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Rainfall and potential evapotranspiration patterns and their effects on climatic water balance in the Western Lithoral Hydrological Zone of Nigeria

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Abstract. This study examined the climatic water balance and aridity in the Western Lithoral hydrological zone of Nigeria. Monthly climatic data from 1976-2015 collected from six Nigeria Metrological Agency (NIMET) stations located in Ikeja, Ibadan, Akure, Abeokuta, Osogbo and Ilorin were used. The climatic variables are rainfall amount, temperature, sunshine hour, relative humidity and wind speed. The FAO Penman-Monteith method was adopted in estimating the potential evapotranspiration (PET). Water balance was determined from PET and rainfall amount. The spatial and temporal pattern of rainfall amount and PET were evaluated using universal kriging interpolation method, Mann-Kendall and regression trend analysis. The results of the Mann-Kendall and regression trend analysis revealed a statistically significant (Z= 2.74, P= 0.005) upward trend in rainfall amount between 1976 and 2015. Similarly, a statistically significant (Z= 4.40, p= 0.001) increasing trend was observed in PET during the same period. Six months of water surplus (May-October) and six months of water deficit (November-April) were identified. Overall, 27 years of water deficit was discovered over the 40 years period. Water balance pattern revealed the highest annual mean water surplus (324.51 mm) in the hinterland of Idanre, Akure, and Owo rather than the coastal city of Ikeja which can be attributed to orographic effect in the hinterland. The study area with a mean Aridity index (AI) of 0.94 can still be regarded as humid environment, although the spatial variability of AI indicates that the northern part is tending towards a dry sub-humid condition (AI= 0.76). This study recommends conservation of water surplus in the wet months for the augmentation of deficit in the dry months; this will not only boost agricultural production, but also alleviate water supply problem in the study area.

Keywords. Aridity index, potential evapotranspiration, water balance.

1 Introduction

Rainfall and evapotranspiration are among the most significant variables that can be used to determine the cause of climate change and show the level of environmental response to climate change on a basin or regional scale (Yao *et al.* 2005, Cannarozzo *et al.* 2006, Liu *et al.* 2008). Precipitation and evapotranspiration represent the volumes of incoming and outgoing water in the hydrological budget which is believed to be the same in the long run (Christopherson 1995). This can be seen in term of water balance which demonstrates the condition of water surplus or deficit at a particular place and time. Spatial and temporal variability in rainfall amount and evapotranspiration as a result of global climate change is posing serious danger to water resources management, rain-fed agriculture, food security and poverty reduction especially in the developing countries. In fact, by the year 2020, crop yield from countries practicing majorly rain-fed agriculture could reduce by about 50%, while access to food in sub-Saharan Africa is projected to be seriously compromised (IPCC 2007).

Evapotranspiration which refers to the combined processes of evaporation and plant transpiration is a key element in the hydrological budget; it does not only control the moisture transfer to the atmosphere, but also influence the principal properties of terrestrial ecosystems such as runoff, soil moisture and plant growth (Fisher *et al.* 2011). Evapotranspiration is used in the assessment of water surplus and deficit among many other components of water balance. However, in many scenarios, direct field measurement of evapotranspiration is typically not attainable because it is costly and time-consuming, and often the required instrumentation may not be available (Ejieji 2011), hence the adoption of potential or reference evapotranspiration. In a situation, where the soil is at field capacity, actual evapotranspiration will equal potential evapotranspiration (PET) and moisture input will exceed potential evaporation. In such circumstance, the excess rainfall over evapotranspiration is known as water surplus, while water deficit is represented by the condition of excess evapotranspiration over rainfall (Egwuonwu *et al.* 2012). Based on this premise, this present study assumed that potential evapotranspiration is equal to actual evapotranspiration and it is used interchangeably.

Penman (1956) defined PET as the amount of water transpired in unit time by a short green crop, completely covering the ground, of uniform height and never short of water. However, the deficiency in Penman (1956) definition resulted to the introduction of reference evapotranspiration (Allen *et al.* 1998), which is defined as 'the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground'. PET is influenced by several factors amongst which include the net solar radiation, size of surface water bodies, wind speed, type and size of vegetative cover, availability of soil moisture, reflective land surface, and change in land use/ land cover. For example, land surface characteristics has been altered in most parts of the world, especially in Africa where larger percentage of the inhabitants depend solely on primary activities for their survival. It is important to note that the alteration of land cover by anthropogenic activities changes the land surface characteristics and influence evapotranspiration process on regional scale, thus altering the regional hydrological cycle.

Africa is one of the continents most vulnerable to the climate change phenomenon, and within Africa, Nigeria is one of the countries expected to be worst affected (Cubasch *et al.* 2001, ERM 2009 cited in Salami *et al.* 2010). The hydrological cycle is anticipated to be amplified in a warming climatic scenario (IPCC 2007) with increasing surface temperature, changes in precipitation patterns, and evapotranspiration rate (Ingol-Blanco 2008). For instance, an increase in temperature and decrease in rainfall amount of about 1.1°C and 81 mm respectively were reported in Nigeria between 1901 and 2005. In fact, the changes in temperature and rainfall in Nigeria differ significantly since the 1970, with rainfall becoming unpredictable (Bello *et al.* 2012). These evidences of decreasing rainfall and increasing temperature suggested the incidence of climate change in Nigeria. Based on the Clausius–Clapeyron equation, a warmer atmosphere will hold more water and in turn results to higher evaporation (Fan and Thomas 2012). Therefore, with the increasing temperature, Nigeria is expected to witness an upward trend in PET. In addition, any changes in PET will affect precipitation and the hydrological regimes. This will also have a direct influence on crop production through changes in the agroecological water balance (Thomas 2000) and availability of soil moisture to meet crop water requirement (Ayoade 2008).

The change in PET and its direct effects on crop production is responsible for the changing ecological zones in Nigeria and the advancement of desertification southwards towards the Western Lithoral hydrological zone (WLHZ) of the country (Medugu *et al.* 2009, Olagunju 2015). The change in the ecological zone of Nigeria can also be attributed to the variability in climatic condition as a result of the increasing global warming (Olagunju 2015), which has consequently increased the level of aridity that has resulted to recurring crop failure (Abdulkadir *et al.* 2015) and water shortages across Nigeria. The above scenario has also induced a southward migration of people, particularly herdsmen and their livestock towards WLHZ of Nigeria (Abdulkadir *et al.* 2013), and this perhaps might be the reason for the recent recurring herdsmen and farmers clashes in Nigeria. Thus, the changes in climatic conditions, coupled with the changes in the ecological zone might slowly results to the expansion of the aridity zones in Nigeria, which will significantly impact water availability for competing users.

Aridity is the interplay between rainfall and evapotranspiration which is usually used to define drought and delineate arid area (Ayoade 2003, Maliva and Missimer 2012). This relationship is often evaluated using the aridity index (AI) and it often used to assess the trends of aridity or humidity in an environment. In a situation where AI is larger than normal in a region, the climate tends to suffer from drought and water resource shortages (Li *et al.* 2017). The AI helps to identify, locate or delimit regions that suffer from water deficit, a situation that can extremely impact the efficient use of land for agriculture or livestock-farming (Paparrizos *et al.* 2016). Although the WLHZ of Nigeria is a humid environment, estimating AI of the area will enhance the understanding of how fast the study area is changing.

