International Scholars Journals

African Journal of Geography and Regional Planning ISSN 3627-8945 Vol. 5 (1), pp. 001-020, January, 2018. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Assessment of water balance indices in Nigeria over two years with contrasting moisture condition

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Accepted 26 December, 2017

A routine study of water balance is a veritable tool in monitoring the amount of water that will be available in the soil of any particular place at a particular time for optimal crop production and other uses. This study assessed water balance indices in Nigeria over two years with contrasting moisture condition. Mean monthly air temperature and monthly rainfall data for 1983 and 2003 were sourced from the archives of the Nigerian Meteorological Agency (NIMET) with respect to twenty-seven weather stations across Nigeria. The data were subjected to Thornwaite's and Climatic water budgeting procedure to estimate water balance indices such as potential evapotranpiration, actual evapotranspiration, water deficit and water surplus. Paired sample test revealed that there is a significance difference between the water balance indices of a dry year and a wet year and across different locations in Nigeria [p=.000]. This study concluded that there is no uniformity in the pattern of water balance indices across Nigeria for over two years. It is recommended that more functional irrigation projects be established in those locations where water deficit is higher in order to boost their crop production throughout the year in Nigeria.

Keywords: Water balance indices, actual evapotranpiration, potential evapotranspitraion, water deficit, water surplus.

INTRODUCTION

One of the important aspects of climatic study that has greatly been neglected in the realm of climate science is the water balance. This might be because water balance indices such as potential evapotranpiration, actual evapotranpiration, soil moisture storage, water deficit, water surplus and runoff are difficult to be determined in an area except through estimation approach. Water balance is an accounting of the inputs and outputs of water on the earth's surface. The water balance of any place, whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output and storage changes of water on the earth's surface. The major input is from precipitation and output is evapotranspiration (Ritter, 2012). Water balance is also a simple accounting scheme used to predict soil-water storage, evapotranspiration, and water surplus. Similarly, water balance can be considered like a financial statement of income and expenditure, that is, an estimation of the quantity of water added, removed, or stored in the soil during a particular period (Seann, *et al*., 1997).

This study focuses on the assessment of some water balance indices in Nigeria over two years with contrasting moisture condition. The year 1983 has been described as a dry year while 2003 has been described as a recovery year from the 1980s drought scenario in Nigeria (Umar, 2013). The aim of this study is to assess the spatial and temporal patterns of water balance indices in Nigeria over the two years with contrasting moisture condition. The objectives of this study are to: calculate the annual potential evapotranspiration for the wet and the dry years across twenty-seven different locations in Nigeria; compute water balance sheets for the twenty-seven selected

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weather stations in Nigeria for the wet and the dry years. In addition, map out the spatio-temporal variations of the water balance indices in Nigeria. The study adopts a method that does not require large data set rather, with available mean monthly air temperature and monthly rainfall data, the water balance components can be calculated (Thornwate, 1948).

Constant assessment of water balance is very crucial in Africa and Nigeria in particular because; there are reports of an increasing trend in aridity in the arid and semi-arid regions of Nigeria (Sawa, *et al*., 2015). As a result, Irrigation agriculture can be 2 to 3 times more productive than rain-fed agriculture in Sudano-Sahelian zone of Africa. The development of irrigation potential in this region has a serious link with the availability of reliable information on water resources. In view of the foregoing, a long-term and routine records of scientifically documented facts about the water balance indices are necessary pre-requisite to sustainable development of water resources for efficient irrigation application. The Knowledge of water balance is very crucial for efficient land and water management strategies as well as crop production. The quality of life of over 600million people who live in semi and arid region is often affected by seasonal rainfall because it determines ultimately the productivity of their cropping system, especially the Sudano-Sahelian zone where the need is of greater concern.

In the past, farmers manage their cropping system through fallowing and shifting cultivation on a long cycle to ensure that the soil nutrient was restored and a reasonable level of water use was maintained. With increasing population pressure on the available land, the method of fallowing and shifting cultivation has been replaced with irrigation method, which is more efficient to boost crop production (Swindale, 1992). In order to assist farmers to succeed maximally in their crop production in the recent time, there is the need for a better understanding of water balance components for proper planning. Water balance will not only provide information on the irrigation need in the areas with water deficit rather, the information will be useful for efficient scheduling of the application of irrigation to ensure proper crop growth and harvest. Lal, (1991) stresses that inadequate water supply is the most important factor affecting agricultural production in Sudano-Sahelian region of Africa and a better understanding of the magnitude and dynamics of the different components of the soil water balance is very crucial to the development of technological options for sustainable management of soil and water resources. Apart from rainfall, adequate knowledge of evaporation and transpiration, runoff, deep drainage and soil water storage is essential for efficient water management and crop production. The effectiveness of rainfall in crop and livestock production can only be enhanced by reducing evaporation, transpiration, runoff and deep drainage. How then can we reduce evapotranspiration, runoff and deep drainage without scientifically documented facts about the amount of these water balance components? With available rainfall (input) data and the potential evapotranspiration (output), other water balance indices like: actual evapotranspiration, water deficit, water surplus and runoff can easily be calculated through climatic water budgeting procedure (Ayoade, 1976b). In spite of the fact that the information on water balance is very crucial in land-atmospheric feedback mechanism at weather and climate time scale because of its major role in the partitioning of the incoming solar radiation into sensible and latent heat, there is still no adequate information on the water balance indices in the literature of climatology.

The few studies on water balance in Nigeria like that of Iroye (2013), Eruola, *et tal*., (2012), Oke *et al*., (2014), Abdullahi *et al*., (2014), Adesiji (2012) and Seann, *et al*., (1997) focused on either a small area like an agricultural field or a Watershed. There has never been any attempt to examine water balance indices over years with contrasting moisture condition (a wet and a dry year). Therefore, there is an existing gap in the literature. Hence, this study covers the gap by making an assessment of some water balance indices in Nigeria over two years with contrasting moisture condition.

METHODS OF THE STUDY

Study Area

Location

The weather stations from which data were collected for this study were selected across Nigeria. Nigeria is located between latitude 4˚N and 14˚N of the equator and longitude 3˚E and 15˚E of the Greenwich meridian. It is bounded in the North by Niger republic, in the South by Atlantic Ocean and the Gulf of Guinea, in the West by Benin republic, in the East by Cameroun republic and in the Northeast by Chad republic. The total landmass of Nigeria is approximately 923, 768km^2 (Iwena, 2000). Nigeria currently comprises thirty-six states and the Federal Capital Territory Abuja. She has a total of 774 local Government areas

Source: Adapted from Umar, (2013)

Materials Used for Calculating the Water Balance Indices and the Source of Data

The materials used for this study include the Thornwaite's Monograph, Journals and other publications used as literature. The data used for this study were the mean monthly air temperature and monthly rainfall for the year 1983 and the year 2003 with contrasting moisture condition. The data used were sourced from the archives of the Nigerian Meteorological Agency (NiMet) with respect to twenty seven (27) selected weather stations well spread across Nigeria

Calculation of Potential Evapotranspiration (PE)

Thornwaite (1948) developed empirical equation for estimating potential evapotranspiration and this is given as:

$$ET_0 = 16\times \left({}^{10i}/_{I}\right)^{a} \left({}^{N}/_{12}\right) \left({}^{1}/_{30}\right) \quad \text{(i)}$$

$$I = {}^{12}{=1} \quad /5\ 1.514 \quad \text{(ii)}$$

Where,

Ti = the mean monthly temperature in (ºC).
N = the monthly Sunshine hours.
I = the heat index.

This formula has been packaged into a monograph. The monograph contains the values of mean monthly heat index (I); the duration of sunshine hours and the correction factors based on the latitudinal and hemispherical location of a place.

The air temperature data collected were subjected to Thornwaite's (1948) method to estimate the monthly and the annual potential evapotranspiration (PE) for the twenty-seven selected weather stations for the selected wet and dry year in Nigeria.

