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ASSESSING THE SPATIAL DISTRIBUTION OF WATER BALANCE IN KADUNA STATE, NIGERIA

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ABSTRACT
The purpose of this paper is to examine the spatial distribution of water balance components for Kaduna State. One of the most important outcomes in the water balance equation for any natural area or water body is Evapotranspiration and it is also a crucial component of the hydrologic cycle. In attaining this, monthly data on temperature (T) and rainfall (P) were obtained from NASA (National Aeronautics and Space Administration) twelve remotely sensed stations around Kaduna State for thirty-seven years from 1984 to 2021. Thornthwaite and Mather Water Balance (WB) model was used to estimate WB components i.e., soil moisture (SM), actual evapotranspiration (AET), Water surplus (S) and Runoff (R). Kaduna State was divided into three sub-basins and the result shown peak of R generally occurs during the wet season (i.e., June through November across the three catchment areas) most especially at Kaduna central catchment area in the month of July (1003.85mm). The study further reveals that 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 Mada- 814.05mm respectively. The area is relatively dry in the months of November–April and has water deficit while Soil moisture recharge takes place from early May to August and mid-May to December is the period of water surplus across the catchment areas. The result of this study provides a reference information on water balance distribution in Kaduna State and utilization for water resources management.

Keywords: Spatial distribution, Water Balance, Water deficit, Water surplus, Kaduna

INTRODUCTION

Water is a vital element to the expansion of any zone. The demand for water has amplified lately because of the rising population, where water for cultivation and other demands becomes inadequate (Al-Sudani, 2020). Climate and hydrological circumstances in any river basin are multi-combined echo of natural features of morphology and surrounding environment, as well as the variations in climate factors that touch directly the surface water cycle (Al-Sudani, 2018).

The investigation of WB in hydrology is the application of the code of protection of mass. The hydrological balance is beneficial in many areas of studies, from agriculture to hydrology and hydraulic engineering or more generally for water administration determinations. WB is define as the balance between received water from rainfall and the discharge of water by evapotranspiration, groundwater recharge, and stream flow (Chinwendu *et al.,* 2017).

Understanding disparities and drifts of the past and present hydroclimatic variable quantity are applicable to the upcoming progress and sustainable administration of water resources of an area (Oguntunde *et al.,* 2016). Data concerning distribution of water balance subjects is vital in the framework of water and energy cycles, climate change and the cumulative demand for water serve as a consequence of urban expansion and economic development in the study area (Sankarasubramanian and Vogel, 2003 Oguntunde *et al.,* 2016). In many advanced nations of the world, hydro climatology of catchment areas has been widely investigated and the spatial and time-based changeability of water balance zones are carefully watched (Wise *et al*., 2018; McCabe and Wolock, 2019). Rigorous hard work has been made by numerous researchers to analyse, detect and model hydroclimatic data in catchment areas (Wise *et al*., 2018; McCabe and Wolock, 2019). Several researches have also assessed time-based changeability and sequence of catchment area hydro-climate, surface water and energy balances (Milly and Dunne, 2001; Qian *et al.,* 2007). Qian *et al*. (2007) stated in their finding on hydroclimatic tendencies in the Mississippi catchment area that precipitation trends were the principal control of trends in evapotranspiration, while temperature and solar radiation trends had only a slight effect. Furthermore, Frans *et al*. (2013) used macroscale hydrology model to assess the effects of land use/land cover vagaries and climate changeability on temporal variations in Mississippi catchment area hydroclimate and discovered that climate variation was the main reason driving runoff variations in the catchment area.

Attempts have similarly been made to study the flow regimes and hydrological variation of some catchment areas in West Africa using hydrological or land surface models (Andersen *et al*., 2008; Durowoju *et al*., 2018). Conway and Mahe (2009) for instance, simulated monthly stream flow in three tributaries of the Niger River Basin (NRB) using conceptual water balance model. In a related investigate, Li *et al*. (2007) applied hydrological routing model and a land surface model to investigate the hydrological changeability in sub-catchments of the Lake Chad basin and Niger River basin between 1950 and 1995. Threre are several approaches for monthly WB analysis available in literature but this paper adopted the Thornthwaite and Mather model (Thornthwaite and Mather,1955; 1957) which is widely accepted for used. It is adopted in numerous fields, especially in hydro climatology and for problems resolutions in water balance distribution in basins.

Apprehensions about hydroclimate variation in Kaduna State catchment areas demand the need for this research in order to mitigate the anthropogenic impacts which may perhaps further be aggravated by climate change. The paper aims to analyse the spatial distribution and trends in some water balance components in Kaduna State and offer an up-to-date appraisal of the spatial and temporal variation of WB components for the Kaduna State. The choice of Galma, Kaduna central and Mada catchment areas is hinged on the fact that the catchment areas have agricultural potential.

Study Area

Kaduna State is sited between latitudes 9º 02″N and 11º32″ North of the equator and between longitude 6º15″E and 8º50″E East of the Greenwich meridian in the North western region of Nigeria (Figure 1). Kaduna State is surrounded to the North by Katsina, Zamfara and Kano States, to the West by Niger state, to the East by Bauchi and to the South by Plateau, Nasarawa and Federal Capital Territory, Abuja (Yusuf, 2015).

The Kaduna State latitudinal zone lies in the part of Western Africa, within the northern limit of the movement of the Inter-Tropical Convergence Zone (ITCZ). This phenomenon of the global circulation of the air masses is responsible for the general climatic characteristics of the study area, which is categorized by distinct two seasonal regimes, oscillating between cool to hot dry and humid to wet season. The climate of the study area can be described as the Sub-Humid type (Nigeria Vision 20:2020, 2009) characterized by tropical wet and dry or savannah climate (Aw).

The 550 km² long River Kaduna is the third-longest river in the country after Rivers Niger and Benue flowing through different topographic and geologic zones in the north-west direction towards Kaduna metropolis and thereafter takes a south-west direction turn at Mureji and drains into River Niger at Nupeko (Chinwendu *et al.,* 2017). 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. River Kaduna takes its source from Sherri Hills (1280 sea level) in Plateau State. The Kaduna River Basin (KRB) approximately covers 65,878 km² area cutting across mainly two States-Niger and Kaduna. The KRB is an important food-producing region, responsible for more than half of Nigeria maize production, among other crops (Agronews, 2019); The Kaduna State Bureau of Statistics, 2019). Additionally, users of the KRB depend on the system for irrigation farming, fishing, industrial uses, drinking water, recreation, navigation, hydroelectricity generation and wildlife habitat. Although its highest headwater is free-flowing and is the only river feeding Shiroro dam (Chinwendu *et al.,* 2017).