The study area is experiencing rapid population growth and the natural tropical rainforest has been depleted and replaced with farm lands, built up areas, paved surfaces, etc. through anthropogenic activities. All the changes experiencing in the study area will no doubt alter the surface characteristics of the area which will influence the rainfall and PET pattern, and affect the climatic water balance of the region. The change in the climatic water balance will also affect the rain-fed agriculture practices in the study area. Thus, understanding the spatio-temporal distribution of rainfall and potential evapotranspiration in a dynamic environment like this will enhance the understanding of the climatic water balance and aridity level for the purpose of water resources management, particularly in the area of agricultural planning.

2 Material and Methods

2.1 The study area

The study area in this investigation, the Western Lithoral hydrological zone (Figure 1) is one of the eight contiguous hydrological catchments known as hydrological zones which are the building blocks of all hydrological evaluations in Nigeria. They serve as units for scientific assessments and management of water resources in the country (Federal Ministry of Water Resources [FMWR] 2014). The area comprises of Lagos, Ogun, Oyo, Osun, Ondo, Edo and Ekiti States lies between longitudes 3°-7°E and between latitudes 4°-8°N. The population of the study area is about 31 million people (National Bureau of Statistics 2012). The climate of the area is influenced by three major wind currents of maritime tropical (mT) air mass, continental tropical (cT) air mass and equatorial easterlies. This geographic zone has an annual rainfall of over 1500mm and exhibit double maxima rainfall pattern, with a dry period of four months in some parts of the region. The annual rainfall in the area varies from 1,600 mm/year in the southeastern part to 1,000 mm/year in the northern part. About 16% of the total rainfall received in the region results in runoff, while the remaining is lost through evapotranspiration (Federal Ministry of Water Resources [FMWR] 2014). The mean annual temperature of 27°C is fairly constant in the zone and annual mean relative humidity is about 70%.

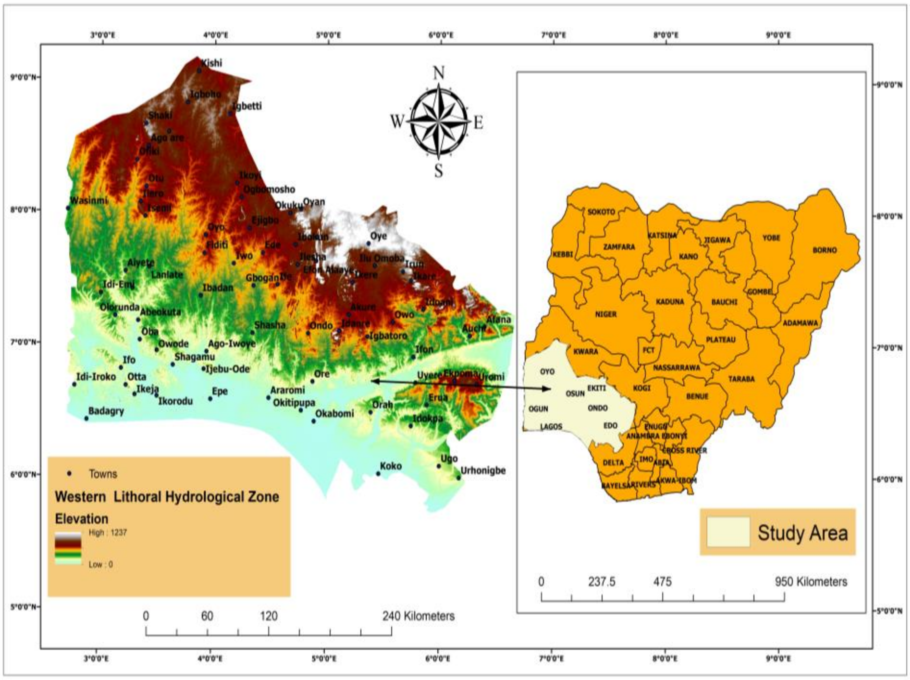

Fig. 1. Western Lithoral Hydrological Zone of Nigeria

The vegetation pattern of the northwestern part of the study area is rainforest in the South, Sudan and Guinea savannah in the North. Thick forest in the south gives way to grassland interspersed with trees in the North. The composition is basically the large tall crowned trees, mixed with thick undergrowth. The northeastern part is covered by secondary forest and derived Savannah mosaic predominates across the area. Originally, the northeastern part of the study area had a natural lowland tropical rain forest vegetation, but this has since given way to secondary forest re-growths as a result of anthropogenic activities. The vegetation of the eastern part of the study area is the high forest, composed of many varieties of hardwood timber such as *Melicia excelsa*. Rainforest is found in the southern part of the eastern section of the study area which has been reduced to derived degraded Savannah. Tropical rain forest and Guinea savanna are found in the western section of the study area in and around Ogun State. Swamp Forest of the coastal belt and dry lowland rain forest are found in the southwestern portion of the study area. The climate in the study area favours the cultivation of crops like maize, yam, cassava, millet, rice, plantain, cocoa tree, palm tree and cashew.

The relief in the northern part of the study area is relatively high with elevation range between 400-500 m, while the elevation in the remaining part undulates around 200 m. Two main relief regions may be identified in the northwestern part of the study area, the first is the inselberg land scape which is part of the Yoruba highlands, while the second is the coastal plain. The region of inselberg landscape covers more than half of this part of the study area. The northeastern part is characterized by numerous domed hills and occasional flat-topped ridges, and the more prominent hills in this region are found at llesa, lgbajo, Okemesi, Elu and Oba. The eastern part composed of lowlands and rugged hills with granitic outcrops in several areas. Undulating lowlands that belong to the coastal sedimentary rocks of western Nigeria is found in the western section of the study area.

Soils in the northwestern part of the study area are fertile loamy derived mainly from the Pre-Cambrian hornblende biotite gneiss. In the forest zone of the southern parts of the study area, clay, laterite and thick rich dark loamy and humus soils are found. The soils are frequently water-logged in many parts during the wet season. Northward, the soils are lighter and become a mixture of laterite and fine grained loamy and humus materials. The soils of the northeastern part of the study area belong to the highly ferruginous tropical red soils associated with basement complex rocks. Older sand ridge complexes develop brown and orange sandy soils, and light grey sandy soils are found in the eastern part around the coastal area.

2.2 Methods

Monthly climatic data for 40 years spanning 1976 to 2015 from six NIMET (Nigeria Metrological Agency) stations located in Ikeja, Ibadan, Akure, Abeokuta, Osogbo and Ilorin were used in the study. The climatic variables include rainfall amount, minimum and maximum temperature, sunshine hour, relative humidity and wind speed. Due to the difficulties in estimating actual evapotranspiration, the potential evapotranspiration was assumed to be equal to actual evapotranspiration in the study area. Thus, this study viewed evapotranspiration from the point of field capacity where potential evapotranspiration always equates actual evapotranspiration. The FAO Penman-Monteith method as used by Allen *et al.* (1998) was adopted in estimating the potential evapotranspiration (PET). The method was selected because it is physically based and clearly incorporates both physiological and aerodynamic parameters. It is regarded as the most reliable predictor of PET rates under all climatic conditions (Jensen *et al.* 1990). Thus, the ETo calculator version 3.2 of FAO was used to compute PET in this study. The details of the ETo calculator may be found in the reference manual by Raes (2012) and is computed from the equation (1),

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(\mathrm{e}_s - \mathrm{e}_a)}{\Delta + \gamma(1 + 0.34\mathrm{u}_2)} \tag{1}$$

where, ET_o= reference evapotranspiration (mm day^{-1}), R_n= net radiation at the crop surface (MJ m^{-2}day^{-1}), G= soil heat flux density (MJ m^{-2}day^{-1}), T= mean daily air temperature at 2m height (°C), u_2= wind speed at 2 m height (ms^{-1}), e_s= saturation vapour pressure (kPa), e_a= actual vapour pressure (kPa), Δ= slope vapour pressure curve (*kPa* °C^{-1}), and γ= psychrometric constant (*kPa*°C^{-1}).