Water Balance Computation

The estimated monthly PE values in conjunction with the monthly rainfall data were subjected to the climatic water budgeting procedure to calculate other water balance indices. These water balance indices include actual evapotranspiration, water deficit, water surplus and runoff. The calculation of these water balance indices was possible with the aid of Thornwaite Monograph. Thornwaite water balance approach is simple, widely used most especially for regional water balance study. The water balance sheet contains the following parameters and they are calculated thus:

Precipitation (P): This is the amount of precipitation in each month.

Potential evapotranspiration (PE): This is the maximum evapotranspiration; when water is not limiting.
P-PE: This is the difference between the precipitation and the potential evapotranspiration.
APWL: This is the accumulated potential water loss. This only arises when PE>P.* If PE>P, then APWL is a cumulative values of (P-PE). * If PE<P, then no APWL.
ST: This is the soil water storage: the highest value is 300. This is obtained in the monograph but only in the months where the APWL occurs. Other months without APWL, ST = preceding ST + P-PE.
ΔST: This is the change in storage. That is, the different in storage value calculated by the difference in storage value of the current months and the preceding month.
AE: This is the actual potential evapotranspiration. That is, the actual amount of evapotranspiration that occurs.*If P<PE, then, AE=P-ΔST. *If P>PE then AE = P
D: This is the water deficit in the soil that is calculated only when P<PE.*If P<PE, then D=PE-AE. *If P>PE, then no D.
S: This is the soil moisture surplus i.e. excess moisture gained in the soil, when capacity. This is only when P>PE and ST is at full capacity.*If P>PE and ST is at full capacity, then S = (P-PE) - ΔST.*If P<PE or ST is not at full capacity or both, then no S.
R: This is the run-off. The runoff most be equal to the surplus i.e. R = S.
To check whether the table is correct, *PE=P-S+D.
After determining the annual water balance indices such as potential evapotranspiration (PE), precipitation (P), actual evapotranspiration (AE), water deficit (D), surplus and (S), the results were presented in tables. spatial maps were produced using Arc GIS to show the spatial pattern of the annual water balance indices. The monthly and annual variations of the water balance indices were presented in charts to show the temporal pattern of the water balance indices for the selected wet and dry years in Nigeria for better understanding.

RESULT AND DISCUSSION

Spatio-Temporal Pattern of PE in Nigeria

Spatial pattern of Annual Potential Evapotranspiration in Nigeria

The results in Table 1 indicate that the rate of PE varies across different locations in Nigeria except Yola and Lokoja where both stations recorded annual PE of 2029mm in 1983. Likewise, in 2003, two stations: Maiduguri and Lokoja both recorded annual PE of 2101mm. It could be observed that most of the stations located in the Northern part of the country experienced higher rate of potential evapotranspiration of 2000mm and above in 1983 and 2003. It is clear in Table 1 that Yelwa recorded the highest annual PE of 2199mm while other stations such as Bida, Makurdi, Sokoto, Minna, Gusau, Katsina, Yola, and Lokoja followed with annual PE of 2161mm, 2132mm, 2131mm, 2125mm, 2106mm, 2046mm, 2029mm and 2029mm respectively. Still from Table 1, result showed that Oshogbo and Ikom in the South also recorded annual PE above 2000mm with their values put at 2065mm and 2007mm respectively. Other stations across the country have annual PE below 2000mm

Table 1. Summary of Annual PE (mm) for the year 1983 and 2003 in Nigeria.

Station	PE 1983	PE 2003
Port/H	1805	1982
Calabar	1906	1987
Warri	1818	1861
Ilkom	2065	2054
Benin	1989	2013
Lagos	1838	1925
Enugu	1924	1977
Ondo	1941	1953
Ibadan	1755	1849
Makurdi	2132	2170
Lokoja	2029	2101
Oshogbo	2007	2056
Ilorin	1798	1887
Bida	2161	2184
Yola	2029	2112
Minna	2125	2145
Jos	1293	1328
Kaduna	1780	1848
Yelwa	2199	2044
Bauchi	1871	2046
Maiduguri	1996	2101
Zaria	1970	2068
Kano	1880	1911
Gusau	2106	2205
Nguru	1989	2087
Katsina	2046	2162
Sokoto	2131	2107

Source: Authors' Computation, 2017.

in 1983. Details of this spatial pattern of PE for 1983 could be seen in Figure 1.1

Similarly, it is evident in Table 1 that in 2003, many of the stations located in the North recorded annual PE above 2000mm with Gusau recording the highest PE of 2205mm. This is followed by Bida, Makurdi, Katsina, Minna, Yola, Sokoto, Maiduguri, Lokoja, Nguru, Zaria and Yelwa with annual PE of 218mm, 2170mm, 2162mm, 2145mm, 2112mm, 2107mm, 2101mm, 2101mm, 2087mm, 2068mm, and 2044mm respectively. Oshogbo, Ikom and Benin in the South also recorded annual PE of 2056mm, 2054mm and 2013mm in that order while other stations in the South like Ibadan, Lagos, Calabar, Porthacourt, Warri, and Ondo recorded annual PE below 2000mm.

Temporal Pattern of Potential Evapotranspiration in Nigeria

The monthly values of PE across the twenty-seven weather stations in Nigeria were summed up and the total was used to map out the temporal pattern of PE for 1983 and 2003. Result in Figure 1.2 revealed that the highest PE of 4956mm was recorded during the month of April followed by March, July and February with monthly values of 4901mm, 4880mm, and 4860mm in that order in 1983. Similarly, the highest PE of 4970mm was recorded in March followed by the months of February, November and October with monthly total of 4915mm, 4675mm and 4598mm accordingly in 2003. It could also be inferred from Figure 1.2 that lower amount of PE below 4000mm was recorded in the month of January and August in 1983. In the same vein, lower amount of PE below 4000mm was recorded in August in 2003. This is followed by Kano, Maiduguri, Katsina, Bauchi, Jos, Zaria and Gusau with values of 28mm, 30mm, 37mm, 43mm, 51mm, 54mm and 66mm in that order in 1983. On the contrary, higher monthly PE between 100mm and 190mm was recorded from January to December in the wet year, 2003 except during the month of July, August and September in which some stations recorded a significantly low PE below 100mm. The result also indicated that the rate of PE is relatively low during the months of January and December in those Northern stations in both years compared to their Southern counterpart. The low amount of PE recorded in the Northern stations during the months of December and January could be attributed to the low temperature in

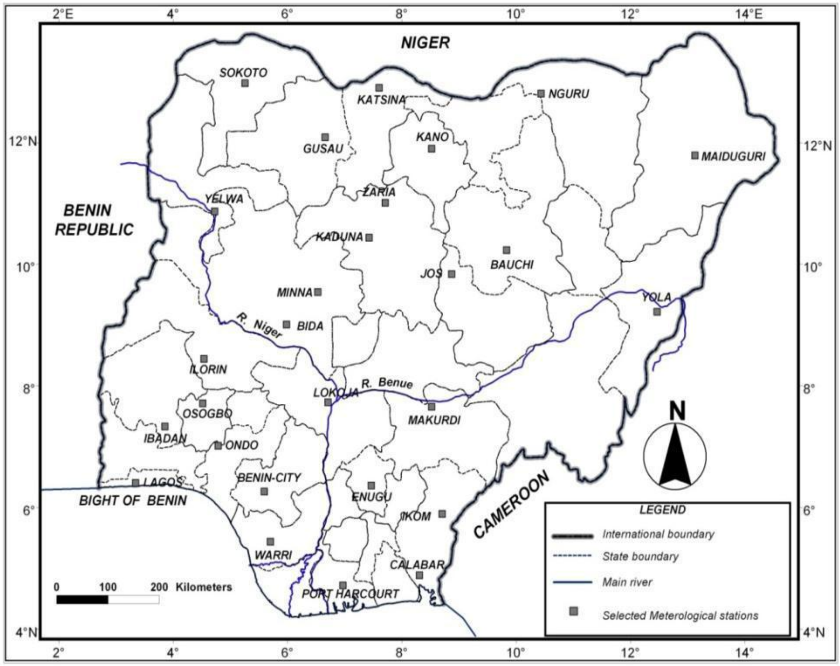

Figure 1. Distribution of Selected Meteorological Stations in Nigeria.