Rainfall is the most important climatic variable and its seasonality and amount are of overriding interest to farmers, pastoralist and foresters. As both South Maritime and North Continental air masses are dominant for roughly half a year over Kaduna, there are two contrasting seasons. From April or May, the moist south-westerly winds bring rain and both cultivation and tree growth respond immediately. However, from month of October to April/May, the study area is subjected to cool dry North-easterly wind which yield virtually no rain. This is the period that irrigation farming mostly take place (Yusuf, 2015). The variation on the onset of rainfall is attributed to the fluctuations of the boundary between these two air masses. Rainfall is substantial in the southern part of the state and ranges an average of 500mm per month between April and September. In the extreme north, the monthly average is 146mm, while Kaduna metropolis receives a monthly average of 361mm (Leah, 2003). The annual rainfall received in Kaduna State range from 1000mm-1270mm, with a raining period of 160-180 days. The peak of the raining season occurred during the month of August (NIMET, 2018). Also, considerable variation take place both in monthly and annual totals. This is typically due to high intensity of various storms and narrow front with which they sweep transversely the country side. Generally, the storms are inter-spread with clear skies although during August and September, there can be consecutive days that are dull and over cast. This unchanging seasonal regimen of dry and wet exercises a key and lasting effect on agriculture as well as on man's dwelling and water availability in the State (Yusuf, 2015).

The combined Temperature and Rainfall of the State shows that, the mean maximum and minimum temperature experience in the State increases during the first part of every year to its peak during the hot season in late March and April. At the beginning of the rain, mean maximum temperature usually fall below 33.0ºC and subsequently minimum temperatures are experienced during rainy season, which remains fairly constant (Yusuf, 2015). Toward the end of rainy season, daily maximum temperature rises throughout the little hot season which allow crops to ripe (KDSG, 2018).

MATERIALS AND METHODS

The mean monthly precipitation and temperature for thirty-seven years (1984-2021) was taken from twelve (12) remotely sensed stations around Kaduna River Basin. The climatic data were obtained from NASA (National Aeronautics and Space Administration) through the net, http://power.larc.nasagov/data-access-viewer/ this is because the climatic data were only available till the end of 2021 which fall within three catchment areas of Galma, Kaduna, and Mada catchment areas.

A soil texture map of Kaduna State was prepared using land and water development division data of Food and Agriculture Organization of the United Nations (FAO, 2021). Three different soil textures, namely silty loam, sandy loam, and loamy sand were identified within the study area.

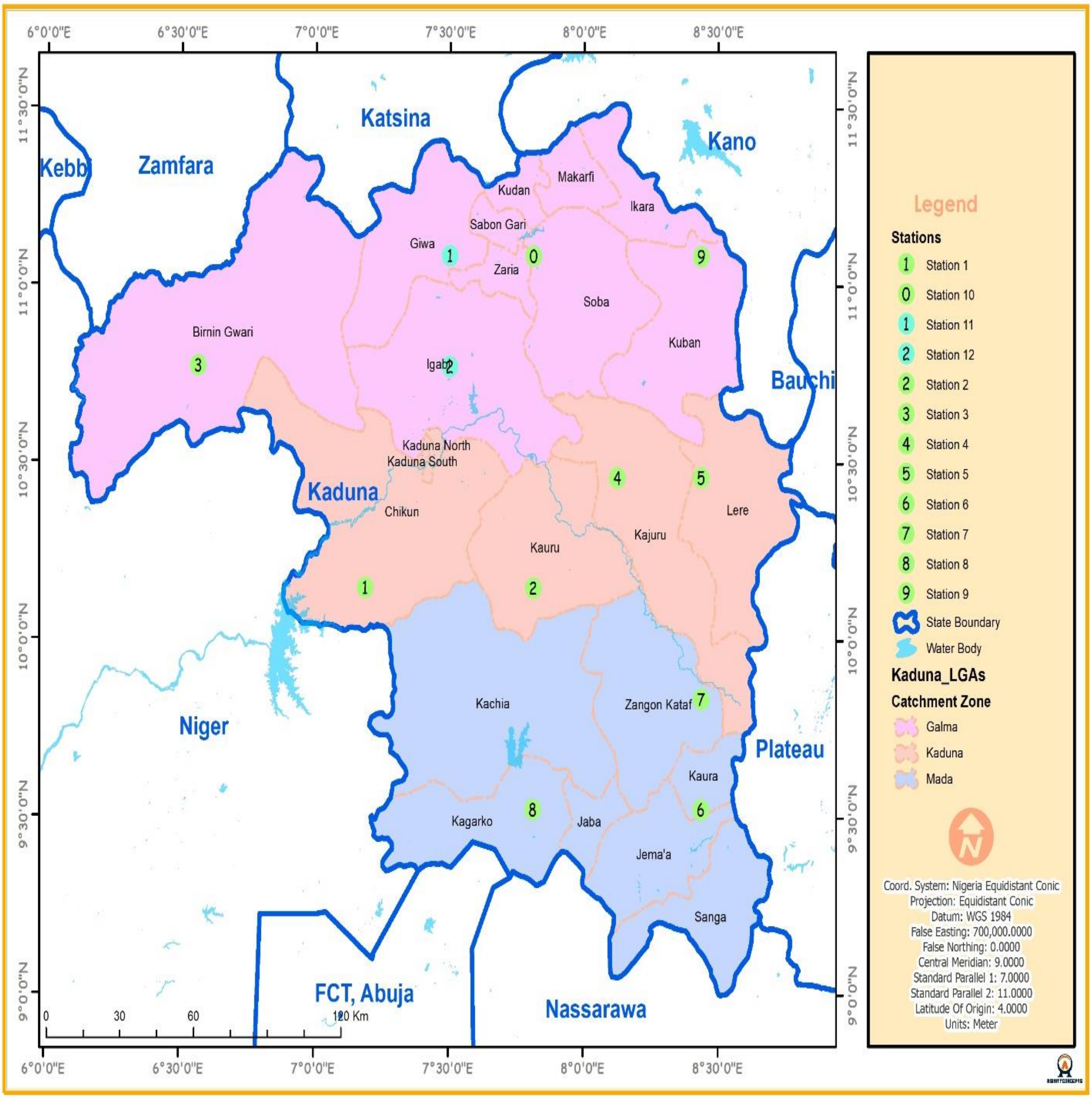

Figure 1: Map of Catchment Areas/ Remotely Sensed Stations within Kaduna State

The Thornthwaite and Mather (TM) Model

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

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

Were.