The rainfall amount and PET for the period 1976 to 2015 in each of the six weather stations were aggregated to find the mean annual rainfall and PET for the study area, while the estimated mean annual and monthly PET were subtracted from mean annual and monthly rainfall data to estimate the annual and monthly mean water balance for the study period. The study assumed there had been no moisture carry-over from previous months, for example, from October to November (Owoade 1989). Hence, water balance for each month were estimated by subtracting the mean PET from mean rainfall amount in each month. The estimated water balance was interpolated using universal kriging method in ArcGIS 10.4 to determine their spatial pattern in the study area. The kriging interpolation method was adopted because studies such as Chong-yu *et al.* (2006), Zhifeng *et al.* (2011) and Tesfamichael *et al.* (2013) have shown that the technique yields better results than other interpolation methods such as Inverse Distance Weighted (IDW) and Thiessen polygon among many others. Three spatial pattern maps were generated which include the mean annual water balance, the mean monthly water deficit (November-April) and the mean monthly water surplus map (May-October).

The trend in rainfall amount, PET estimated water balance, AI were determined from the non-parametric Mann-Kendall trend test statistics and regression statistics; this enables the comparison of results from the two methods. The null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered. This test does not require the assumption of normality, and only shows the direction but not the magnitude of significant trends (McBean and Motiee 2008, Olofintoye and Sule 2010). The Mann-Kendall test statistic S is calculated using the formula in equations (2) and (3),

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} Sgn\left(x_j - x_k\right) \tag{2}$$

where x_j and x_k are the annual values in years j and k, $j>k$, respectively and

$$Sgn(x_j - x_k) = \begin{pmatrix} 1 & if & x_j - x_k > 0 \\ 0 & if & x_j - x_k = 0 \\ -1 & if & x_j - x_k < 0 \end{pmatrix} \quad (3)$$

A very high positive value of S is an indicator of an increasing trend, while a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size n, to statistically quantify the significance of the trend (Khambhammettu 2005, Olofintoye and Sule 2010); the computation of variance of S is from equation (4).

$$VAR(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p>1}^{q} t_p(t_p-1)(2t_p+5)\right] \quad (4)$$

Here q is the number of tied groups and tp is the number of data values in the p^{th} group. The values of S and $VAR(S)$ are used to compute the test statistic Z as shown in equation (5).

$$Z = \begin{pmatrix} \frac{S-1}{\sqrt{VAR(S)}} & if & S > 0 \\ 0 & if & S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if & S < 0 \end{pmatrix} \quad (5)$$

Z follows a normal distribution. The Z value is tested at 95% level of significance (Z0.025=1.96). The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend (Khambhammettu 2005, Olofintoye and Sule 2010). In addition, the regression statistics model for determining trend was computed from equation (6),

$$Y = a + b_{X_t} \quad (6)$$

where Y is the trend value, a is the intercept, b is the slope of trend and X_t is the time point coded. Also, the descriptive statistics such as mean and standard deviation were used to describe the data set. The coefficient of variation (CV) was adopted to show the percentage of variability in the PET and rainfall amount. The CV is calculated using the formula in equation (7).

$$CV = \left(\frac{SD}{\overline{X}}\right) \times 100 \quad (7)$$

The Aridity index (AI) for the study area was computed using the rainfall and PET data from the six stations used in this study. The AI for each of the weather station were aggregated to find the annual aridity for the study area between 1976-2015, and the same data was used to estimate the spatial distribution of aridity in the study area using universal krigging interpolation method in ArcGIS 10.4. The AI in the study area is estimated using equation (8),

$$AI = \frac{AR}{APET} \tag{8}$$

where AR is the mean annual rainfall amount, and APET is the annual potential evapotranspiration. The aridity classification for various level of aridity is displayed in Table 1.

Table 1. Aridity Classification.

Classification	**Aridity Index (AI)**
Hyper-arid	AI ≤ 0.05
Arid	0.05 ≤ AI < 0.20
Semi-arid	0.20 ≤ AI < 0.50
Dry sub-humid	0.50 ≤ AI < 0.65
Sub-humid	0.65 ≤ AI < 0.80
Humid	0.80 ≤ AI < 1.5
Very humid	1.5 ≤ AI

Source: FAO, 1993

3 Results and Discussion

3.1 Rainfall amount and potential evapotranspiration in the study area

The highest mean monthly rainfall amount (228.09 mm) was recorded in June, then followed by month of September (219.10 mm), while the lowest (9.23 mm) was in January (Table 2). The results of the coefficient of variation shows that the mean monthly rainfall amount in the study area were homogeneous, except in February (34.10%) and March (20.14%) that are slightly varied. These results can be attributed to the fact that February and March falls within the peak period of dry season in the study area. The variation in monthly pattern of rainfall amount in the study area may not be unconnected with the movement and location of the Intertropical Convergent Zone (ITCZ) that governs rainfall occurrence in Nigeria (Ashaolu 2018). The highest mean rainfall amount in June can be attributed to the position of ITCZ over the Tropic of Cancer in June. The months of June and September recording the highest mean rainfall amount is as a result of the ITCZ passing over the study area two times in the year. The movement north of the ITCZ first towards the Tropic of Cancer as well as its return southward towards the Tropic of Capricorn, explains why rainfall amount in the area varies over space and time. However, this observed variation might be affected by local conditions such as vegetation, presence of highlands in the northeastern part of the study area which might influence the microclimate of such areas. The lowest mean rainfall amount observed in January may not be unconnected with the movement south of ITCZ to the Tropic of Capricorn, which is responsible for the study area experiencing little or no rainfall at this period of the year. This agrees with the NIMET (Nigeria Metrological Agency) findings (2013, 2012) on the rainfall pattern in Nigeria.

Table 2. Monthly pattern of rainfall and potential evapotranspiration (PET) in the study area (1976-2015).