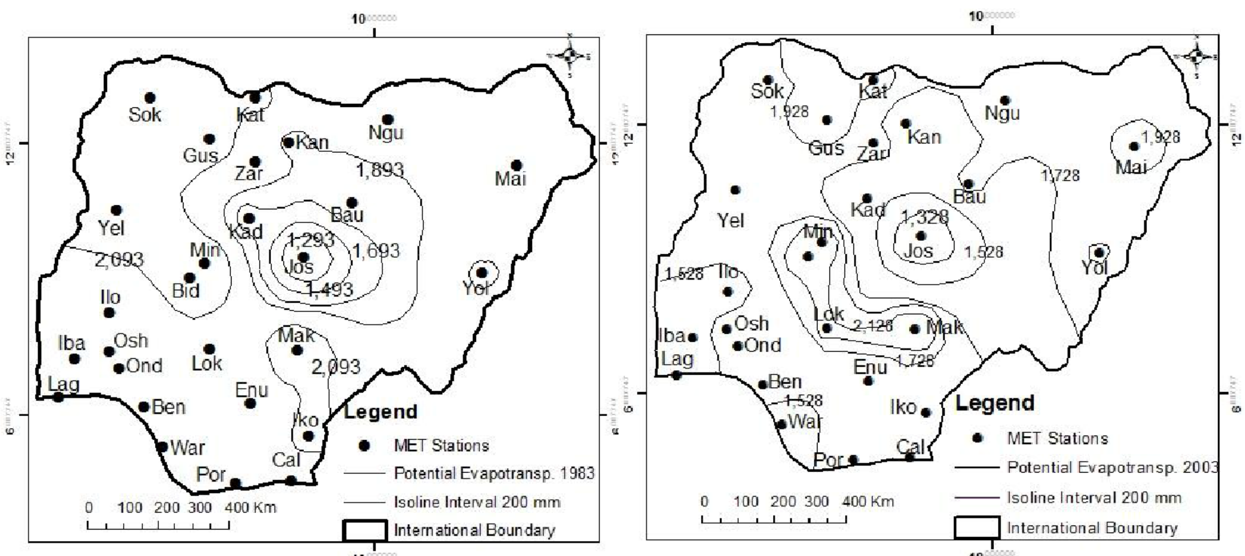

Figure 1.1 Spatial Pattern of Annual Potential evapotranspiration.

those months as a result of harmattan wind. This finding is in line with Zhang *et al*., (2010) where they stress that the rate of reference evapotranspiration was low during the cool months (January to April) and high during the warm months (May to August) in their study area. Moreover, the driving variables resulting from the spatial variation in warm months was related to the variation in the amount of solar radiation among months.

Comparison between the Annual Potential Evapotranspiration for 1983 and 2003 in Nigeria

The results in Table 1 and Figure 1.3 revealed that many stations recorded high annual PE of 2000mm and above in 2003 compared to 1983. Stations like Yelwa, Warri, Sokoto and Ikom were the only exception, in which the annual PE of 2044mm, 1861mm, 2107mm and 2054mm

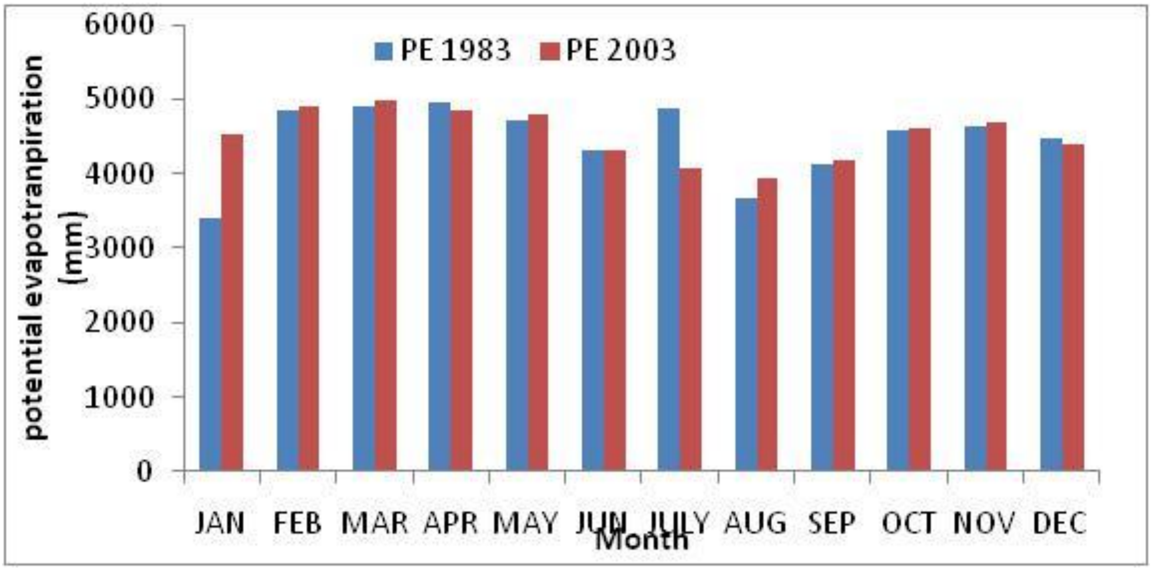

Figure 1.2. Temporal Pattern of Potential evapotranpiration for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

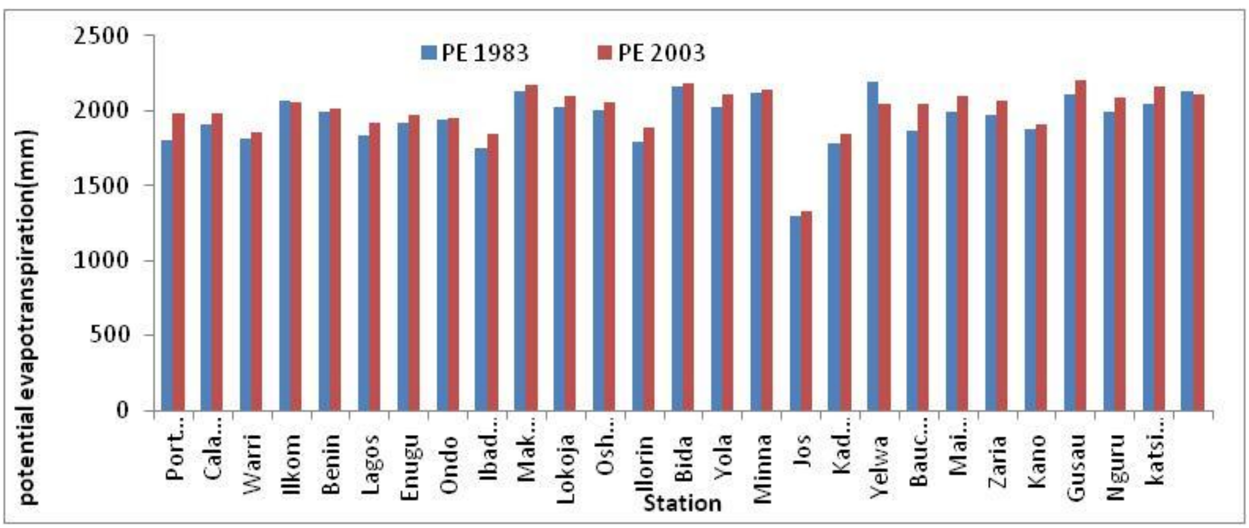

Figure 1.3. Comparison between the Annual PE for 1983 and 2003 in Nigeria Source: Field Work, 2017.

recorded in that order, were slightly lower than the annual PE of 2199mm, 1818mm, 2056mm and 2131mm that they recorded accordingly in 1983. The variation exhibited by PE across the stations in Nigeria may not be unconnected with the variation in those factors influencing the rate of PE in any place such as the availability of unlimited water, availability of energy, relative humidity and cloud cover etc. (Burba, 2013). The monthly air temperature is higher in the Northern part of Nigeria because of lack of cloud cover and the distance from the Sea compared to the Southern part (Ayoade, 1974 cited in Ayoade, 1995). The higher PE recorded in 2003 might be ascribed to higher air temperature and higher rainfall recorded in 2003 compared to 1983. Similarly, (Ayoade, 1995) asserts that the rate of evaporation or evapotranspiration is being influenced by two major factors namely: the availability of moisture at the surface and the ability of the atmosphere to vapourized the water, remove and transport the vapour into the atmosphere. Therefore, if moisture availability is not the constraint, then evapotranspiration will depend only on the atmospheric conditions of that particular environment. This is the concept of PE by (Thornwaite, 1944). It is important to note that, adequate energy is required to convert the available water into vapour.

