	-93.42	-74.82	-116.3 0	131.5 6	640.4 9	1315. 13	735.0 6	584.9 2	131.5 0	-70. 19	-59.33
<i>APW</i> <i>L</i>	-208.7 3	-302.1 5	-376.9 7	-493.2 8	0.00	0.00	0.00	0.00	0.00	0.00	-70. 19	-129.5 2
Kaduna Central Catchment Area (KCCA)												
<i>P</i>	0.00	0.00	204.3 5	52.26	794.6 2	1289. 87	1443. 82	945.1 9	1008. 65	384.8 1	0.00	0.00
<i>PET</i>	97.16	111.99	126.6 3	124.3 8	120.6 8	70.54	57.33	60.96	61.02	69.00	67.5 3	64.22
<i>P</i> – <i>PET</i>	-97.16	-111.9 9	77.72	-72.12	673.9 3	1219. 33	1386. 49	884.2 3	947.6 3	315.8 0	-67. 53	-64.22
<i>APW</i> <i>L</i>	-228.9 0	-340.8 9	-263.1 7	-335.3 0	0.00	0.00	0.00	0.00	0.00	0.00	-67. 53	-131.7 4
Amere/Mada Catchment Area (MCA)												
<i>P</i>	0.00	0.00	93.16	67.70	484.0 9	793.5 9	814.0 5	484.3 8	625.9 1	268.0 4	0.00	0.00
<i>PET</i>	98.90	110.7 6	122.3 5	117.1 9	103.9 6	70.66	57.66	57.73	60.36	65.75	62.6 5	66.96
<i>P</i> – <i>PET</i>	-98.90	-110.7 6	-29.19	-49.48	380.1 4	722.9 3	756.3 9	426.6 5	565.5 5	202.3 0	-62. 65	-66.96
<i>APW</i> <i>L</i>	-98.90	-209.6 6	-238.8 5	-288.3 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Researcher’s Analysis, 2024

The result in Table 3, revealed that the onset of rain occurred in the month of March while the cessation of rain occurred in the month of October. The rain begins to stabilise in the month of May which indicates that the acceptable duration of the rainy season covers the months of May to October which could be regarded as the length of growing season in the KRB. The finding is in tandem with Oladipo (1993), who asserts that the month’s state above the study area receives over 85% of its annual rainfall total.

The precipitation data over the last thirty-seven years (1984-2021) shows relatively dry season months from November to April across the three catchment areas which is due to the peak of the catastrophic Sahelian drought with little precipitation in the month of March in KCCA area having a monthly average precipitation of 204.35mm but the mean monthly summation of precipitation has a symmetrical increasing pattern from May to October every year used. This implies that KRB is gradually getting drier and highly variable in daily, monthly and annual precipitation received.

The bulk of the rains still occur between these months with the peak being reached in July having the peak of rainy season for the three catchment areas with Galma-1378.21mm, Kaduna

Central-1443.82mm and Amere/Mada- 814.05mm respectively (Table 3). All the catchment areas have a one-peaked rainfall regime. This has not changed from what it has been over time, but the rainfall distribution and occurrences sometimes come earlier or later. The increase in the monthly precipitation yield in the period understudy was predominantly because of the substantial increase in July and August precipitation for both Galma and Kaduna Central catchment areas and in June and July rainfall for Amere/Mada Catchment Area has indicated by the statistically significant wetter conditions of those months. The increase in rainfall supply of these three months, especially in July and August, corresponds with the frequent occurrences of August floods in the study area. This agrees with the finding of Abaje *et al.*, 2013; Ologunorisa *et al.*, 2021; Danbaba, 2023) which asserted that the months have been witnessing increasing annual rainfall totals. There is no year rain was totally absent in the period understudy. Thus, what was noticed throughout was climate variation and not climate change.

On the other hand, the distribution of PET as an opposite pattern from precipitation with an increased value from January to May across the three catchment areas of the KRB, as mentioned before there is a positive relationship between temperature and potential evapotranspiration, thus high relative humidity rates in the months of June to December in the study area is due to its geographic location within tropic and its climate condition which reduce the mean monthly temperatures as well as the potential evapotranspiration consequently.

The temporal differences between P-PET have shown a similar pattern in the KRB, whereby there was an increase from May to October which indicates a positive value that reveals excess water because of the rainy season while November to April indicate negative values because of the dry season which implies water deficit. Only the month of March in KCCA has a positive value of 77.72mm in the dry months.

The difference in the hydrological conditions in the Galma, Kaduna central and Amere/Mada catchment areas can be seen from the calculated accumulated potential water loss (APWL) value. The final APWL values of the three catchment areas revealed that, from the months of November to April, areas in both Galma and Kaduna central catchment areas have negative values and January to April are equally negative in Mada Catchment Area. Subsequently, May to October in both Galma and Kaduna Central catchment areas have zero values while in the case of Mada catchment area, months of May to December have zero values which showed a positive value. The values in the study area revealed that the potential water loss is less in Mada catchment area than Galma and KCCA. This means that the Southern part of the State has good water preservation potential, whereas Northern and the Central parts need to manage their water resources more carefully. The finding of the study agrees with Adam *et al.*, (2019), which posited that the driest month of the year has deficit values, potential water loss, higher evapotranspiration and lower water holding capacity.