	Mean (mm)		SD (mm)		CV (%)	
	Rainfall	PET	Rainfall	PET	Rainfall	PET
January	9.23	143.45	0.96	18.87	10.40	13.15
February	33.28	147.69	11.35	16.21	34.10	10.98
March	75.09	156.84	15.12	17.9	20.14	11.41
April	127.88	145.80	15.20	11.19	11.89	7.67
May	172.14	129.99	3.24	8.93	1.88	6.87
June	228.09	109.82	29.01	7.28	12.72	6.63
July	203.18	94.95	18.76	4.51	9.23	4.75
August	149.68	92.74	18.04	4.59	12.05	4.95
September	219.10	101.37	19.41	2.52	8.86	2.49
October	167.65	115.22	11.75	4.47	7.01	3.88
November	44.18	128.20	8.98	7.82	20.33	6.10
December	10.67	132.16	1.84	13.88	17.24	10.50

SD= Standard Variation, CV= Coefficient of Variation

The highest mean monthly PET (156 mm) was recorded in March, while the lowest mean PET (92.74 mm) was recorded in August (Table 2). The highest mean PET in March can be attributed to the dominance of the tropical air mass at this period of the year which is also the dry season in most part of the study area. The high PET in this period may not be unconnected with the dusty air mass that carries no moisture. Iroye (2013) has earlier reported high evapotranspiration rate in the dry period in Ilorin, a location which bounded the study area in the north. The results of the coefficient of variation shows that monthly PET is homogeneous, except in January (13.15%) and March (11.41%) which are slightly higher than the other months during the study period.

Trend in rainfall amount (1976-2015)

Table 3 reveals the nature of rainfall trends in Abeokuta, Ibadan, Ikeja and Osogbo which shows positive values. The Z values obtained for these stations which shows greater values than the level of significance (1.96) indicates that the increasing trend in rainfall amount observed in those locations are statistically significant. This implies that the positive trends demonstrated at these stations have an underlying causative factor(s). It can therefore be ascertained, based on the evidence at hand (1976-2015) that the rainfall amount in Abeokuta, Ibadan, Ikeja and Osogbo would increase into the future. On the other hand, the increasing trend in rainfall amount in Akure and the decreasing trend in Ilorin are not statistically significant. The results signify that the positive and negative trends observed in Akure and Ilorin, respectively occurred by chance and cannot be associated to a particular factor. Thus, the near future direction of rainfall amount in these two locations cannot be predicted based on the records used in this study.

Table 3. Trends in rainfall amount in the Western Lithoral hydrological zone of Nigeria (1976-2015).

Methods	SN	Stations	S	Z	Q	Trend Significance	Nature of Trend
Mann-Kendall	1	Abeokuta*	221.00	3.12	13.76	Significant	Positive
	2	Akure	138.00	1.60	5.52	NS	Positive
	3	Ibadan	182.00	2.11	10.12	Significant	Positive
	4	Ikeja	265.00	3.08	13.80	Significant	Positive
	5	Ilorin	-34.00	-0.38	-1.11	NS	Negative
	6	Osogbo	170.00	1.97	6.05	Significant	Positive
		Study Area	236.00	2.74	7.34	Significant	Positive

	SN	Weather Variables	P-value	Regression equation	Sample correlation	Trend Significance	R^2 (%)
Linear Regression	1	Abeokuta*	.002	Y=1018.21+12.81X	.496	Significant	2
	2	Akure	.613	Y=1618.10+1.84X	.082	NS	0.7
	3	Ibadan	.048	Y=1166.60+8.07X	.315	Significant	9
	4	Ikeja	.001	Y=1276.40+13.89X	.522	Significant	27
	5	Ilorin	.987	Y=1166.80-0.05X	-.003	NS	0.001
	6	Osogbo	.050	Y=1254.90+5.21X	.312	Significant	9
	Study Area		.005	Y=1273.90+5.91X	.434	Significant	19

*Abeokuta record covers only 1981-2015; Z= normalized test statistic; Q= Sen Slope estimate; NS= Not significant

The result of the linear regression presented in Table 3 further strengthen the results of the Mann-kendall trend analysis. The result of the regression shows that there is a statistically significant positive relationship between rainfall amount and year at 95 % confidence level in Abeokuta (p = 0.002), Ibadan (p= 0.048), Ikeja (p= 0.001) and Osogbo (p= 0.50). Non-significant increasing trend was however observed in Akure (p= 0.613), while a non-significant decreasing trend was observed in Ilorin (p=0.987). The regression equation, revealed that rainfall amount increased at a rate of 12.81 mm/year in Abeokuta during the period 1981 to 2015. Rainfall amount also increased at a rate of 1.84 mm/year in Akure; 8.07 mm/year in Ibadan; 13.88 mm/year in Ikeja and 5.42 mm/year in Osogbo between 1976 and 2015. However, rainfall amount decreased at the rate of 0.05 mm/year in Ilorin during the same period.

The aggregated rainfall amount for the Western Lithoral hydrological zone (WLHZ) exhibits an increasing trend over the study period with Z value of 1.97 which is greater than the 1.96 level of significance. This indicates a statistically significant increasing trend in rainfall amount in the study area (Table 3). The linear regression analysis also confirmed the statistically significant ($p = 0.005$) positive relationship between rainfall amount and year at 95% confidence level in the area. The trend line equation revealed that rainfall amount increased at the rate of 5.91 mm/year in the study area between 1976 and 2015 (Figure 2). This result is at variant with the study of Oriola *et al*. (2017) who observed a downward trend of about 6.99 mm/year in rainfall amount of Niamey in Niger Republic. This is anticipated as Niamey is located in Sahel environment.

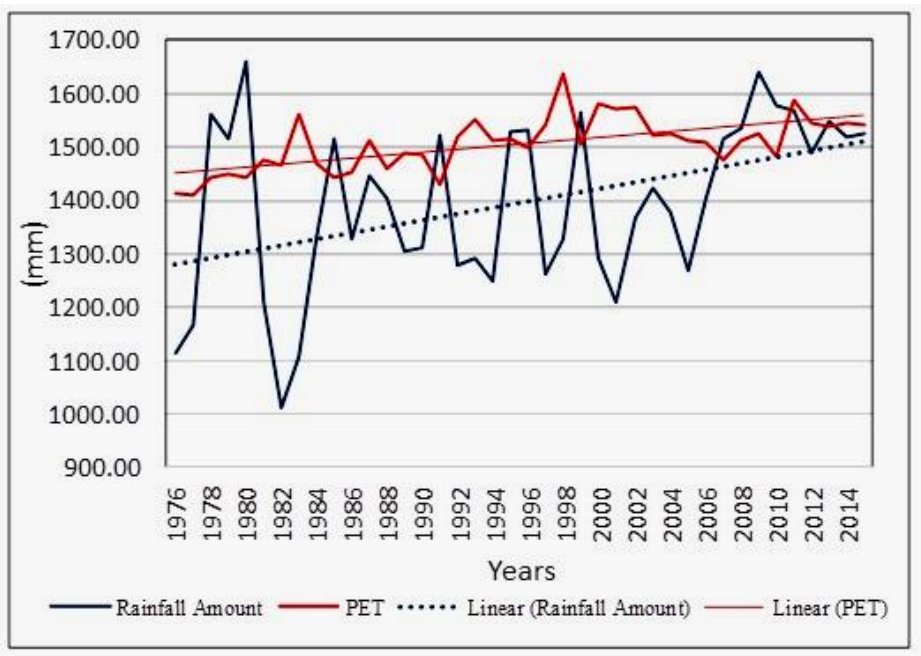

Fig. 2. Trends in rainfall amount and potential evapotranspiration (PET) in the Western Lithoral Hydrological Zone of Nigeria, 1976-2015.