Other factors that influence the rate of PE and its spatial and temporal variations include humidity, wind speed, energy budget, turbulence; plants growth heights etc (wikipedia.org, 2016). Pidwirny (2006) stresses that the amount of energy received from the sun accounts for 80% of the variations in potential evapotranspiration. Eventhough, Thornwaite's (1948) method did not consider wind in his PE estimate, Pidwirny (2006) in his own case, stresses that wind is the second most important factor influencing the rate and variations of PE. According to him, "wind enables the water molecules to be removed from the ground surface by a process known as: "eddy diffusion". The above factors could be responsible for the spatial variations of PE in Nigeria. A related study conducted in Nigeria by Idowu and Gbuyiro, (1999) also reveals that the rate of PE increases northwards. By implication, places with higher rate of PE across the country may likely face the problem of water deficit and hot climatic condition if the higher trend of PE persists over a long period. This is because one of the characteristics of a dryland is when the rate of potential evaporanspiration is greater than the precipitation (Thornwaite, 1948; Middleton and Thomas, 1997).

Spatio-Temporal Pattern of Rainfall

Spatial Pattern of Annual Rainfall in Nigeria

The monthly rainfall data collected from the NiMet for twenty-seven synoptic weather stations across Nigeria for 1983 and 2003 were summed up to determine the annual total for each station. However, the result in Table 2 showed that the annual rainfall varies across the twenty-seven weather stations in Nigeria. It could be inferred from Table 2 that higher rainfall of 2000mm and above was recorded in most of the stations located in the Southern part of Nigeria compared to those stations located in the North. There were exceptional cases of Ibadan, Lagos, and Enugu in the South that recorded annual rainfall of 858mm, 893mm and 918mm which were slightly lower than 928mm recorded by Minna that is located in the north in 1983. Stations like Ibadan, Ilorin, and Oshogbo also recorded annual rainfall of 1460mm, 1157mm and 1293mm in that order in 2003, which are less than 1633mm that Kaduna in the North recorded. See Figure 2.1 for the spatial pattern of the annual rainfall across Nigeria for 1983 and 2003 respectively. The result in Table 2 also revealed that stations such as Calabar, Warri and Ikom in the South recorded annual rainfall above 2000mm. Warri received the highest annual rainfall of 2523mm while Calabar and Ikom followed with annual rainfall of 2298mm and 2110mm respectively in 1983. In contrast, it could be observed from Table 2 that many stations in the South recorded annual rainfall above 2000mm in 2003. Calabar received the highest annual rainfall of 2440mm while Warri, Portharcourt and Ikom received annual rainfall of 2252mm, 2248mm and 2041mm accordingly in 2003. It is also obvious in Table 2 that, apart from Lagos, Ibadan and Enugu in the South that recorded annual rainfall below 1000mm in 1983, all other stations located in the South received annual rainfall above 1000mm. Similarly, result Table 2 unfolds that apart from those stations that received annual rainfall above 2000mm, all other stations in the South recorded annual rainfall above 1000mm in 2003. The result in Table 2 further showed that only Jos recorded rainfall above 1000mm in 1983 in the North. On the contrary, Jos, Kaduna, Kano, Zaria, Yelwa and Minna recorded annual rainfall above 1000mm in 2003. Some few stations received annual rainfall between 500mm to 900mm in the North while other stations recorded annual rainfall below 500mm. In fact, Nguru recorded the least annual rainfall of 227mm in 1983 and 329mm in 2003. See Figure 2.1 for detail of the spatial pattern of annual rainfall in Nigeria for 2003. The variation and distribution of rainfall across the stations in Nigeria as revealed in this work could be related to the findings of Okoloye, *et al*., 2013) and (NIMET, 2012). The irregularity in the patterns of rainfall over Nigeria as depicted in Figure 2.1 could be linked to the irregularity in the movement of the ITD. This to a greater extent, bring changes in land surface characteristics as well as anomalous wet and dry condition as asserted by Ayoade (1974) cited in Ayoade, (1995), Charney (1975), Oladipo (1995) and Okoloye *et al*., (2013).

Temporal Pattern of Rainfall in Nigeria

The monthly rainfall recorded by the twenty-seven weather stations were added month by month to plot the monthly variations of rainfall in Nigeria**.** The result in Figure 2.2 revealed that higher amount (aggregate of all the twenty-seven stations) of rainfall between 3000mm and 5000mm and above was recorded during the month of June, July, August and September in Nigeria in 1983 and 2003. It could be observed that the highest total amount of rainfall of 5139mm and 6576mm were recorded in the month of September in 1983 and 2003 respectively. On the other hand, lower amount of rainfall was recorded during the months of January, February, March, April, November and December in both 1983 and 2003. All other stations located towards the North and extreme North recorded no rainfall from January to April

Table 2. Summary of Annual Rainfall (mm) for 1983 and 2003 in Nigeria.

Station	P 1983	P 2003
Port/H	1633	2248
Calabar	2298	2440
Warri	2523	2252
Ilkom	2110	2041
Benin	1630	1833
Lagos	893	1691
Enugu	918	1769
Ondo	1126	1660
Ibadan	858	1460
Makur	930	749
Loko	854	924
Oshogbo	1089	1293
Ilorin	1152	1157
Bida	882	891
Yola	738	927
Minna	928	1024
Jos	1176	1280
Kadun	885	1633
Yelwa	563	1080
Bauch	779	967
Maidu	257	635
Zaria	683	1183
Kano	464	1366
Nguru	227	329
Katsin	409	546
Sokoto	618	801

Source: Author's Computation, 2017.

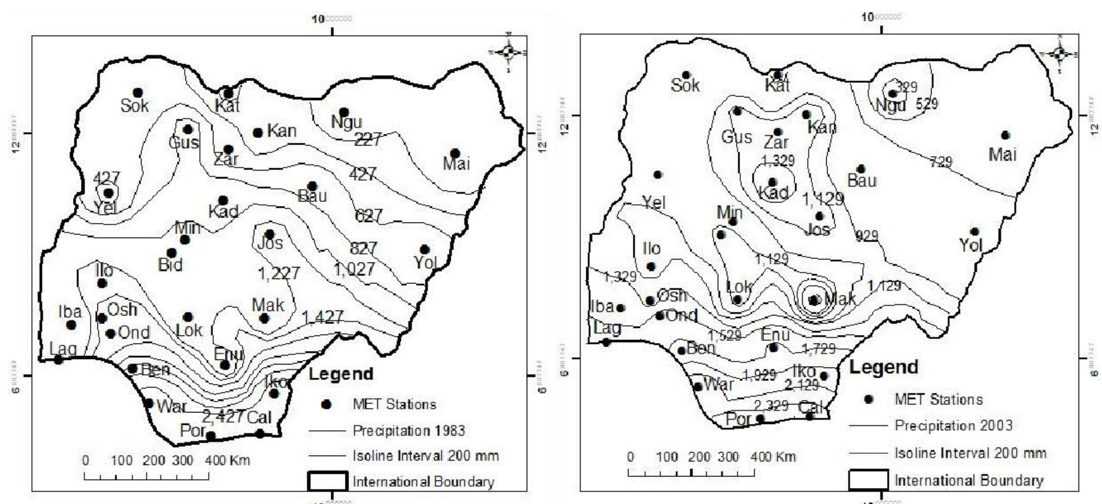

Figure 2.1. Spatial Pattern of Annual Rainfall for 1983 and 2003 in Nigeria **Source:** Author's Compilation, 2017.

and November to December.