PET = the potential evapotranspiration (mm month [1]);
T = the mean monthly temperature (°C).
I = the annual heat index for the 12 months in year ($I = \Sigma i$).
i = the monthly heat index$\left(i = \left[{}^{T}/_{5}\right]^{1.514}\right)$;
$a = 6.75 \times 10^{-7} \times I^{3} - 7.71 \times 10^{-5} \times I^{2} + 1.792 \times 10^{-2} \times I + 0.49239$
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 and 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:

$$STOR = AWC \times e^{(APWL/AWC)} \quad (2)$$

Where *AWC* is the moisture storage capacity (i.e., the available water capacity) of the soil. This was calculated based on the land cover, soil texture and rooting depth as suggested by Thornthwaite and Mather (1955, 1957). The results were summarized in Table 1. Changes of actual storage (ΔSM) for all the months were calculated as:

$$\Delta SM_{month} = STOR_{month} - STOR_{previous\ month}. \quad (3)$$

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 1: 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, 2023).

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

$AET = \Delta SM + P$ *if* $\Delta SM < 0$ - -(4)

$AET = PET$ $\Delta SM > 0$ - - (5)

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

$DEF = PET - AET$ - - -- (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):

$SUR = P - PET$ - - -- (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):

$SUR = P - (AET + \Delta SM)$ - -- (8)

here 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 areas 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 represent the monthly real evapotranspiration and runoff from each catchment area.

RESULT AND DISCUSSION

Accumulated Potential Water Loss (*APWL)*

From Table 2 Thornthwaite and Mather (TM) Model showed in equations (1 to 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 Mada) catchment areas in Kaduna State and presented in Table 2.

The result in Table 2, indicated that the onset of rain occurred in the month of March while the cessation of rain occurred in the month of October. The rain gains its stability in the month of May which shows that the adequate duration of rainy season covers the months of May to October which could be viewed as the length of growing season in the study area. The finding is in tandem with Oladipo (2010; 1993), who asserts that the months stated above the study area receives over 85% of its annual precipitation 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 Kaduna Central Catchment area having a monthly average precipitation of 204.35 mm but the mean monthly summary of precipitation has a regular increasing pattern from May to October when used every year. This suggests that Kaduna State is progressively getting drier and extremely flexible in daily, monthly and annual rainfall received.

The major 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-1443.82 mm and Mada- 814.05mm respectively (Table 2). All the catchment areas have one-peaked rainfall regime. This has not changed from what it has been over time, but the rainfall distribution and occurrences sometime come earlier or late. 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 Mada Catchment Area has shown by the statistically important wetter conditions of those months. The upsurge in precipitation supply of these three months, especially in July and August, agrees with the recurrent occurrences of August floods in the study area. This agrees with the finding of Ati, Muhammed, and Ati, (2008); Ati, Stigter, Iguisi and Afolayan, (2009) and Abaje, Ati, Iguisi and Jidauna (2013) which asserted that the months have been observing cumulative annual rainfall sums. There is not year rain was totally absent in the period understudy. Thus, what was noticed throughout was climate variation and not climate alteration.

Furthermore, 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 State, as stated 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 state which decrease the mean monthly temperatures as well as the potential evapotranspiration subsequently.

The temporal difference between P-PET have shown 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 rainy season while November to April indicate negative values because of dry season which implies water deficit. Only the month of March in Kaduna central catchment area have positive value of 77.72 mm in the dry months.

The difference in the hydrological conditions in the Galma, Kaduna central and Mada catchment areas can be seen from the considered accumulated potential water loss (APWL) value. The final APWL values of the three catchment areas indicatedd that, from the months of November to April both Galma and Kaduna central catchment areas have negative value 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 has 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 Kaduna central catchment areas. This means that the Southern part of the State have good water conservation potential, whereas Northern and the Central parts need to manage their water resource more prudently. 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.

Intensity Distribution of Rainfall within Kaduna State

It was observed in Figure 2 that, intensities of rainfall were obtainable from the interpolated map, which revealed an growing length of return periods for all the stations. Stations 6 and 8 has highest return of rainfall intensity in the study area with mean annual rainfall of greater than >212 mm, followed by station 7 with rainfall intensity between the range 178-212 mm. Station 2 indicates that the length of return period is between 138-178 mm rainfall intensity and station 1 is within the range of 107-13 8 mm of the rainfall in the State. The least stations with rainfall intensity are 3, 4,5,9,10, 11 and 12, the rainfall intensity is less than <107 mm which cover most part of Galma and Kaduna central catchment areas. The result implies that, parts around coastlines and rivers should expect swelling rise in flood because of precipitation. It can be realized also that for given length of return period, intensity of rainfall declines with increasing duration of rainfall. This infers that, an increasing trend rainfall intensity is expected for extreme (short duration) rainfall. The long-term consequence of this is the substantial precipitation which could lead to inundating in those stations with positive trend. This finding is in tandem with the IPCC (2014) statement, cumulative substantial precipitation is predictable to upsurge erosion and flood, and this has the significance of destructive many low-lying ecosystems, infrastructure, and housing. Precipitation variations may also move the base of farming production sectors, and many plant kind may face local or global annihilation. Settlements with adverse trend may also experience submerging due to soil texture and topography, physical, architectural, and engineering glitches. Hassan (2012), asserted that the previous account that precipitation upsurges from the south to the north in the FCT which is else in other parts of the country. The motive for this as implied previous is the effect of Jos plateau on the north east border of the territory. That is why Bwari which is at the extreme end of that border with Kaduna State appear to enjoy this influence more than the other areas coupled with the contribution from many large bodies of water (Hassan, 1996). The zonal monthly rainfall depicts the actual rainfall typical in these zones.