Trend in potential evapotranspiration

Positive PET trends were observed in Abeokuta, Akure, Ikeja and Ilorin, which is an indication of an increasing PET (Table 4). The Z-values obtained in these stations suggested a statistically significant increasing trend that can be attributed to causative factor(s). Such factors may not be unconnected to the duration of sunshine hour, wind speed and relative humidity which have significant impact on PET than the air temperature (Gao *et al.* 2006). Based on the evidence at hand (1976-2015), it can be ascertained that PET in Abeokuta, Akure, Ikeja and Ilorin would continue to increase in the future. On the other hand, the positive PET in Ibadan with Z-value of 1.20 indicated an increasing trend that is not statistically significant, while in Osogbo, the downward trend in PET is not statistically significant. Thus, the evidence at hand (1976-2015) is not enough to ascertain the future trend in PET in Ibadan and Osogbo.

Table 4: Trend in potential evapotranspiration in the Western Lithoral hydrological zone of Nigeria (1976-2015).

Methods	SN	Stations	S	Z	Q	Trend significance	Nature of trend
Man--Kendall	1	Abeokuta*	316.00	4.47	5.13	Significant	Positive
	2	Akure	357.00	4.15	1.77	Significant	Positive
	3	Ibadan	104.00	1.20	1.51	NS	Positive
	4	Ikeja	331.00	3.85	4.26	Significant	Positive
	5	Ilorin	289.00	3.36	4.49	Significant	Positive
	6	Osogbo	-39.00	-0.44	-0.32	NS	Negative
		Study Area	380.00	4.42	2.77	Significant	Positive

Methods	SN	Weather Variables	P-value	Regression equation	Sample correlation	Trend Significance	R^2 (%)
Linear Regression	1	Abeokuta*	.001	Y=1322.20+5.36X	.716	Significant	51.30
	2	Akure	.001	Y=1244.90+3.74X	.631	Significant	39.8
	3	Ibadan	.275	Y=1502.70+1.46X	.177	NS	3.12
	4	Ikeja	.001	Y=13989 + 4.32X	.608	Significant	36.99
	5	Ilorin	.002	Y=1757.90+3.89X	.482	Significant	23.24
	6	Osogbo	.604	Y=1427.70-0.05X	-.084	NS	0.71
		Study Area	.001	Y=1448.80+2.77X	.633	Significant	40

*Abeokuta record covers only 1981-2015; Z= normalized test statistic; Q= Sen Slope estimate; NS= Not significant

The results obtained from the regression trend (Table 4) further reinforced the observed trend in PET in the six locations estimated with the Mann-Kendall trend statistics. The results of the non-significant trend in Osogbo is an indication of uncertainty in the future direction of PET in the area, hence, an upward trend might occur in Osogbo in the future. However, the decreasing PET rates as observed in Osogbo will not only increase availability of soil water but will also encourage the growth of natural vegetation. If the trend observed in rainfall and PET remain unchanged, agricultural activities, particularly in Akure and Ilorin may be adversely affected by shortage of water in the growing season. Also, the increasing trend in rainfall and PET in Ikeja and Abeokuta will have both positive and negative effect in those two locations depending on the amount of rainfall in relation to PET. The regression equation shows that PET increased at the rate of 5.36 mm/year in Abeokuta during the period 1981 to 2015. PET is also increasing at the rate of 3.74 mm/year in Akure; 1.46 mm/year in Ibadan; 4.32 mm/year in Ikeja; and 3.89 mm/year in Ilorin between 1976 and 2015, while it decreased at the rate of 0.51 mm/year in Osogbo during the same period (Table 4).

The aggregated PET for the WLHZ exhibits an increasing trend over the period of study. The Z-value was 4.42 which indicated a statistically significant upward trend in PET amount in the study area (Table 5). The linear regression analysis also suggested a statistically significant ($p<0.001$) positive relationship between PET and year at 95 % confidence level in the study area. The regression equation revealed that PET increased at the rate of 2.77 mm/year in the study area between 1976 and 2015 (Figure 2).

3.2 Climatic water balance in the study area (1976-2015)

Figure 3 shows the water balance graph for the study area between 1976 and 2015. The figure revealed that the mean monthly rainfall is higher than the mean monthly PET in the study area from May to October (six months), while the mean monthly PET is higher than the mean monthly rainfall from November to April (six months). The implication of this is that water availability is at surplus for six months and at deficit for the same period of time. The six months of water surplus is also the cultivation season in the study area. A similar pattern was observed by Iroye (2013) on water budget situation in Ilorin, Nigeria. The six months with high PET coincide with dry season in the study area when insolation is high and relative humidity is low compared to the rainy season when insolation is low and relative humidity is high (Ayoade 2003). The water scenario in the study area is like a two-sided coin with positive and negative implications, while the six months of water surplus may positively influence agricultural practices and increase the income of local famers in most of the rural settlements on the one hand, the surplus moistures condition may also negatively influence hydrological processes in the area through flood generation with all its attendant problems.
Also, the six months of water deficit will not only affect peasant farmer operations but also affect groundwater resources of the study area. For example, reduced soil moisture may lead to crop failure, while reduced

recharge will lead to a significant drop in groundwater level which is the source of domestic water consumption for most of the rural dwellers and a large percentage of the urban residents in the study area. The relationship between mean monthly rainfall and PET in the Western Lithoral hydrological zone between 1976 and 2015 is as depicted in Figure 3.

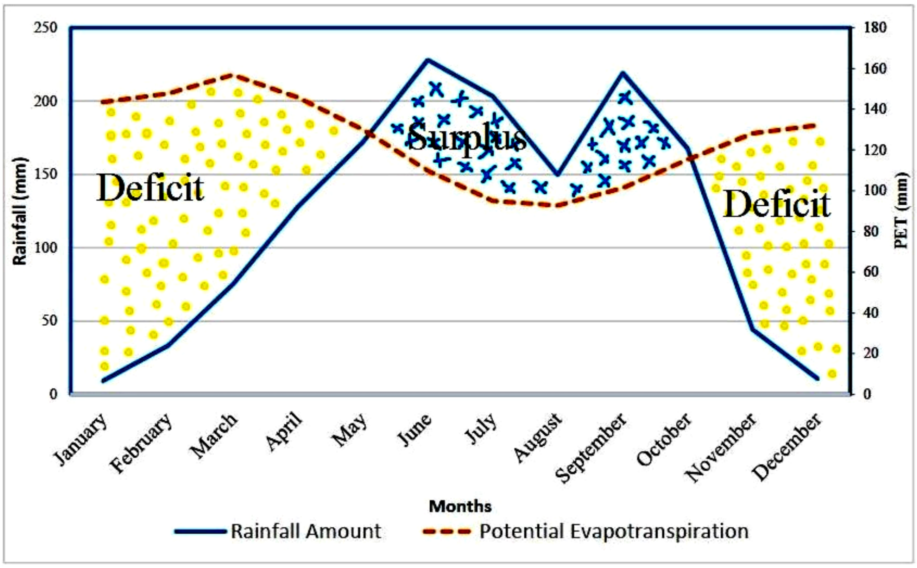

Fig. 3. Relationship between monthly rainfall and potential evapotranspiration in the Western Lithoral Hydrological Zone of Nigeria (1976-2015).