The irregularities in the movement of ITD as pointed out by Ojo, *et al*., (2000), residential time of the prevailing air masses at different period of the year and the contemporary incident of climate change associated with different activities of man could be additional factors in explaining rainfall variability in Nigeria. This finding could be related to the quarterly compilation of *DEKAD* rainfall pattern over Nigeria by the Nigerian Meteorological Agency (NIMET, 2012; 2013).

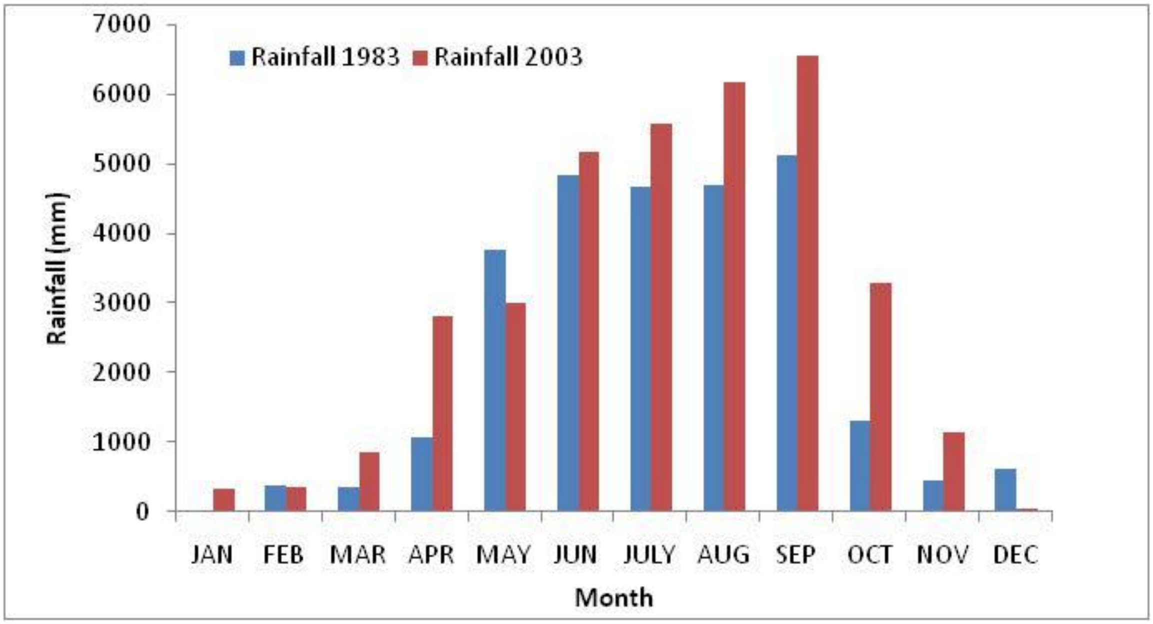

Figure 2.2. Temporal Pattern of Rainfall for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

Comparison between the Annual Rainfall for 1983 and 2003 in Nigeria

A comparative analysis in Figure 2.3 showed that many stations recorded higher annual rainfall of 2000mm and above in 2003 compared to 1983 in Nigeria. It is also very important to note that, the variation between 1983 and 2003 and notably the lower rainfall below 1000mm recorded in Ibadan, Lagos and Enugu might be attributed to the drought incident of the 1980s as reported by Umar, (2013). The low rainfall recorded in most of the stations in Nigeria in 1983 may be attributed to the droughts of different magnitudes of 1980s as reported by (Umar, 2013).

Spatio-Temporal Pattern of Actual Evapotranspiration

Spatial pattern of Annual Actual Evapotranspiration in Nigeria

Actual evapotranspiration is the actual "amount of water use" that is, water that is actually evaporating into the atmosphere based on the environmental condition of that particular location (Ritter, 2012). However, result from Table 3 showed that the rate of AE varies across the twenty-seven weather stations in Nigeria over the two selected years (1983 and 2003). It is also evident from Figure 3.1, that the rate of annual AE increases from below 1000mm in the North to 1000mm and above towards the South where there are abundant rainfall in both 1983 and 2003. Investigation reveals that AE, contrary to PE, is higher in most of the Southern stations compared to their Northern counterpart in both 1983 and 2003. Unlike in the case of PE, no station recorded annual AE up to 2000mm and above. Stations that experience higher AE in 1983 and 2003, recorded annual AE between 1000mm and 1500mm and between 1000mm and 1800mm respectively. Result in Table 3 revealed that Ikom recorded the highest annual value of 1521mm in 1983 followed by Warri, Calabar, Benin, portharcourt, Oshogbo and Ondo with annual values of 1494mm, 1428mm, 1331mm, 1244mm, 1089mm and 1008mm accordingly. Other stations in the South such as Lagos, Ibadan, Ilorin and Enugu recorded annual AE below 1000mm while none of the stations in the North recorded AE above 1000mm. Rather, they entirely experienced annual AE between 500mm and 900mm. Some stations such as Nguru and Maiduguri even recorded AE as low as 227mm and 257mm respectively in 1983. It could be inferred from Table 3 that, Calabar recorded the highest AE in both 1983 and 2003. Calabar recorded the highest annual AE of 1771mm while other stations like: Warri, Portharcourt, Lagos, Ikom, Benin, Enugu, Ondo and Oshogbo recorded annual AE of 1424mm, 1610mm, 1521mm, 1455mm, 1598mm, 1382mm, 1309mm and 1198mm in that order.

It is very imperative to understand that the rate of AE is low in those stations located in the North where most of the stations recorded low annual rainfall below 1000mm in 2003. Nguru and Katsina recorded AE as low as 330mm and 546mm respectively. Another important observation is that, most of the stations located in the North

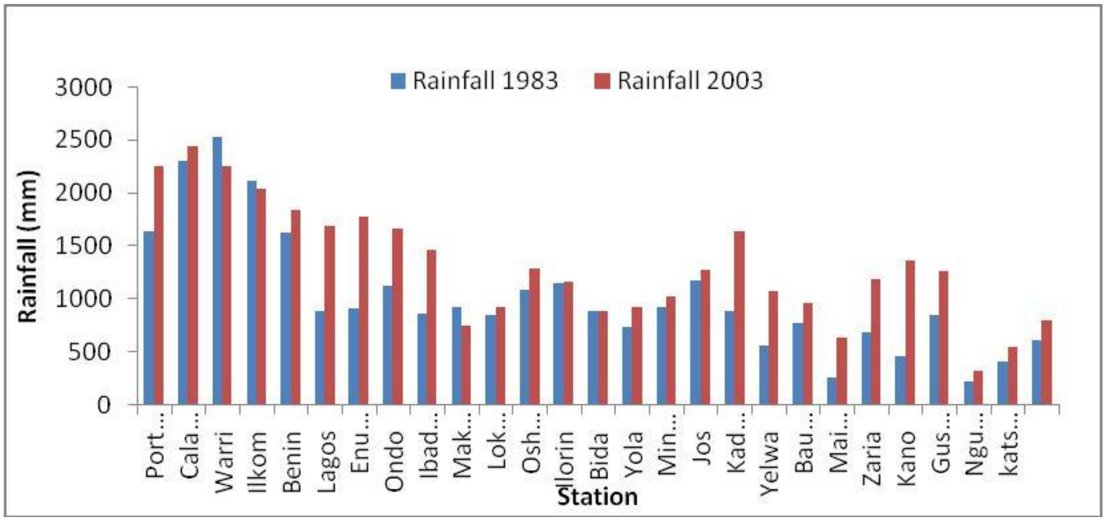

Figure 2.3. Comparison between the Annual Rainfall for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

in both 1983 and 203 have their annual AE equal to their annual rainfall. It means the total rainfall received was evapotranspirated probably because the places are characterized with high solar radiation input and low rainfall. This is because actual evapotranspiration is dependent on the surface moisture (Ayoade, 1995). By implication, those locations will lack sufficient water needed for crop production, ecological function and other uses. Details of the spatial pattern of annual AE across Nigeria for 1983 and 2003 could be seen in Figures 3.1 respectively.