Run-off

1. Galma Catchment Area (GCA)

The study revealed that the Galma catchment area receives an average precipitation of 1256.96mm annually with the lowest recorded annual precipitation being 533.68mm in 2004 and the highest recorded annual precipitation was 4219.72mm in 2021. It was also evident that annual precipitation recorded in the wet season (1199.56mm on average annually) is higher than that of dry season (57.40mm on average) in the Catchment Area (figure 3). The study also revealed that precipitation is at its highest during the wet season.

The study observed runoff in Galma catchment area to 486.07mm on average annually throughout the study period with 0.00mm (i.e., the least annual runoff recorded in 2004), and

majority of dry season with little to no runoff but only in 1994 with runoff of about 125.41mm in dry season. Thus, the study reveals that runoff primarily occurs in the wet season with the highest runoff of 2896.86mm in 2021 (figure 3).

The table shows the runoff coefficients for each year. Generally, higher runoff coefficients are observed during the wet season months of each year, particularly in September and October, with values of 60% and 73%, respectively. It was also revealed that the least runoff coefficient of less than 1% was recorded in the year 1999 and 2004. This suggests that a significant portion of the precipitation during the wet season contributes to runoff rather than being absorbed by the soil (figure 2). The months with the highest precipitation area July, August and September in the catchment area.

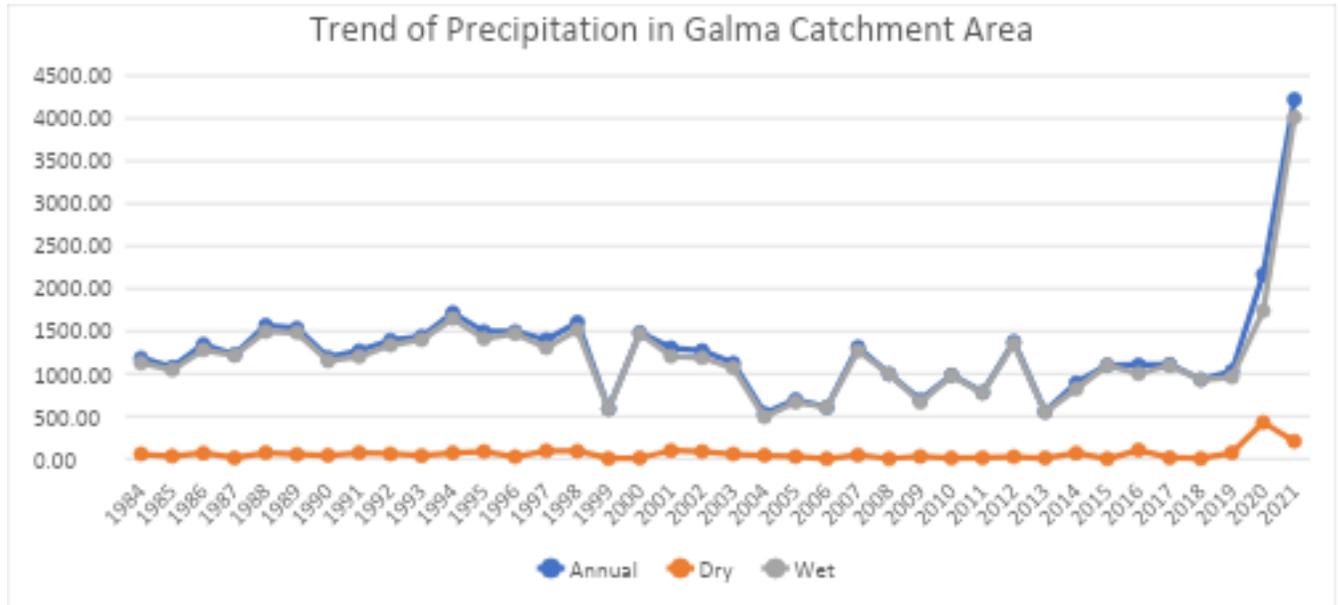


Figure 2: Trend of Annual, Dry season and Wet Season Precipitation in GCA

Figure 2, displays the graphical trend of annual, dry season, and wet season statistics of precipitation in the Galma Catchment area. The graph shows the trend of precipitation over time, indicating the variations in rainfall patterns throughout the years with 2021 with the highest precipitation and the wet season line following the same pattern with the rainfall. The different lines represent the annual, dry season, and wet season precipitation.