The aggregated mean annual rainfall amount for the study area from the six weather stations is 1395 mm, while the mean annual PET is 1505mm between 1976 and 2015 (Table 5). Four out of the six stations used in this study (Abeokuta, Ibadan, Ilorin, and Osogbo) had water deficit, while two stations (Akure and Ikeja) had water surplus. The highest water surplus (217 mm) was observed in 1980, while the lowest (8 mm) was in 2013. The year 1983 witnessed the highest water deficit situation (-455 mm), while the lowest (-18 mm) was in 2015 (Figure 4). Between 1976 and 1985, 4 periods (1978, 1979, 1980 and 1985) of water surplus were observed, while only two period (1991 and 1995) of water surplus were observed between 1986 and 1995. In like manner, two period (1996 and 1991) of water surplus were observed between 1996 and 2002, while 5 periods (2007, 2008, 2009, 2010 and 2013) of water surplus were observed in the last 10 years covered by this investigation. Overall, 13 years of water surplus were discovered, while the remaining 27 years were period of water deficit. This result shows water deficit of about 68% of the total period of investigation. The long period of water deficit situation can be aggravated by the farmers' in the region because of their low level of adoption of minimum tillage practice. The adoption of irrigation and tillage practices is desirable in the study area because such practices usually minimize PET (Chineke *et al.* 2011) and thus sustain agricultural productivity. In general, it can be concluded that there was water deficit situation in the study area over the 40 years (Table 5). Oriola *et al*. (2017) has earlier observed similar result of water deficit situation for Niamey, Niger Republic located north of the study. Based on the result from this study, it can be concluded that the practice of rainfed agriculture may not be sustainable in the study area because the rainfall pattern which has been changing over the years (Odekunle and Eludoyin 2008).

Table 5. Mean annual rainfall amount and potential evapotranspiration (PET) in the Western Lithoral hydrological zone of Nigeria (1976-2015).

SN	Stations	Rainfall (mm)	PET (mm)	Remarks
1	Abeokuta*	1249	1439	Deficit
2	Akure	1656	1321	Surplus
3	Ibadan	1354	1533	Deficit
4	Ikeja	1561	1487	Surplus
5	Ilorin	1166	1838	Deficit
6	Osogbo	1366	1417	Deficit
Study Area Annual Average		1395	1506	Deficit

*Record covers only 1981-2015

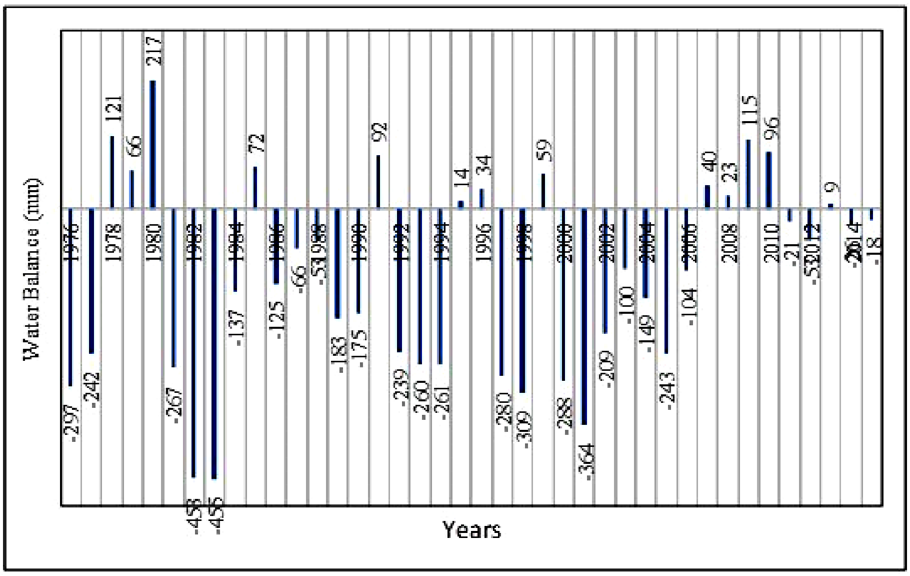

Fig. 4. Yearly pattern of water balance in the study area (1976-2015)

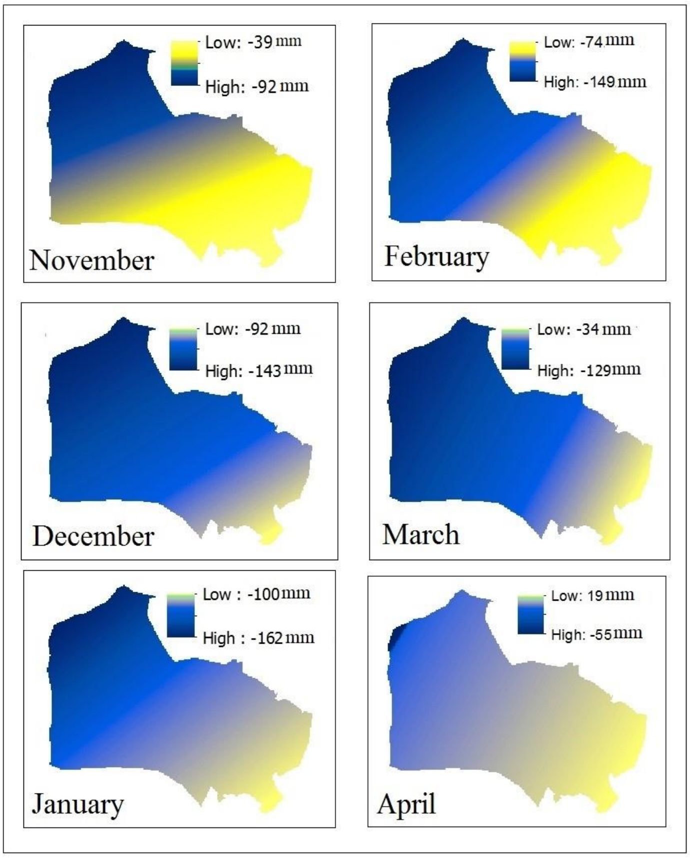

Fig. 5. Mean monthly pattern of water deficit in the study area (November - April)

Pattern of mean monthly water deficit (November-April)

Figure 5 shows the spatial variation in mean monthly water deficit across the study area. The highest deficit (-92 mm) was observed in November in settlements such as Kishi, Ogboro, Shaki and Ofiki located in the northwest, while the lowest deficit (-39 mm) were observed in southeastern settlements that include Urhonigbe, Ewonimi and Uromi. The highest deficit (-143 mm) in December was in the northwestern part of the study area in settlements like Ago Are, Shaki and Agbonle, while the lowest deficit (-92 mm) was at the fringe of the southeastern part in settlements such as Oben, Urhonigbe and Ugo, etc. The highest deficit (-162 mm) in January was in the northwestern part in settlements such as Agbonle, Kishi and Ogbooro, etc., while the lowest deficit (-100 mm) was recorded at the fringe of the southeastern part in settlements such as Ewonimi, Ubiaju, Uromi and Ekpon. The deficit recorded in February and March follow similar pattern to the other months with water deficit, although with varying spatial coverage (Figure 5).