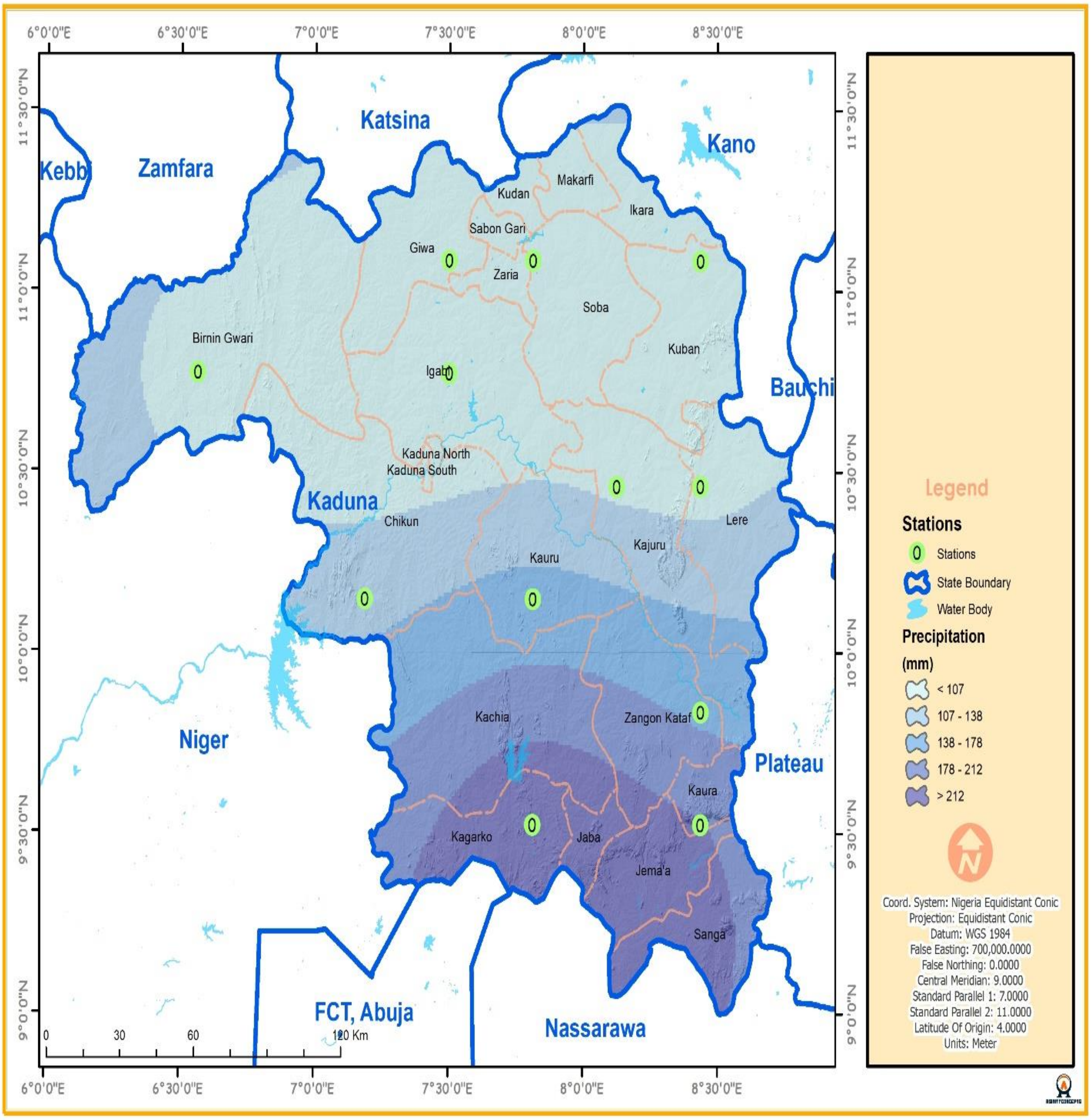

Figure 2: Intensity Distribution of Rainfall within Kaduna State

Monthly Water Balance in Galma Catchment Area

The monthly difference of rainfall, potential and actual evapotranspiration and runoff in the catchment area is presented in Table 3.

Table 3 Showed the actual evapotranspiration (AE), where a comparable pattern of precipitation distribution has been designated. In several tropical areas with different dry seasons, the annual rainfall regularly revealed to be lesser than the annual potential evapotranspiration. Nevertheless, Galma catchment area has average annual rainfall of 4067.69 mm, about 3045.38 mm higher than its average annual potential evapotranspiration, 1022.31mm. On the other hand, the average annual actual evapotranspiration in the whole catchment area is 426.25 mm, lower than the average annual potential evapotranspiration. The surplus water in Thornthwaite-Mather method was assumed as water that becomes runoff. In this study, the most surplus month are only seven months (June, July, August, September, October, November, and December) and of deficit are five months (January, February, March, April, May) in the catchment area, respectively. The total annual runoff for the catchment area is 3417.31mm and the month with the highest runoff is July with a monthly runoff of 819.76 mm. In implication since actual evapotranspiration depends directly on excess water during calculating water balance and whenever potential evapotranspiration was less than precipitation, the actual evapotranspiration will be equal to potential evapotranspiration which will produce water surplus. While whenever potential evapotranspiration was more than precipitation, the actual evapotranspiration will be equivalent to precipitation making water shortfall. The obtained water surplus contour map in the study area contingent on the water balance equation. The map displays the similar pattern of precipitation distribution and actual evapotranspiration about amplified values to Kaduna central catchment area. The water surplus hinge on directly on both precipitation and actual evapotranspiration.