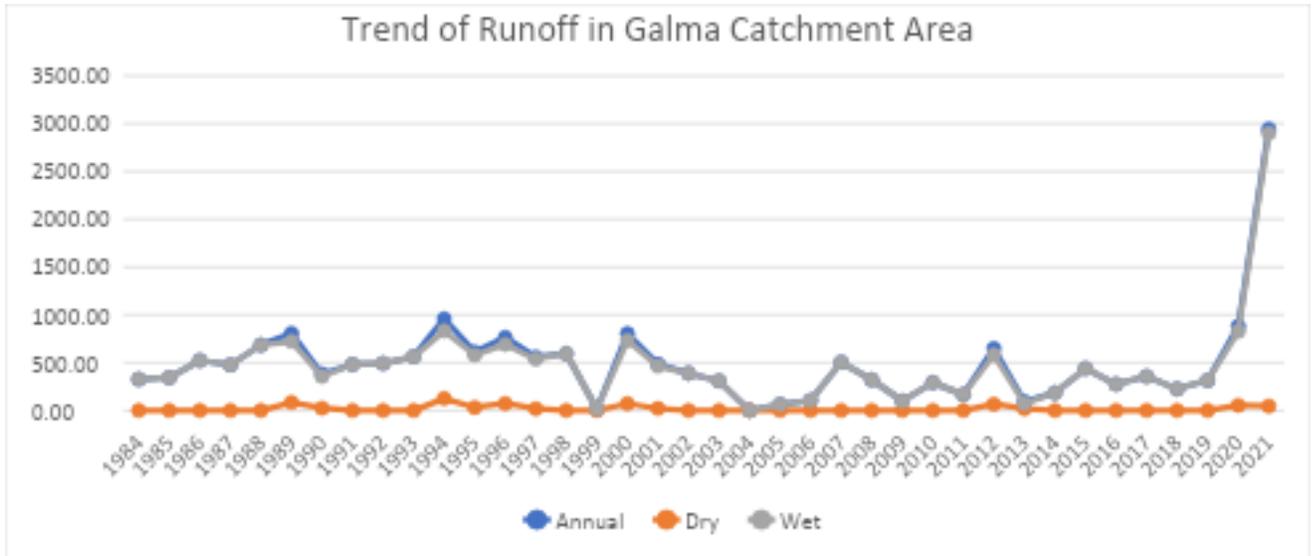


Figure 3: Trend of Annual, Dry season and Wet Season Precipitation in GCA.

Figure 3, presents the graphical trend presentation of the annual, dry season, and wet season statistics of runoff in the Galma Catchment area. This graph illustrates the trend of runoff over time, indicating the variations in the amount of water flowing out of the catchment area. The different lines represent the annual, dry season, and wet season runoff.

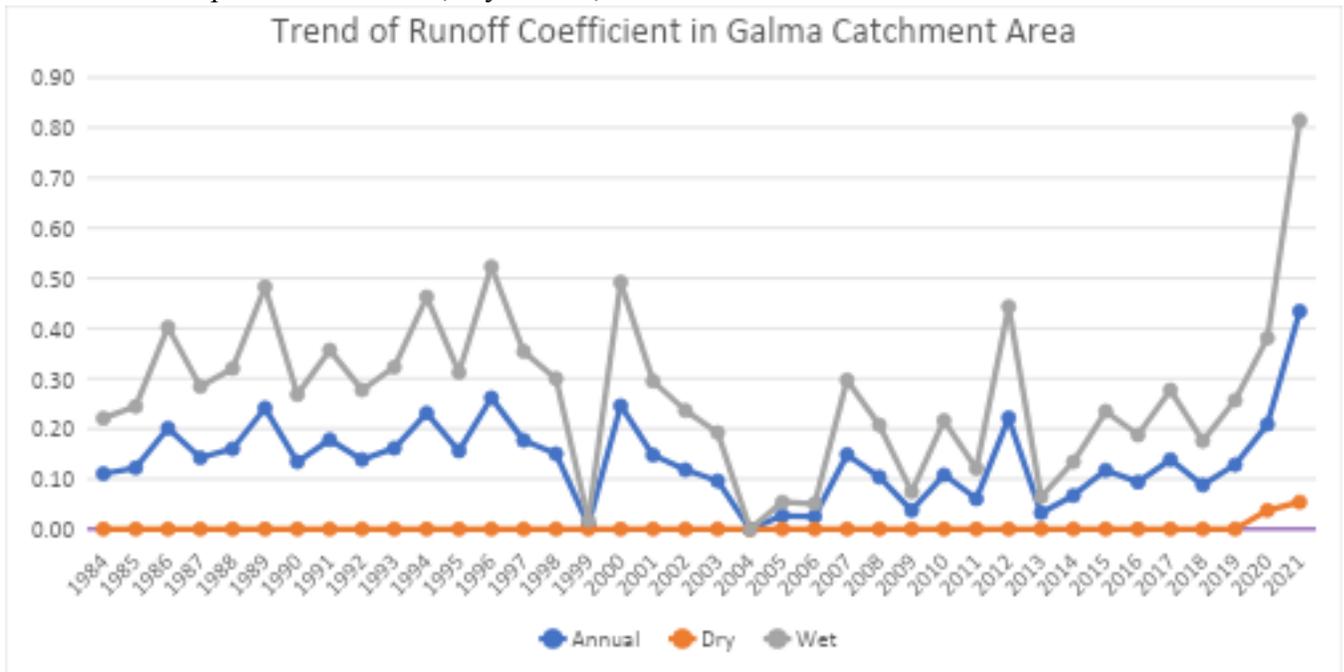


Figure 4: Trend of Annual, Dry season and Wet Season Runoff Coefficients in GCA.