Although, there are water deficit (-55 mm) in the extreme northwestern part in April, larger portion of the study area recorded a very low water surplus. Some parts experiencing surplus in April is because this month marks the beginning of rainy season in most parts of the study area, although rainfall during this period is sporadic and unpredictable. For example, a surplus of 19 mm was recorded at the southeastern part of the study area in settlements that include Urhonigbe, Ewonimi and Ubiaju. This indicates that more rainfall was recorded in these settlements in April compared to other settlements during the period of investigation.

The highest water deficit in northwestern part of the study area may not be unconnected with the duration of sunshine hour, and low rainfall amount. This condition is also being aggravated by the nature of land use/land cover in the area. The water deficit in the six months period is no doubt posing serious implications on socioeconomic activities of residents of the rural communities within the hydrological zone. These are people whose livelihood are majorly based on subsistence arable agriculture and livestock rearing. Also, the changes in rainfall amount which is lower than the observed PET in the six months of deficits will pose serious hydrological implications in the region depending on other prevailing environmental conditions. According to Chen *et al.* (2006), generally, any changes in PET rates influences the terrestrial ecosystem, particularly the crop production. Other effects that can be manifested by water deficit situation in the study area include hunger, malnutrition, and deterioration of soil moisture and water resources.

Pattern of mean monthly water surplus (May-October)

Figure 6 reveals the spatial pattern of monthly water surplus in the study area. For the month of May, the highest surplus (70 mm) was in the southeastern settlements such as Uromi, Ugbenu, and Auchi, while the lowest surplus (18 mm) was in the northwestern settlements such as Agbonle, Ogbooro and Shaki. Also, the highest surplus (203 mm) in June was in southeastern settlements such as Owena, Ikare, Idokpa and Auchi, while the lowest surplus (53mm) was in northwestern part fringe in settlements such as Kishi, Agbonle and Ogboro. The highest surplus (146 mm) in July was in southeastern settlements such as Ugbenu, Urhonigbe and Ekpon, while lowest surplus (67 mm) was at the fringe of northwestern part of the study area around settlements such as Wasinmi, Awoye and Ago Are, etc. The water surplus pattern from May through July indicated that the southwestern part which exhibits the lowest water deficit is also the axis with the highest surplus. The southwestern part of the study area is likely not to surfer severe water shortage if the excess water from the surplus months can be properly managed.

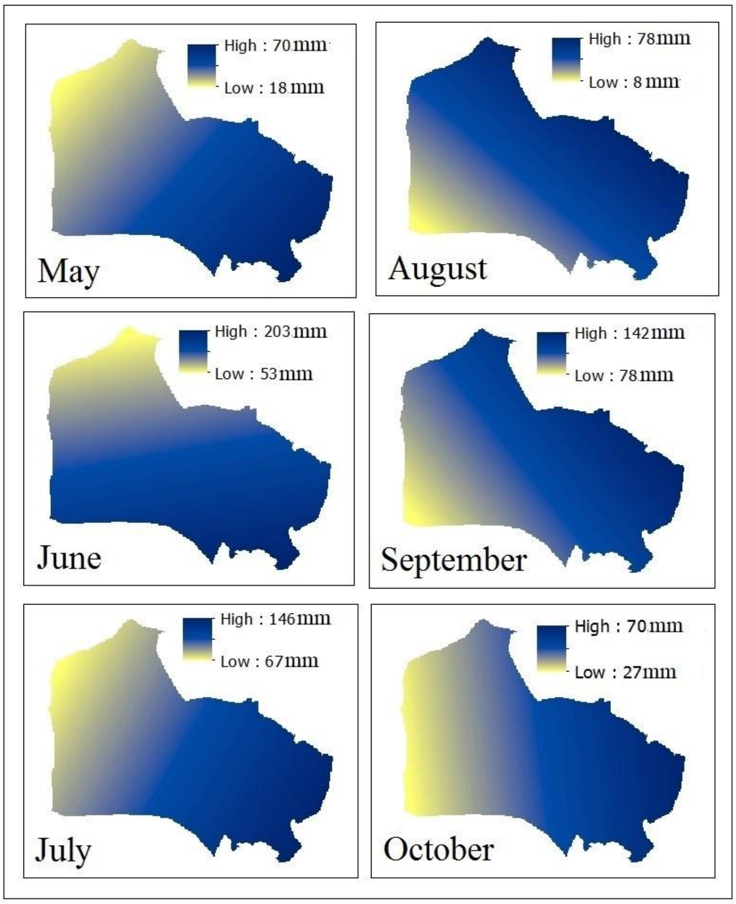

Fig. 6. Mean monthly spatial pattern of water surplus in the study Area (May - October)

The finding also revealed that highest surplus (78.81 mm) in August was in the hinterland around northeastern part and some parts of northwestern area in the zone. This include settlements such as Omuo, Auchi, and Ikare among many others in the northeastern part. The settlements with highest surplus in northwestern part include Ogbomosho, Ikoyi, and Igbeti, while the lowest surplus (8.85 mm) was recorded at the fringe of southwestern part in settlements such as Badagry, Ijofin and Idi-Iroko. The September record also revealed a similar surplus pattern like the month of August.

The highest water surplus (70 mm) in October was in the northeastern and southeastern settlements such as Ifon, Idokpa, Uromi, and Oben, while the lowest surplus (27.73 mm) was at the fringes of southwestern and northeastern settlements such as Ijofin, Idi-Iroko, Idi Emi and Awoye. The change in the spatial pattern of water surplus from August through October may not be unconnected with local conditions such as the presence of highlands, vegetation, level of urbanization, etc. that may influence the microclimate of various locations in the study area.

Pattern of mean annual water balance

The highest mean annual water surplus (324 mm) was recorded in the southeastern and northeastern parts of the study area (Figure 7). This region comprises hinterland settlements such as Idanre, Akure, Owo, Uromi, and Auchi. The lowest annual water deficit (-424 mm) was in the northwestern and southwestern parts. The northwestern and southwestern parts comprise settlements such as Agbonle, Kishi, Shaki, Awoye, Idi Emi, Aworo and Wasinmi. The mean annual pattern of water balance (Figure 7) revealed that settlements in the northeastern and southwestern parts have the highest annual water surplus. These are places with highest mean rainfall amount and very low mean annual PET. This suggests that water surplus experienced in those locations, will increase the soil water storage that will enhance crop production, industrial development and domestic water consumption. In addition, increase in groundwater recharge is expected. This will sustain the domestic water usage, and subsequently maintain the river channels during period of low flow; and sustain the ecosystem of the study area.

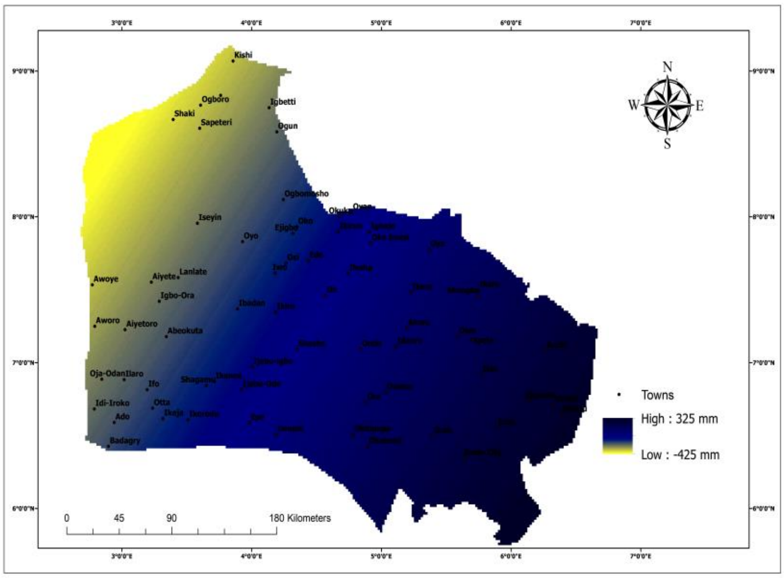

Fig. 7. Mean annual pattern of water balance in the study area (1976-2015).