4.3.2 Temporal Pattern of Actual Evapotranspiration in Nigeria

The result in Figure 3.2 showed that the rate of AE varies from the month of January up to December in 1983 and 2003. It could be inferred from Figure 3.2 that the rate of monthly AE increases from the lowest value of -1176mm in January to as high as 3293mm in June 1983. It also increases from lowest value of -43mm in January to as high as 3728mm in October 2003. The highest monthly AE of 3284mm and 3728mm were recorded during the month of May 1983 and October 2003 respectively while the lowest monthly AE of -1176mm and -43mm were recorded during the month of January in 1983 and in 2003 respectively. A visual observation of Figure 3.2 showed that the month with the highest AE value is June. This is followed by the months of May, September, August, October, and July with values of 3293mm, 3284mm, 3006mm, 2890mm and 2575mm in 1983. In 2003, the highest AE of 3728mm was recorded in October followed by the months of August, June, September and July with total amount of 3691mm, 3387mm, 3360mm and 3225mm accordingly. It is also evident from Figure 3.2 that the months of January, February, March, November and December recorded lower AE with the least amount of -1176mm in January. Others months with lower AE are with values of 949mm, 1290mm, 1806mm, and 1272mm accordingly in 1983. The monthly variation in actual evapotranspiration may be as a result of the monthly variation in the available water and the energy (solar) input over the time. .

Comparison of Annual Actual Evapotranspiration for 1983 and 2003 in Nigeria

The result in Figure 3.3 showed that most of the stations recorded a very high AE of 1000mm and above in Nigeria in 2003 compared to the year 1983. It could be inferred from Figure 3.3 that apart from Makurdi and Warri that recorded low annual AE of 930mm and 1424mm respectively in 2003, all other stations across Nigeria in 2003 recorded annual AE higher than that of 1983. This is as a result of the higher rainfall of 2000mm and above recorded in most of the stations in 2003 compared to that of 1983.

Spatio-Temporal Pattern of Water Deficit in Nigeria

Spatial pattern of Annual Water Deficit in Nigeria

Moisture deficit occurs when the demand for water on the earth's surface exceeds what is actually available. In other words, deficit occurs when PE exceeds input precipitation and AE i.e. (PE>AE). The result Figure 4.1 showed that all the stations experienced deficit in those months where the rate of Potential evapotranspiration is greater than both the precipitation and the AE. It could be observed from Table 4 that the occurrence of moisture

Table 3. Summary of Annual AE (mm) for 1983 and 2003 in Nigeria.

Station	AE 1983	AE 2003
Port/H	1244	1610
Calabar	1428	1771
Warri	1494	1424
Ilkom	1521	1455
Benin	1331	1598
Lagos	887	1521
Enugu	843	1382
Ondo	1008	1309
Ibadan	858	1184
Makur	930	749
Loko	780	924
Oshogbo	1089	1198
Ilorin	969	965
Bida	882	891
Yola	738	927
Minna	928	986
Jos	647	805
Kaduna	720	1005
Yelwa	563	933
Bauchi	779	878
Maiduguri	257	635
Zaria	683	991
Kano	464	957
Gusau	846	1117
Nguru	227	330
Katsina	409	546
Sokoto	618	779

Source: Author's Computation, 2017.

deficit is higher Northwards in both years when compared to the Southern stations.

Furthermore, results in Figure 4.1 and Table 4 showed that stations such as Gusau, Bida, Sokoto, Makurdi, Lokoja, Katsina, Nguru, Bauchi, Yola, Maiduguri, Kano, Yelwa, Zaria and Minna, recorded higher annual water deficit between 1150mm to 1200mm in both 1983 and 2003. On the contrary, Kaduna, Jos and Yelwa recorded relatively low annual water deficit of 843mm, 523mm and 1111mm compared to other stations in the North. It could also be observed from Table 4 that stations such as Calabar, Portharcourt, Warri, Benin, Enugu, Jos and Lagos recorded lower annual moisture deficit between 200mm and 500mm in both 1983 and 2003. The spatial pattern of the annual water deficit for 1983 and 2003 were depicted in (Figure 4.1).

It is important to note that the amount of moisture in the soil of any particular place depends on how much precipitation and evapotranspiration occur in that place (Ritter, 2012). Therefore, the pattern exhibited by water deficit across Nigeria is a function of the spatial distribution of the annual rainfall and the annual potential evapotranspiration. Result in Table 4 reveal that the amount of rainfall recorded by above-mentioned stations with higher records of water deficit was very low and their rate of PE is higher compared to other stations. Udoeka, *et al.,* (1998) also stress that the rate of evapotranspiration has steadily increased and rainfall decreased over the Sudano-Sahelian zone of Nigeria. The assertion made by Udoka, *et al*., (1998) might be one of the reasons why the water deficit increases over the Sudano-Sahelian zone of Nigeria.

Temporal Pattern of Water Deficit in Nigeria

The results of the monthly water deficit in Figure 4.2 revealed that stations such as Nguru, Katsina, Minna, Yelwa, Kano, Maiduguri, Sokoto, Bida, except Jos, Yola

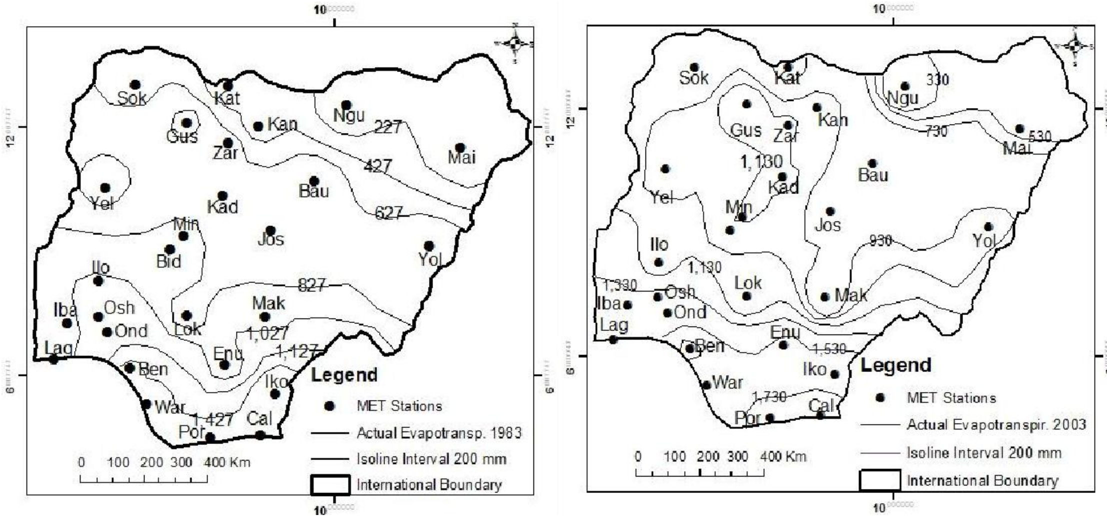

Figure 3.1. Spatial Pattern of Annual Actual Evapotranspiration for 1983 and 2003 in Nigeria.
Source: Author's Compilation, 2017.