Figure 4 shows the graphical trend presentation of the annual, dry season, and wet season statistics of runoff coefficient in the Galma Catchment area. The runoff coefficient represents the ratio of runoff to precipitation and provides insights into the efficiency of water retention in the

Catchment area. The graph displays the variations in the runoff coefficient over time for the annual, dry season, and wet season in the Catchment area.

The annual precipitation in Kaduna catchment area is shown for the entire period. The study revealed that Kaduna catchment area receives an average precipitation of 1521.87mm annually with the lowest recorded annual precipitation being 531.3mm in 1999 and the highest recorded annual precipitation was 6584.55mm in 2021. It was also evident that annual precipitation recorded in the wet season (1386.71mm on average annually) is higher than that of dry season (133.27mm on average) in the catchment area. The year 2020 was revealed to have an abnormal ratio for highest precipitation in the dry season (i.e., 1429.10mm) than in the wet season. The study also revealed that precipitation is at its highest during the wet season. The study observed runoff in Kaduna catchment area to be 750.04mm on average annually through the study period with 10.1mm (i.e., the least annual runoff recorded in 1999), and majority of dry season with little to no runoff. Thus, the study reveals that runoff primarily occurs in the wet season with the highest runoff of 4588.91mm in 2021 (figure 4).

The table shows the runoff coefficients for each year. Generally, higher runoff coefficients are observed during the wet season months of each year, particularly in July and August, with values of 60% and 73%, respectively. It was also revealed that the least runoff coefficient of 1% was recorded in the year 1999 and 2004. This suggests that a significant portion of the precipitation during the wet season contributes to runoff rather than being absorbed by the soil (figure 4). The months with the highest amount of precipitation are July, August and September throughout the years in the catchment area.

2. Kaduna Central Catchment Area (KCCA)

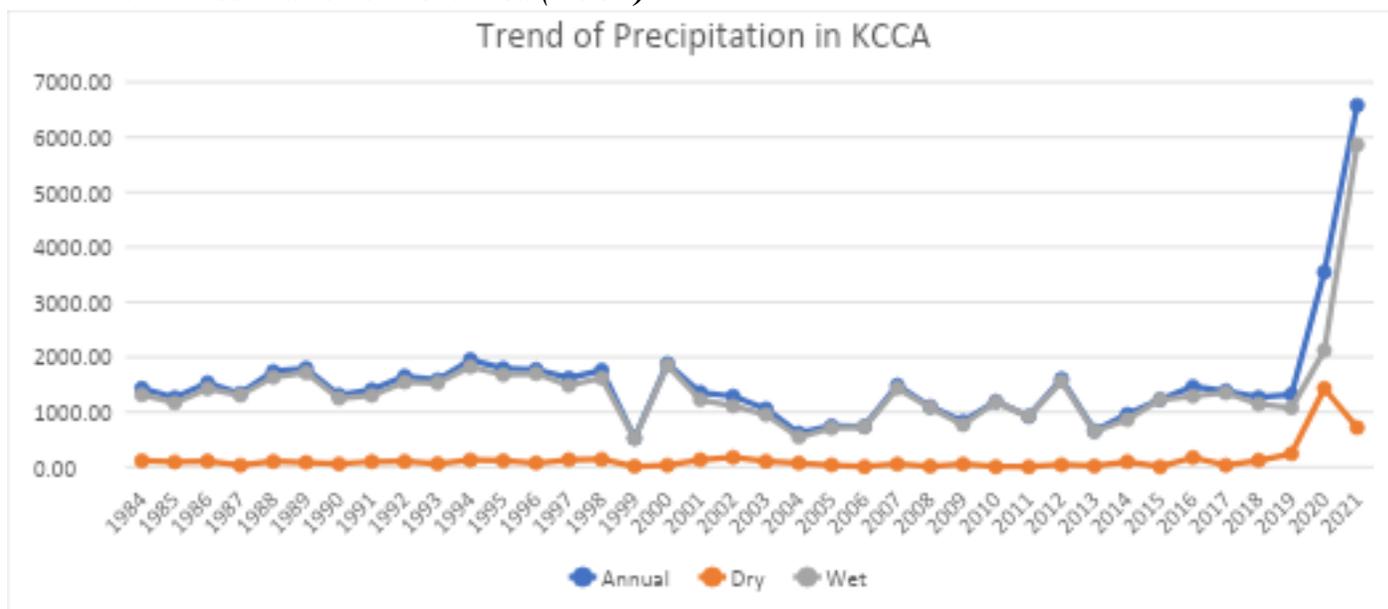


Figure 5: Trend of Annual, Dry season and Wet Season Precipitation in KCCA.

Figure 5, displays the graphical trend of annual, dry season, and wet season statistics of precipitation in the KCCA. The graph shows the trend of precipitation over time, indicating the variations in rainfall patterns throughout the years. The different lines represent the annual, dry season, and wet season precipitation.