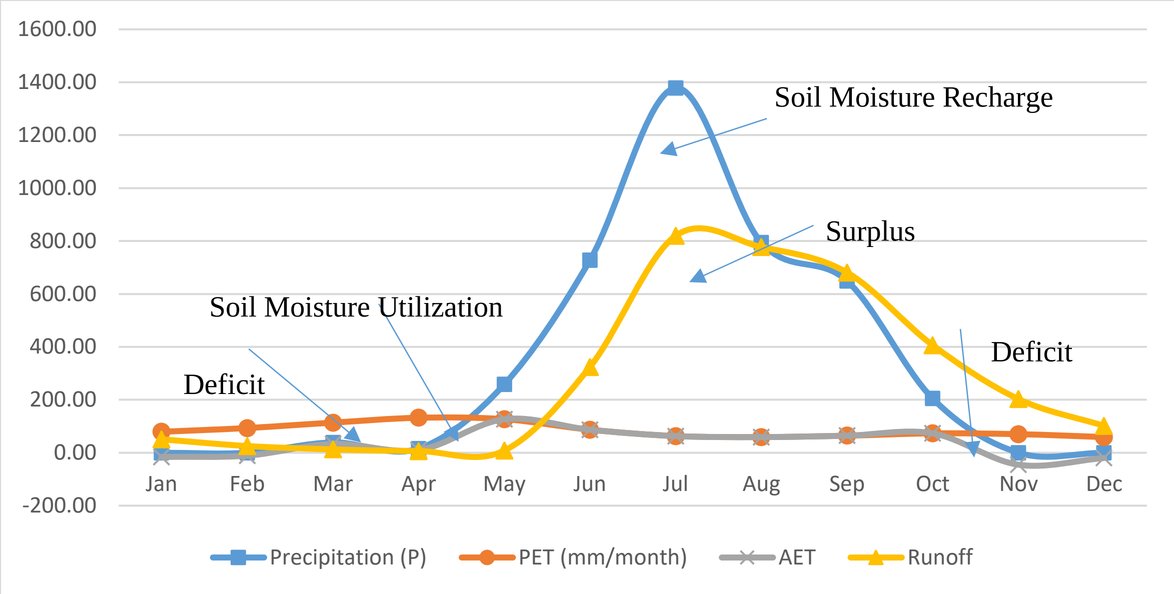

Figure 3: Water Balance Status of Galma Catchment Area.

It reveals information concerning the water balance of the Galma catchment area. Also show the seasonal pattern of precipitation, actual evapotranspiration (*AET*), potential evapotranspiration (*PET*) and runoff, it shows the periods of humidity deficit, soil moisture revive and soil moisture utilization (Figure 3).

The dampness deficit shows that plants will be under some pressure during that period, signifying the need for irrigation. The area is relatively dry in the months of November–April. Furthermore, there is a water deficit again in the months of October–December. Soil moisture recharge takes place from early May to August. From mid-May to December is the period of water surplus.

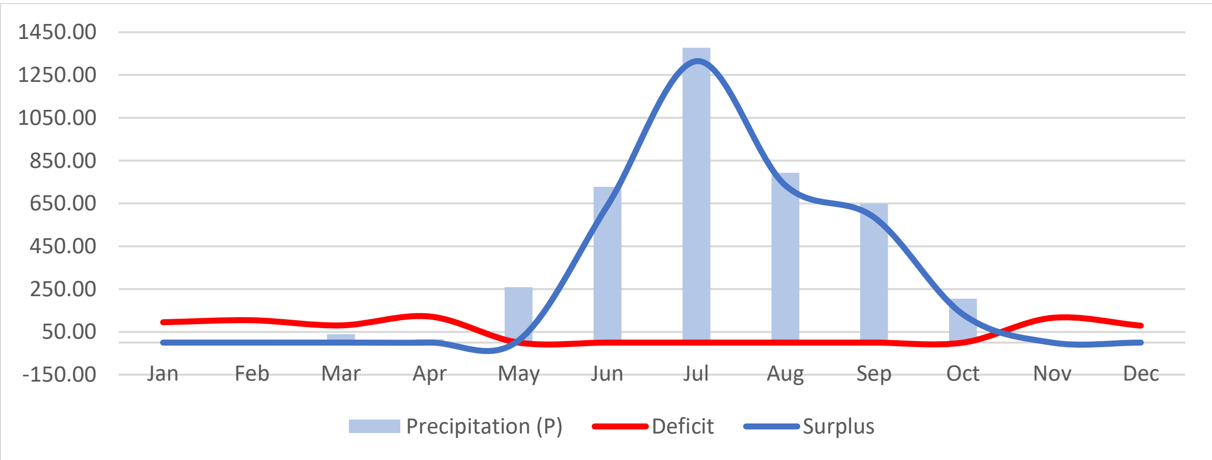

Figure 4: Water Balance Comparison between Surplus and Deficit in Galma Catchment Area.

Comparatively, it was observed from figure 4, that surplus within this Catchment Area starts at May and ends mid-October. Whereas deficit reigns through mid-October back to May with peak deficit in the month of April (i.e., 121.8 mm).

Monthly Water Balance in Kaduna Catchment Area

The monthly difference of rainfall, potential and actual evapotranspiration, and runoff in Kaduna central catchment area is presented in Table 4.

Table 4, Presented the actual evapotranspiration (AE), where a comparable pattern of precipitation distribution has been showed. In several humid areas with separate dry seasons, the annual rainfall often found to be lower than the annual potential evapotranspiration. Nevertheless, Kaduna Central Catchment Area has average annual rainfall of 6123.56mm, about 3045.38mm higher than its mean annual potential evapotranspiration, 1031.44mm. On the other hand, the mean annual actual evapotranspiration in the entire Catchment area is 517.08mm, lesser than the mean annual potential evapotranspiration. In this study, the most excess month are only four months (June, July, August, and September) and shortfall are equally four months (January, February, November, and December) in the Catchment Area, respectively. The total annual runoff for the Catchment Area is 4842.86mm and the month with the highest runoff is July with the runoff of 1003.85mm. In implication since actual evapotranspiration rest on straight on excess water during calculating water balance and when potential evapotranspiration was less than precipitation, the actual evapotranspiration will be equivalent to potential evapotranspiration which will produce water surplus. While whenever potential evapotranspiration was greater than precipitation, the actual evapotranspiration will be equivalent to precipitation creating water shortfall.