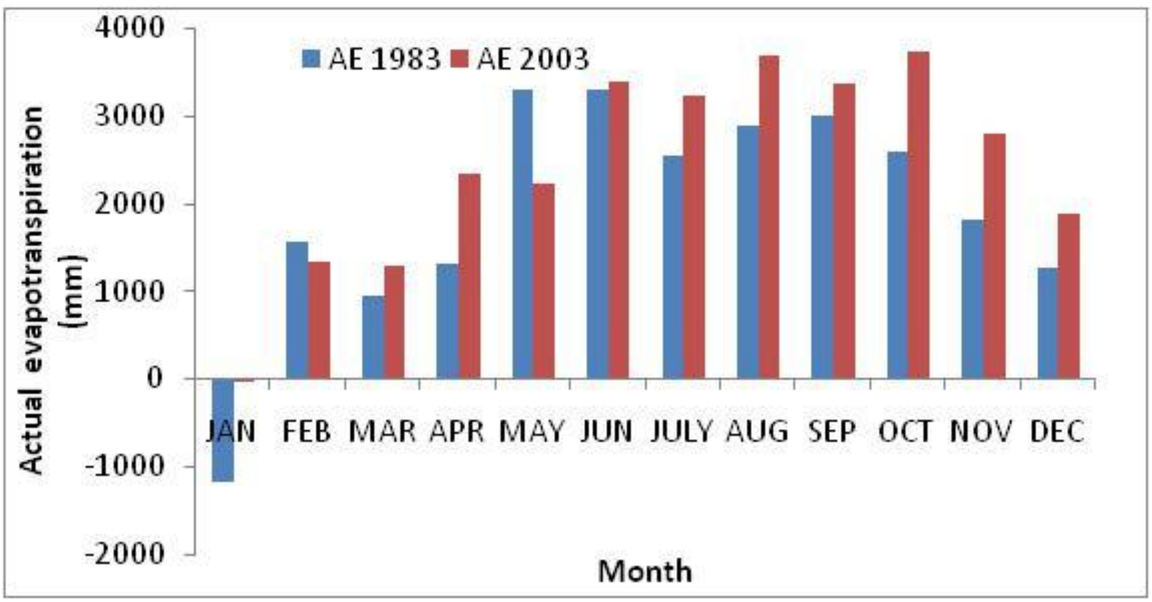

Figure 3.2. Temporal Pattern of Actual evapotranspiration for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

and Kaduna in the North, experience water deficit throughout the year while virtually all the stations located in the south experience water deficit between four and five months in a year. Result in Figure 4.2 showed that the amount of water deficit decreases from higher amount of 4000mm and above in January to as low as 786mm and 124mm in August in 1983 and 2003 respectively. It could also be observed that the amount of water deficit increases from lowest value of 786mm in August to as high as 3191mm in December 1983. In addition, it increases from lowest value of 124mm to as high as 2697mm in December in 2003. It is very clear from Figure 4.2 that the highest water deficit of 4586mm and 4819mm were recorded in January 1983 and 2003 respectively while the lowest water deficit of 786mm and 124mm were recorded during the month of August in1983 and 2003 respectively.

These monthly variations of water deficit in Nigeria depend largely on the variations in the distribution of rainfall and the rate of PE over time. It is important to understand that deficit occurs in those months where the amount of potential evapotranspiration exceeds the preci-

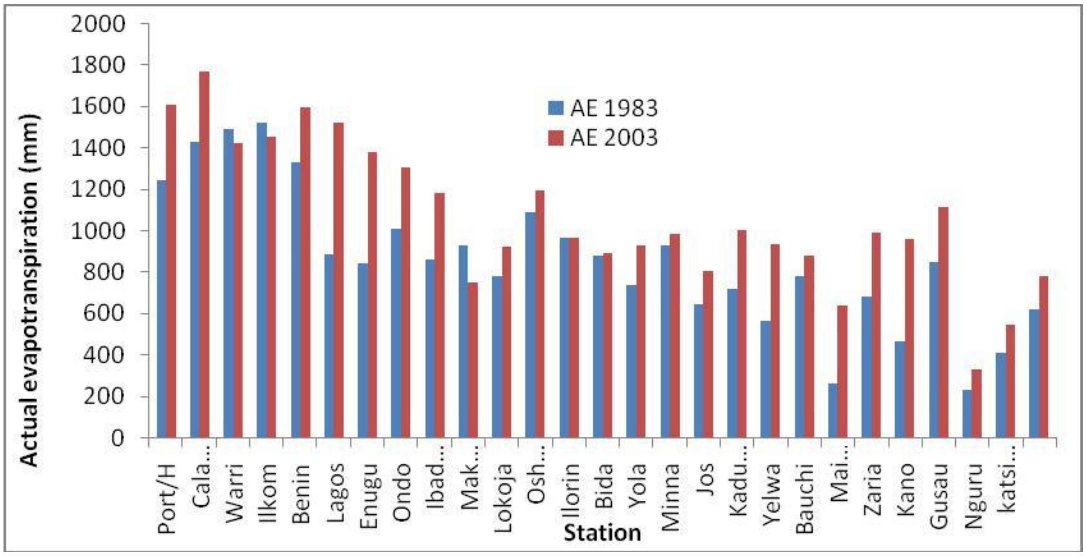

Figure 3.3. Comparison between the Annual AE for 1983 and 2003 in Nigeria
Source: Field Work, 2017.

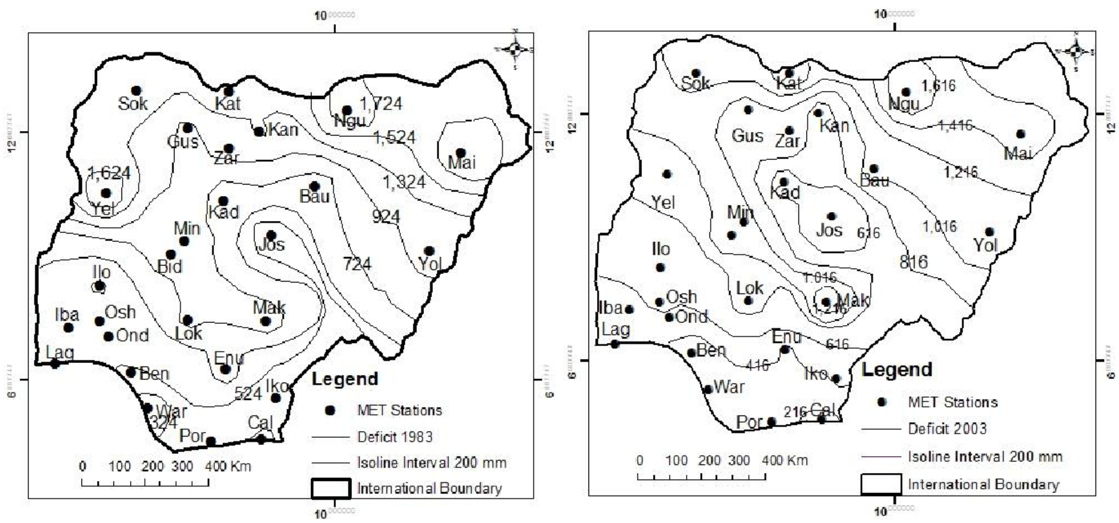

Figure 4.1: Spatial Pattern of Annual Water Deficit for 1983 and 2003 in Nigeria.
Source: Authors, Computation, 2017.

pitation. This information will enable farmers to know when and how much water is required to irrigate their crops for efficient crop production.

Comparison between the Annual Water Deficit for 1983 and 2003 in Nigeria

It is very crucial to note that the rate of moisture deficit is higher in the year 1983 where many stations recorded annual water deficit of 1000mm and above in 1983 compared to 2003 where only few stations recorded water deficit of 1000mm and above. See details of the annual water deficit variation in Figure 4.3. The observed reasons for this variation are the lower amount of rainfall and high PE recorded in 1983 compared to 2003. The low rainfall recorded in 1983 might be because, 1983 has been reported to be a dry year due to the 1980s drought of different magnitudes across Nigeria (Umar, 2013). The report from Okoloye, *et al*., (2013) also indicates that the year 1980s were characterized by consistent and slight decrease in rainfall compared to 2003 when the country began to recover from the incident of 1980s drought.

Table 4. Summary of Annual Water Deficit (mm) for 1983 and 2003 in Nigeria.