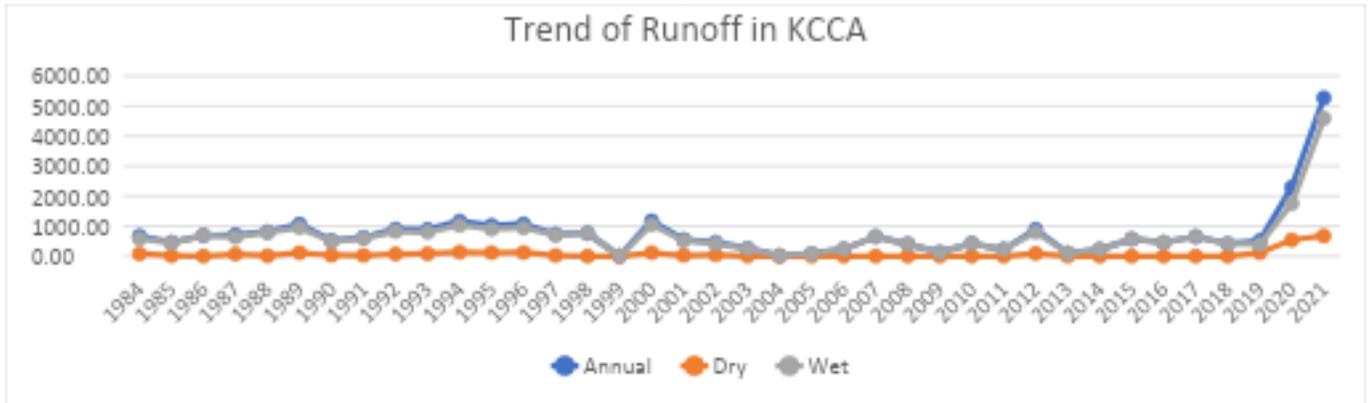


Figure 6: Trend of Annual, Dry season and Wet Season Runoff in KCCA.

Figure 6, presents the graphical trend presentation of the annual, dry season, and wet season statistics of runoff in the Kaduna catchment area. This graph illustrates the trend of runoff over time, indicating the variations in the amount of water flowing out of the catchment area. The different lines represent the annual, dry season, and wet season runoff.

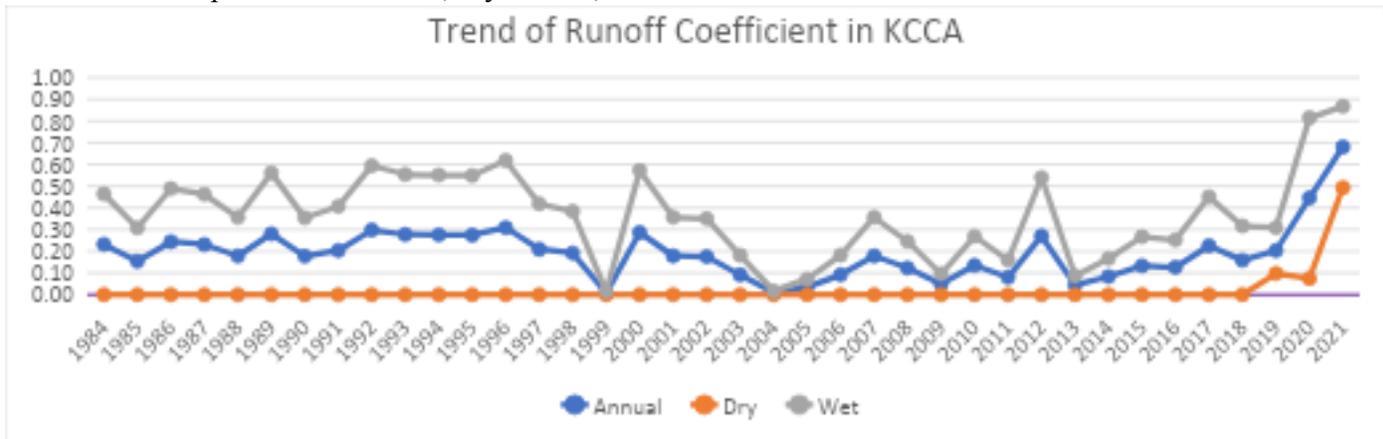


Figure 7: Trend of Annual, Dry season and Wet Season Runoff Coefficient in KCCA

Figure 7, shows the graphical trend presentation of the annual, dry season, and wet season statistics of runoff coefficient in the Kaduna Catchment Area. The runoff coefficient represents the ratio of runoff to precipitation and provides insights into the efficiency of water retention in the catchment area. The graph displays the variations in the runoff coefficient over time for the annual, dry season, and wet season.

The study revealed that the catchment area receives an average precipitation of 4081.99mm annually with the lowest recorded annual precipitation being 416.59mm in 2004 and the highest recorded annual precipitation was 4041.97mm in 2021. It was also evident that annual precipitation recorded in the wet season (1162.20mm on average annually) is higher than that of Dry season (126.85mm on average) in the Catchment Area (figure 5). The study also revealed that precipitation is at its highest during the wet season. The study observed runoff in the catchment area to 238.76mm on average annually throughout the study period with -30.26mm (i.e., the least annual runoff recorded in 2004), and majority of dry season with little to no runoff but only in 1994 with runoff of about 832.86mm in dry season. Thus, the study reveals that

runoff primarily occurs in the wet season with the highest runoff of 2975.56mm in 2021 (figure 6).