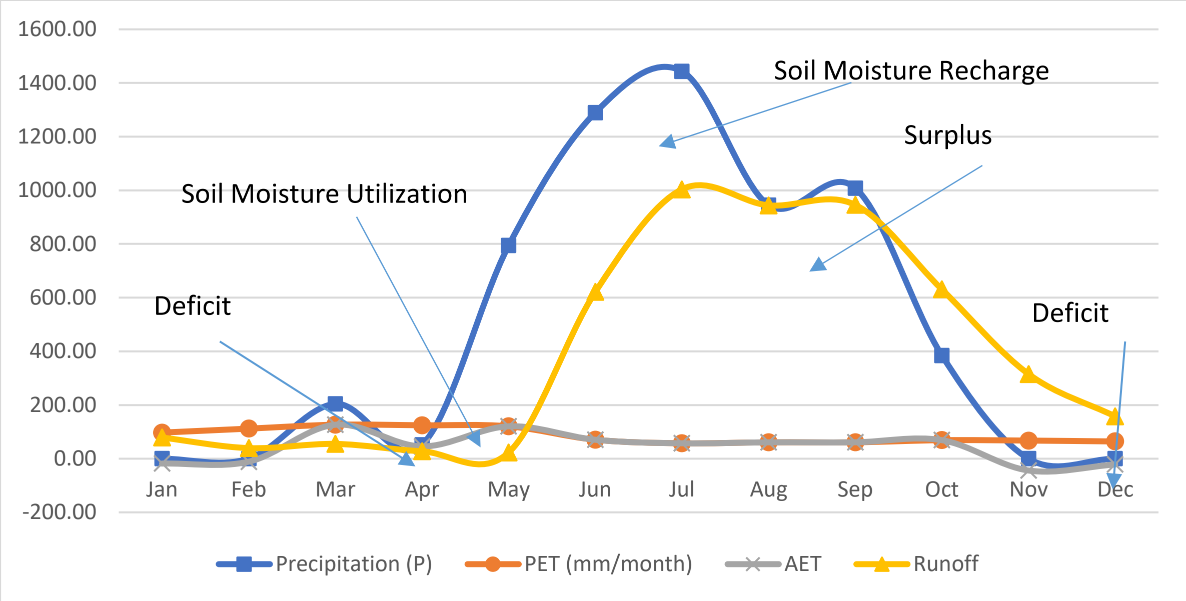

Figure 5: Water Balance Status of Kaduna Catchment Area

Figure 5 reveals information concerning the water balance of the Kaduna Central Catchment Area. Also display the seasonal pattern of precipitation, actual evapotranspiration (*AET*), potential evapotranspiration (*PET*) and runoff, it shows the periods of moisture shortfall, soil moisture recharge and soil moisture use (Figure 5.21).
The moisture shortfall shows that plants will be under some pressure during that period, signifying the need for irrigation.

The area is comparatively dry in the months of January to mid-April interrupted by little precipitation in March. Furthermore, there is a water shortfall again in the months of October–December. Soil moisture recharge takes place from early May to August. From early April to November is the period of water excess.

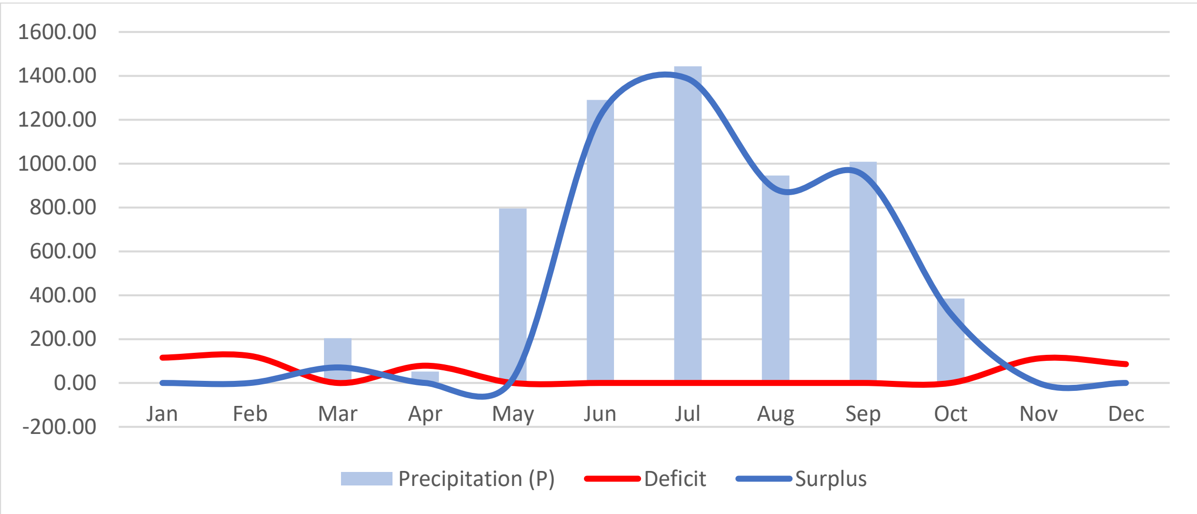

Figure 6: Water Balance Comparison between Surplus and Deficit in Kaduna C.A.

Comparatively, it be observed from figure 5.22, that surplus within this Catchment Area starts at May and ends mid-October. Whereas deficit reigns through mid-October back to May (interrupted by 70.76 mm surplus in the month of March) with peak deficit in the month of February (i.e., 123.10 mm).

Monthly Water Balance in Mada Catchment Area
The monthly disparity of rainfall, potential actual evapotranspiration, and runoff in the catchment area is presented in Table 5.
The finding of the average monthly precipitation over the time under-study is in Table 5. The maximum precipitation for the catchment area is noted in June, July, and September, which represented about 47% of the total average annual precipitation of the catchment area with the annual rainfall 3630.93mm, however the minimum precipitation is showed in March, April, May, and October. The catchment area is categorised by single peak rainy season during the years, i.e., at these stations rainy months are not divided into more than one group of rainy months by dry months. There is a single dry season during the year. The rainy season in total have eight months: March, April, May, June, July, August, September, and October. The rains in March are small rain which account for average annual rainfall of 93.16mm.
Mada catchment area have an average annual potential evapotranspiration of 994.92 mm higher than actual

evapotranspiration in the whole catchment area with 486.57 mm. The total annual runoff for the catchment area is 2696.40mm and the month with the maximum runoff is July with a runoff value of 562. 47mm. In implication since actual evapotranspiration rest on straight on water surplus during the calculation of water balance and when potential evapotranspiration is less than precipitation, the actual evapotranspiration will be equivalent to potential evapotranspiration which will yield water excess. The months with water surplus are May, June, July, August, September, and October. Although when potential evapotranspiration is greater than precipitation, the actual evapotranspiration will be equivalent to precipitation creating water shortfall.