The northwestern part has the highest water deficit. This result is expected because these are locations with lowest annual rainfall amount and highest PET in the study area. This result follows the general pattern of decrease and increase in rainfall amount and evaporation, respectively in Nigeria. This observation agrees with Ayoade (2003) findings on pan-measured evaporation in Nigeria which revealed a general increase northward towards the interior. The highest amount of PET in these areas may not be unconnected to location towards the north where high solar radiation is recorded as a result of longer period of sunshine hours. It is important to note that these are areas where rain-fed agriculture is being practiced, staple foods are being grown and larger percentage of the population depends on subsistence farming as source of income. In a situation, whereby the mean annual PET rises above the mean rainfall, the crop production and food security of the dwellers will be threatened, their level of income and the general well-being will be compromised. This situation can bring untold hardship, especially on the rural populace whose lives depends entirely on rain-fed agriculture.

3.3 Spatio-temporal variation in Aridity Index in the study area

The variation in annual aridity index (AI) in the Western Lithoral hydrological zone of Nigeria (WLHZ) between 1976 and 2015 is presented in Figure 8.

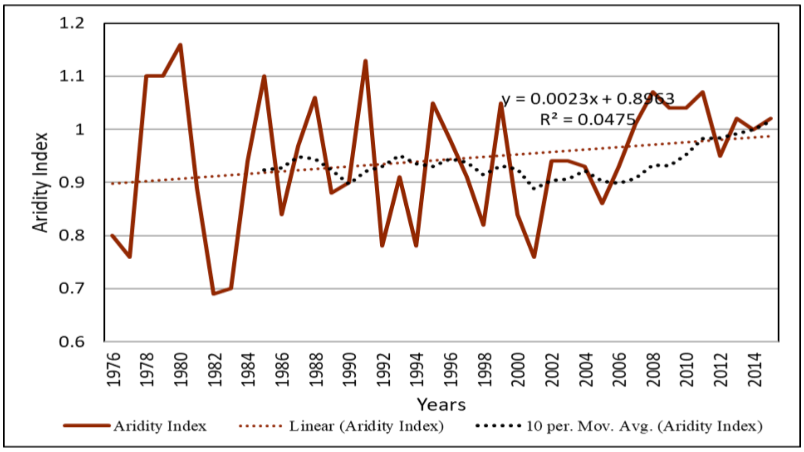

Fig. 8. Trend in Aridity Index in the Western Lithoral Hydrological Zone of Nigeria, 1976-2015.

The annual AI varied from 0.69 to 1.16 across the study area. The mean annual AI for the study area during the period 1976 to 2015 was 0.94, with a coefficient of variation of 12.98%. This result shows that AI was homogeneous during the period of study in the study area. The AI however increases at a rate of 0.0023 year^{-1} in the period of study (Figure 8). The 10-years moving average computed for the study area reveals that AI has been on the rise in the last 10 years of the study, with a mean of AI of 1.01. Based on FAO (1993) AI classification (Table 1), the mean for the last 10 years indicates that the WLHZ of Nigeria is still a humid environment.

Nevertheless, there is spatial variation in AI from the northwestern part to the southeastern part of the study area (Figure 9). The AI ranged from 0.76, a sub-humid condition in the northwestern part to 1.20, which is a humid condition in the southeastern part of the study area. The results of the spatial variation revealed that the northern part of the study area is tending towards dry sub-humid condition. This result thus corroborates the earlier observation that the ecological zone of Nigeria is changing and the semi-arid condition in the northern part of Nigeria is advancing towards the study area (Medugu *et al.* 2009, Abdulkadir *et al.* 2013, Olagunju 2015). However, the trend in aridity in the northern part of Nigeria above the study area is increasing (Sawa *et al.* 2015), which confirms the possibility that the aridity level in the study area, especially in the northern part is likely to change in no distant future.

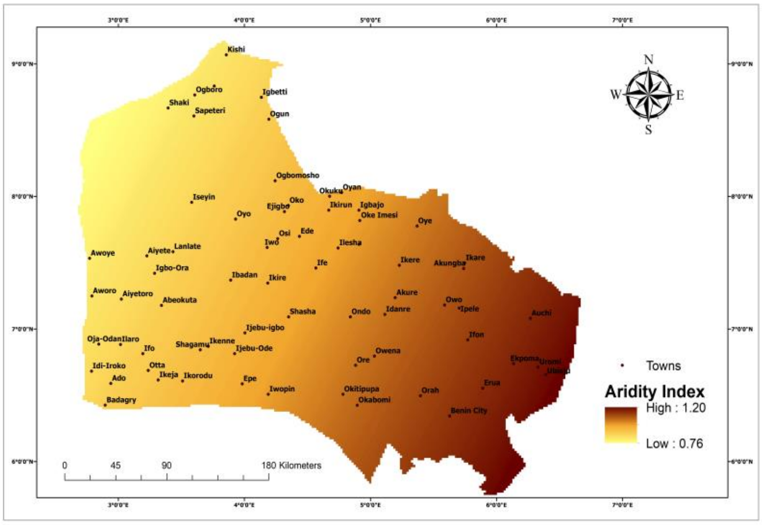

Fig. 9: Spatial distribution of Aridity Index in Western Lithoral Hydrological Zone of Nigeria (1976-2015).

4 Conclusions

Generally, the level of water balance in the Western Lithoral hydrological zone on a monthly time scale revealed six months of water surplus (May-October) and six months of water deficit (November-April). The six months of water surplus coincided with crop cultivation period in the study area. Although there are spatial variations with the length of crop cultivation period because some part of the study area experienced seven months of water surplus. The study concluded that the water surplus of the wet months be conserved to augment the deficit experienced in the dry months, especially to boost agriculture and water supply in the study area. This can be achieved through construction of barriers across rivers, use of large depressions to store runoffs from open fields and bare surfaces. The pounded water which can subsequently be used to irrigate farmlands during the dry period can also be treated for both domestic and industrial usage. There was 27 years of water deficit from the 40 years (1976-2015) of record, thus, it can be concluded that there was water deficit in the study area for the period of study. However, the statistically significant increase in both rainfall amount and PET suggested that the differences in the rate of increase of these two hydrological components will determine the climatic water balance scenario of the study area in the future. Despite being a humid environment, AI in the northern part of the study area is tending towards dry sub-humid condition, thus a change in the general pattern of AI is expected in the near future. Based on the observed temporal and spatial pattern of rainfall and PET and their influence on climatic water balance in the study area, it is recommended that the influencing factors of rainfall amount and PET in the Western Lithoral hydrological zone of Nigeria be investigated in subsequent study.

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