The Table 7, shows the runoff coefficients for each year. Generally, higher runoff coefficients are observed during the wet season months of each year, particularly in September and October, with values of 60% and 73%, respectively. It was also revealed that the least runoff coefficient of less than 1% was recorded in the year 1999, 2004, 2009 and 2013. This suggests that a significant portion of the precipitation during the wet season contributes to runoff rather than being absorbed by the soil (figure 5). The months with the highest precipitation are July, August and September in the catchment area.

3. Amere/Mada Catchment Area (A/MCA)

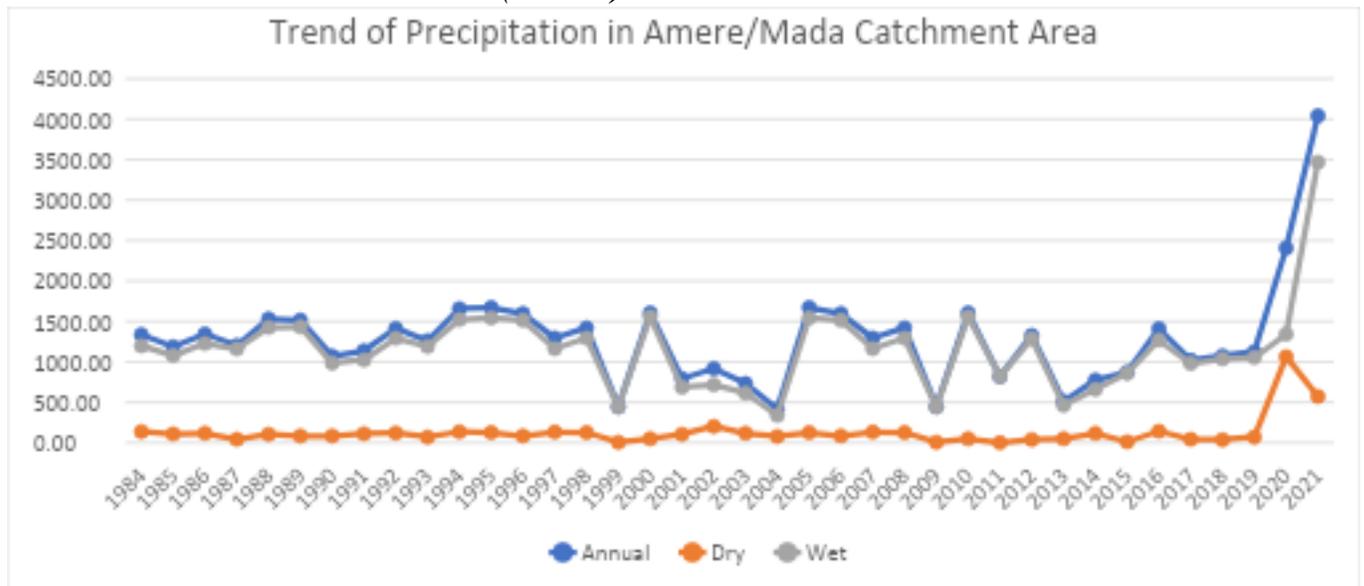


Figure 8: Trend of Annual, Dry season and Wet Season Statistics of A/MCA

Figure 8, shows the graphical trend of annual, dry season, and wet season statistics of precipitation in A/MCA. The graph shows the trend of precipitation over time, indicating the variations in rainfall patterns throughout the years with 2021 as the highest precipitation and the wet season line follows the same pattern with the rainfall. The different lines represent the annual, dry season, and wet season precipitation.