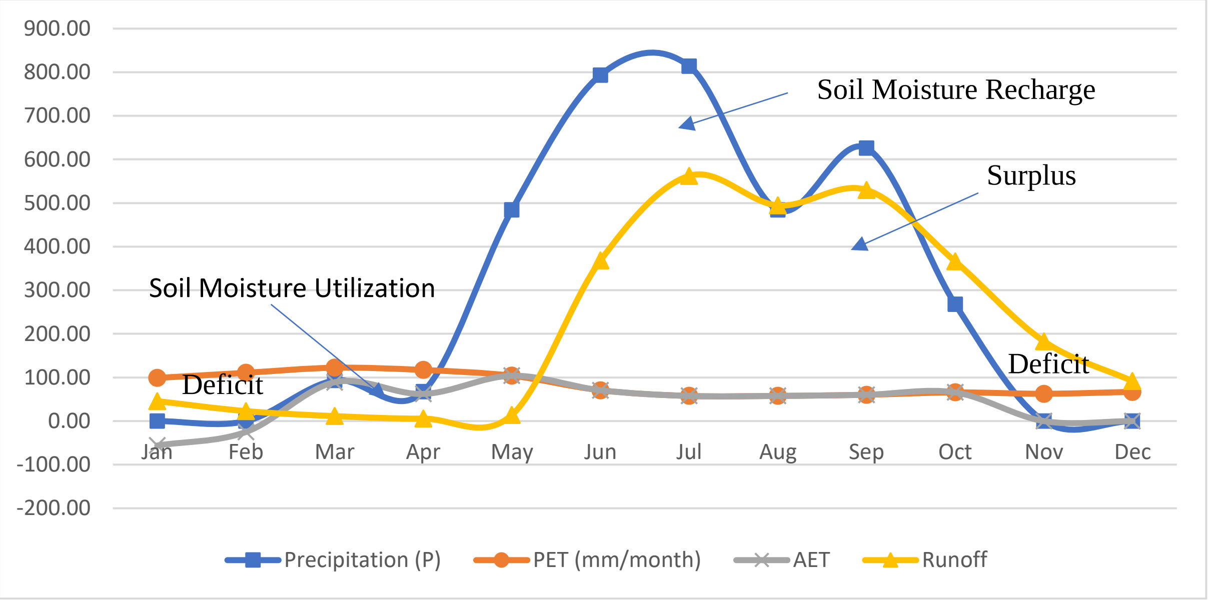

Figure 7: Water Balance Status of Mada Catchment Area.

Figure 7 reveals information concerning the water balance of the Mada catchment area. As well show the seasonal pattern of rainfall, actual evapotranspiration (*AET*), potential evapotranspiration (*PET*) and runoff, it shows the times of moisture shortfall, soil humidity recharge and soil moisture use (Figure 8).

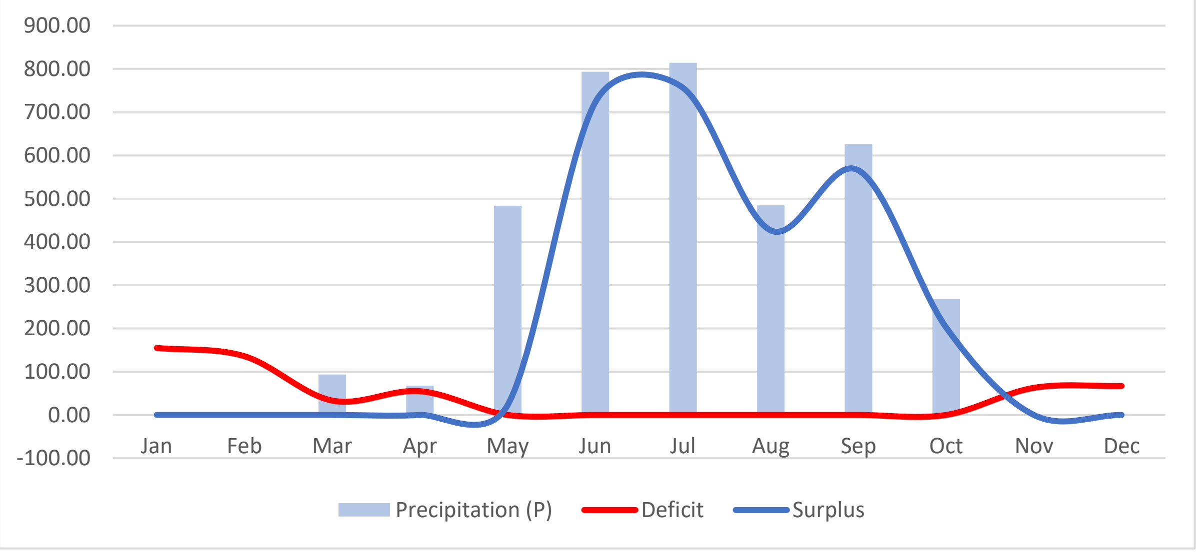

Figure 8: Water Balance Comparison between Surplus and Deficit in Mada Catchment Area.

Table 2: Accumulated Potential Water Loss at studied catchment area in Kaduna State

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Galma Catchment Area							
P	0.00	0.00	39.03	15.90	258.43	727.58	1378.21	794.31	649.40	204.84	0.00	0.00
PET	79.21	93.42	113.85	132.20	126.87	87.08	63.08	59.26	64.48	73.34	70.19	59.33
P – PET	-79.21	-93.42	-74.82	-116.30	131.56	640.49	1315.13	735.06	584.92	131.50	-70.19	-59.33
APWL	-208.73	-302.15	-376.97	-493.28	0.00	0.00	0.00	0.00	0.00	0.00	-70.19	-129.52
					Kaduna Central Catchment Area							
P	0.00	0.00	204.35	52.26	794.62	1289.87	1443.82	945.19	1008.65	384.81	0.00	0.00
PET	97.16	111.99	126.63	124.38	120.68	70.54	57.33	60.96	61.02	69.00	67.53	64.22
P – PET	-97.16	-111.99	77.72	-72.12	673.93	1219.33	1386.49	884.23	947.63	315.80	-67.53	-64.22
APWL	-228.90	-340.89	-263.17	-335.30	0.00	0.00	0.00	0.00	0.00	0.00	-67.53	-131.74
					Mada Catchment Area							
P	0.00	0.00	93.16	67.70	484.09	793.59	814.05	484.38	625.91	268.04	0.00	0.00
PET	98.90	110.76	122.35	117.19	103.96	70.66	57.66	57.73	60.36	65.75	62.65	66.96
P – PET	-98.90	-110.76	-29.19	-49.48	380.14	722.93	756.39	426.65	565.55	202.30	-62.65	-66.96
APWL	-98.90	-209.66	-238.85	-288.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Researcher's Analysis, 2023