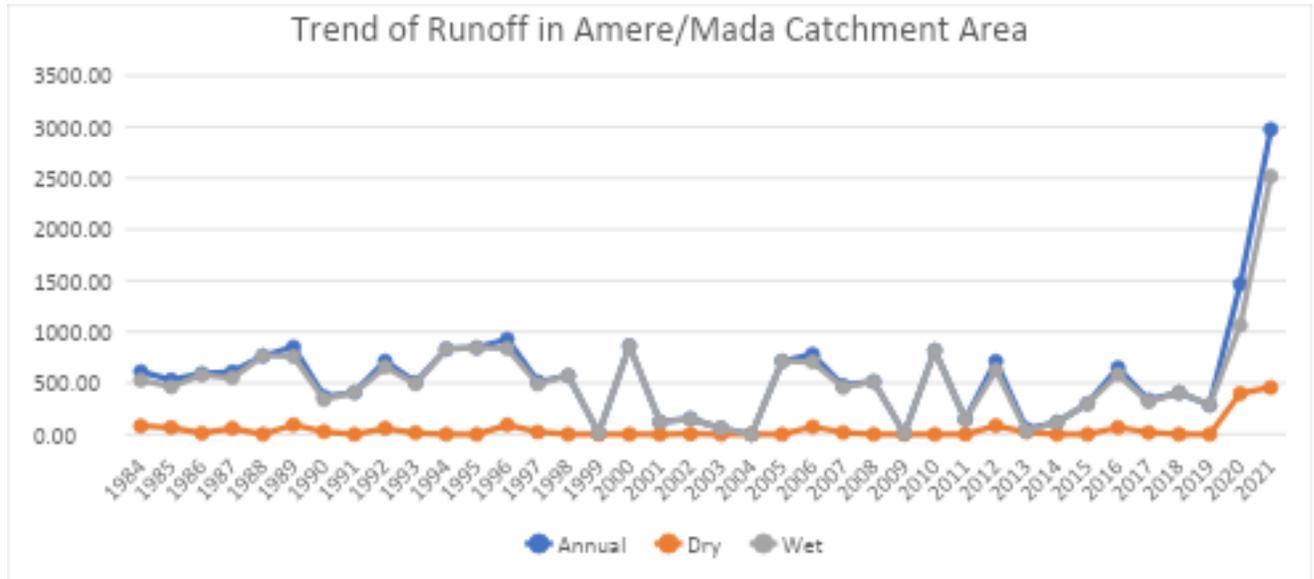


Figure 9: Trend of Annual, Dry season and Wet Season Runoff in A/MCA.

Figure 9, presents the graphical trend presentation of the annual, dry season, and wet season statistics of runoff in the A/MCA. This graph illustrates the trend of runoff over time, indicating the variations in the amount of water flowing out of the catchment area. The different lines represent the annual, dry season, and wet season runoff.

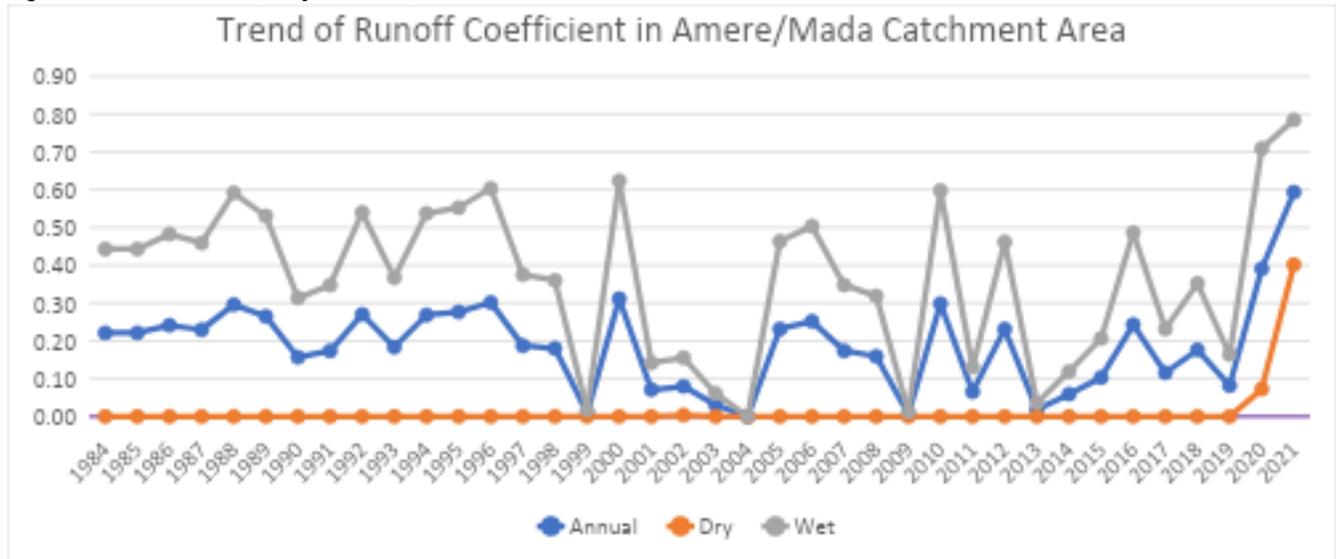


Figure 10: Trend of Annual, Dry season and Wet Season Runoff Coefficient in A/MCA.

Figure 10, shows the graphical trend presentation of the annual, dry season, and wet season statistics of runoff coefficient in A/MCA. The runoff coefficient represents the ratio of runoff to precipitation and provides insights into the efficiency of water retention in the catchment area. The graph displays the variations in the runoff coefficient over time for the annual, dry season, and wet season in the catchment area.

4. Hypothesis Testing Analysis

Correlational Analysis between rainfall and Runoff in Kaduna River Basin

Table 5 and 6: presented the result of the correlation between rainfall and runoff in the three catchment areas.

Table 5: Results of Correlation Analysis between Precipitation and Runoff in KRB

	KCCA	GCA	A/MCA
Annually	0.993622	0.980383156	0.985720582
Dry season	0.838934	0.245616088	0.846943114
Wet season	0.992481	0.990868898	0.978361399

Source: Researcher’s Analysis, 2024.

Correlation was sought between rainfall and runoff using the Pearson product moment correlation in the three Catchment Areas. The correlation results of annual rainfall and runoff showed significant relationships in annual rainfall of (0.99mm) in KCCA, (0.98mm) in GCA and (0.99mm) in A/MCA. The dry season rainfall correlation with runoff indicated ($r=0.84$) in KCCA, ($r=0.25$) in GCA and ($r=0.84$) in A/MCA. The wet season rainfall correlation with runoff shown ($r=0.99$) in KCCA, ($r=0.99$) in GCA and ($r=0.98$) in A/MCA of the KRB. The study concluded that KRB is experiencing an increase in the annual rainfall. The rise in the annual rainfall is possibly an influencing factor to the frequent occurrences of flooding in recent time across the ecological zone.

Differences between Annual Precipitation and Runoff within the Three Catchment Areas

Table 6, shows the results of an ANOVA test for a single factor, comparing annual precipitation and runoff in KCCA, GCA and A/MCA. Where, the ANOVA table shows the Source of variation (Between Groups and Within Groups), SS (Sum of Squares), df (degrees of freedom), MS (Mean Square), F value, p-value, and F crit value.

Table 6: ANOVA between Annual Precipitation and Runoff within three Catchment Areas.

Sn.	Catchment	Source of Variation	SS	df	MS	F	P-value	F crit
1	KCCA	Between Groups	11530337.2	1	11530337.2	13.335	0.00048	3.97
		Within Groups	63985804.62	74	864673			
2	GCA	Between Groups	11291208.09	1	11291208.1	37.824	3.60E-08	3.97
		Within Groups	22090559.37	74	298521.1			
3	A/MCA	Between Groups	9854909.298	1	9854909.3	30.383	4.93E-07	3.97
		Within Groups	24002540.99	74	324358.7			

Source: Researcher’s Analysis, 2024

The p-value for KCCA, GCA and A/MCA are 0.00048, 3.60E-08, and 4.93E-07 respectively, which is less than the common alpha level of 0.05. This indicates that there is a statistically significant variation between the means of the annual Precipitation and Runoff of the observed groups. This is also evident in analysing the overall F value and F critical value based on the premise that “when F is greater than the F critical value, we can reject the null hypothesis”. Thus, given that in all three catchment areas, the F value (13.335, 37.824, and 30.383 respectively) is greater than the F critical value (3.97); we then reject the null hypothesis which states that all

group means are equal, which in this case can be stated that ‘all group means are not equal’ and that there is statistically significant difference between the means of the annual Precipitation and Runoff of the observed groups. In summary, the results suggest that there is a significant variation in the amounts of annual precipitation and runoff in the three Catchment Areas. This could have implications for water management strategies in KRB.

Runoff characteristics vary considerably over the three catchment areas. Most of the inflows to KCCA from the hydrological area originated from two areas namely the Jos plateau and the Saminaka Mountains. The A/MCA of the study area which is made up of rock outcrops has a very high relief and therefore high relief ratio. this area has low infiltration rate and thus relief ratio, the percentage of runoff from a given rainfall amount the high relief ratio, the low infiltration rate, low temperature, high relative humidity and higher rainfall of the A/MCA are the cause of the humid behaviour of the upstream in that part of the catchment. The downstream portion of the study area has very low relief and is made up of sandy dunes. Thus, the lower relative humidity and higher temperature also encourage evaporation. The loss of water through evaporation as the rivers move downstream is also caused by high infiltration rates of the sandy formation.

Milly *et al.* (2008) suggests that the eastern part of the U.S.A will experience increased runoff, accompanied by declines in the west. This means that wet areas are projected to become drier and dry areas drier, thus increasing the vulnerability of agricultural and forest-dependent communities in KRB whose livelihoods (or incomes) in many cases are sensitive to water availability. Urban water users may be subjected to higher water expenses and residential users may also be required to conserve water. Population growth in these arid and semi-arid regions could also stress water supplies. The impact is likely to become more severe for urban centres than rural areas. Farley *et al.* (2011) points out that vulnerability to climate variability in the water sector may vary by location and the amount of water use, urbanized areas are more vulnerable to water stress. In addition, they point out that the demographic growth exacerbates the impact of climate variability in water supply sectors. In fact, it has been pointed out by many studies that the joint effect of climate variability and population growth will profoundly affect the availability and quality of water resources (Salihu *et al.*, 2020; SanchezGoni and Harrison, 2010; Milly *et al.*, 2005; Evans, 2008). The large amount of available water during the rainy season; crop varieties that can withstand much water should be planted in areas of high rainfall; and government policies related to agriculture and water resources development should be based on increase in rainfall and water resources trends in KRB.

5. CONCLUSION

A monthly water balance model was used to study the variation and trends of P, PET, AET and R from 1984 to 2021. The studies indicate that P has been the principal climate factor driving the variation in R, even during periods when PET has augmented. This research makes known that PET surpasses P at all the catchment areas and all P is evaporated and transpired even though AET and P are nearly equivalent in extent, resulting in R being steadily made in the catchment area each year. It is also distinguished that the peak of R usually happens throughout the wet season (i.e., April through October) most specially at the Kaduna catchment area.

6. RECOMMENDATIONS

The results of this research offer a reference point of the hydro climatology of the KRB which can be used as a preliminary idea for more studies. Furthermore, the reference point hydro

climatology portrayed in this research can be used to lead the variety of sub-catchment within the KRB for explicit studies particularly water resources planning and management.

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