Table 3: Summary of the P, PET, AET and runoff for Galma Catchment Area (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	0.00	0.00	39.03	15.90	258.43	727.58	1378.21	794.31	649.40	204.84	0.00	0.00	4067.69
PET	79.21	93.42	113.85	132.20	126.87	87.08	63.08	59.26	64.48	73.34	70.19	59.33	1022.31
AET	-15.79	-10.86	33.50	10.32	126.87	87.08	63.08	59.26	64.48	73.34	-45.20	-19.84	426.25
Runoff	50.79	25.40	12.70	6.35	8.28	324.39	819.76	777.41	681.16	406.33	203.17	101.58	3417.31

Source: Researcher's Analysis, 2022

Table 4: Summary of the P, PET, AET and runoff for Kaduna Catchment Area (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	0.00	0.00	204.35	52.26	794.62	1289.87	1443.82	945.19	1008.65	384.81	0.00	0.00	6123.56
PET	97.16	111.99	126.63	124.38	120.68	70.54	57.33	60.96	61.02	69.00	67.53	64.22	1031.44
AET	-18.08	-11.10	126.63	45.71	120.68	70.54	57.33	60.96	61.02	69.00	-44.05	-21.56	517.08
Runoff	78.85	39.43	55.09	27.55	23.08	621.21	1003.85	944.04	945.83	630.82	315.41	157.70	4842.86

Source: Researcher's Analysis, 2022

Table 5: Summary of the P, PET, AET and runoff for Mada Catchment Area (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	0.00	0.00	93.16	67.70	484.09	793.59	814.05	484.38	625.91	268.04	0.00	0.00	3630.93
PET	98.90	110.76	122.35	117.19	103.96	70.66	57.66	57.73	60.36	65.75	62.65	66.96	994.92
AET	-56.02	-24.95	89.15	62.28	103.96	70.66	57.66	57.73	60.36	65.75	0.00	0.00	486.57
Runoff	45.77	22.89	11.44	5.72	14.15	368.54	562.47	494.56	530.05	366.18	183.09	91.54	2696.40

Source: Researcher's Analysis, 2022

The wetness shortfall shows that plants will be under some pressure during that period, signifying the requirement for dry season farming. The area is comparatively parched in the months of January–May. Furthermore, there is a water shortfall once more in the months of October–December. Soil wetness boost takes place from early May to August. From mid-May to December is the period of water excess. Comparatively, it be observed from figure 5.24. that surplus within this catchment area starts at May and ends mid-October. Whereas deficit reigns through mid-October back to May with peak deficit in the month of January (i.e., 154.92 mm).

The volume of precipitation does not only fluctuate from month to month, but it also displays variation from year to year. The maximum precipitation for the catchment areas is noted in June, July and September and the volume of precipitation in March, April, May, and October is practically little. The disparity in the periodic distribution of rainfall is ascribed to the location of the Inter-Tropical Convergence Zone (ITCZ), the connection among upper and lower air flow, the effects of landscape and the role of local convection currents and the volume of precipitation (Kebede and Tadesse, 1964; Daniel). It is well-known that the trend of precipitation is short in August because of the August breakdown and precipitation influences its maximum in September. The rainy season in total have eight months: March, April, May, June, July, August, September, and October. Minor rains are knowledgeable in March while big rains with reasonable available in April, May, June, July, August, September and October and these attributable to 89.5 % of the average annual precipitation of Kaduna State. This finding is in tandem with Oladipo (1993) which posited that 85% annual total rainfall in Northern Nigeria is within the stated months. Months in the rainy seasons are warmer than months in dry seasons (Ufoegbune *et al*., 2011). The peak temperature value is experiential during the dry season while the uppermost wind speed values are found both in the rainy months where rains occurred in reasonable concentration. Equally, the uppermost humidity values are start in the rainy months while the lowermost values are in dry months even though the maximum sunshine hours are found in dry months whereas the minimum are very high in rainy months. When the temperature is at its highest, the relative humidity is very low in the dry season and vice versa in the rainy season. The trend of evaporation is like that of the rainfall and the maximum value of evaporation was in month of March in which the temperature begins to be higher. The maximum monthly values of potential evapotranspiration and actual evapotranspiration in the State generally comes just before the onset of the rainy season; and lowest values during the rainy season, when the cloud cover decrease air temperatures. The movement of any watercourse is determined by climatic factors (mainly rainfall) and the physical features of the catchment Areas. The latter consist of land use, type of soil, type of vegetation, area shape, elevation slope, type of drainage network, extent of indirect drainage and artificial drainage (Wisler and Brater, 1959)**.** The average annual runoff produced from the basin were at their peak flows in urban areas which results to an upsurge in the volume of rapid movement and additional quick flow of runoff in built-up areas. Additionally, because of the aforementioned reasons, poor and inadequate drainage system and absence of inundation control mechanisms have led to in momentary inundating of the area attached to the river Kaduna. The difference in annual movement is owing to variations in the climatic state of the catchment areas in Kaduna State. The great variation in movement from one spell to another largely echoes the climatic surroundings, i.e., seasonality of precipitation and volume of evapotranspiration in the Catchment Areas. Frequently, the net runoff constituent will not be significant amount (apart from the cases of powerful tempests) till most of the soil humidity shortfall has been replaced (Ward and Robinson (1990). Subsequently the soil has been occupied to the storing capacity, the surface runoff upsurges rather quickly and will characterize a huge and continuous ratio of rainfall during the storm. The underground water runoff on the other side signifies the foremost long-term constituent of the net runoff and may be of a specific consequence during the long spells when precipitation and subsequently surface runoff are completely absent.

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 indicates that P has been the principal climate factor driving the variation in R, even during periods when PET has augmented. This research make 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. The results of this research offer a reference point of the hydro climatology of the Kaduna River Basin 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 Kaduna State for explicit studies particularly water resources planning and management.

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