Station	D 1983	D 2003
Port/H	561	372
Calabar	478	216
Warri	324	437
Ilkom	544	599
Benin	658	415
Lagos	951	404
Enugu	1081	568
Ondo	933	644
Ibadan	897	665
Makurdi	1202	1421
Loko	1187	1177
Osho	918	858
Ilorin	829	922
Bida	1279	1293
Yola	1291	1185
Minna	1197	1159
Jos	646	523
Kadun	1060	843
Yelwa	1636	1111
Bauch	1092	1168
Maidu	1739	1466
Zaria	1287	1077
Kano	1416	954
Gusau	1260	1088
Nguru	1762	1757
Katsin	1637	1616
Sokoto	1513	1328

Source: Author's Computation, 2017.

This result could also be linked to the study conducted on the spatio-temporal pattern of Thornwaite's Moisture Index in Nigeria by Kehinde *et al*., (20015). It was discovered that the state of aridity and moisture deficit is significantly higher in the Northern part of Nigeria in 1983 compared 2003. Kehinde *et al.,*(2015) further stress that if the annual Moisture Index determined for each stations located in the Northern part of Nigeria is compared with Thornwaite's Climatic Classification, most of the places across the Northern Nigeria could be classified into either Semi-arid or Arid.

Spatio-Temporal Pattern of Water Surplus

Spatial pattern of Annual Water Surplus for 1983 and 2003 in Nigeria

Moisture surplus occurs only when the precipitation exceeds the potential evapotranspiration and the soil has reached its water holding capacity. This indicates that any further additional water after the soil has reached its full capacity will definitely runs off. It could be inferred from Table 5 that virtually all the stations located in the Northern part of Nigeria lack water surplus except Kaduna, Jos and Lokoja that recorded annual water surplus of 165mm, 529mm and 12mm accordingly in 1983. In the same year, 1983, many stations in the southern part of Nigeria recorded water surplus compared to their counterpart in the North. Notable among the stations that recorded water surplus in the South include Ikom, Calabar, Lagos, Ilorin, Portharcourt, Warri, Ondo, Benin and Enugu.

The result in Table 5 revealed that Warri recorded the highest water surplus of 1029mm in 1983 followed by Calabar, Ikom, Portharcourt, Benin, Ilorin, Ondo and Lagos with annual total of 870mm, 589mm, 389mm, 229mm, 183mm, 118mm and 6mm in that order. See details of the spatial pattern of water surplus across Nigeria for 1983 and 2003 in Figure 5.1. The spatial pattern of surpluses across the country could be related to the findings of Ayoade, (1995) where he stresses that the amount of water surplus reduces from the South towards the Northern part of Nigeria.

Contrary to what is obtained in 1983, many stations recorded water surplus across Nigeria in 2003. All the stations in the South recorded surpluses of varied magnitudes. Warri recorded the highest annual water surplus of 828mm in 2003. Many other stations also

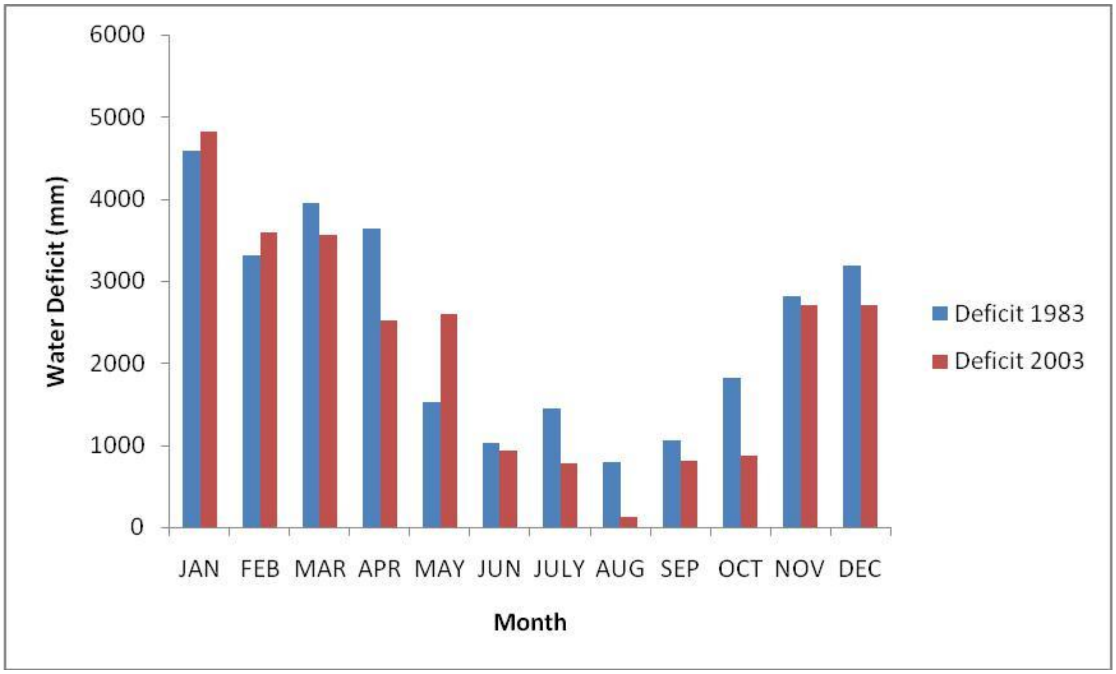

Figure 4.2. Temporal Pattern of Water Deficit for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

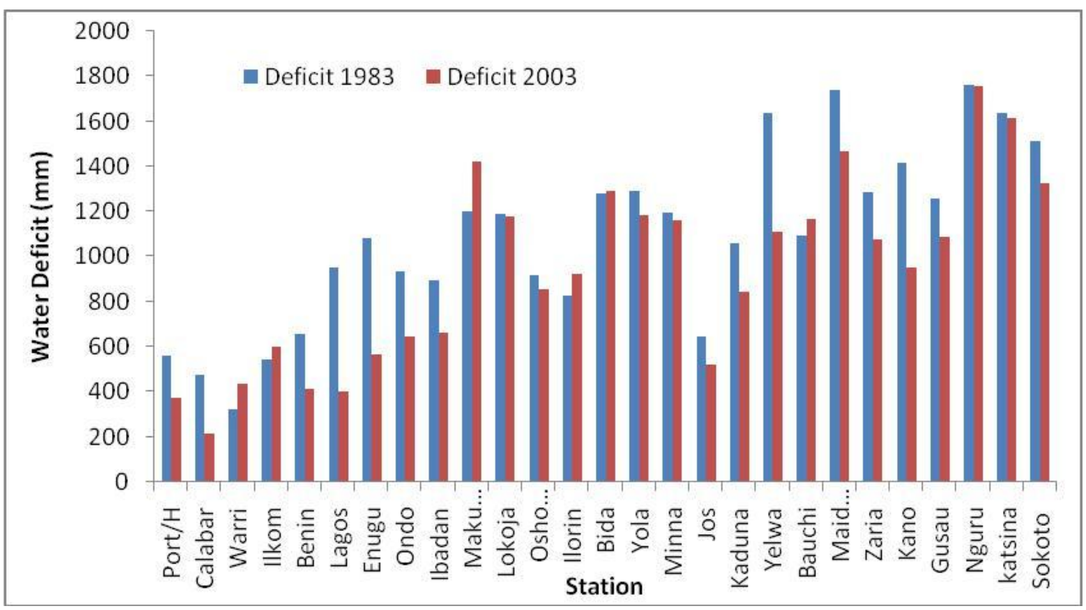

Figure 4.3. Comparison between the Annual Water Deficit for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

recorded water surplus in the North in 2003 when compared to that of the year 1983. Notable among stations that recorded annual water surplus in the North are Minna, Yelwa, Zaria, Kano, Kaduna, Bauchi, Jos, Sokoto and Gusau. Kaduna recorded the highest annual surplus of 628mm in the North in 2003. This is followed by Jos, Kano, Zaria, Gusau, Yelwa, Bauchi and Minna with annual water surpluses of 475mm, 409mm, 192mm,

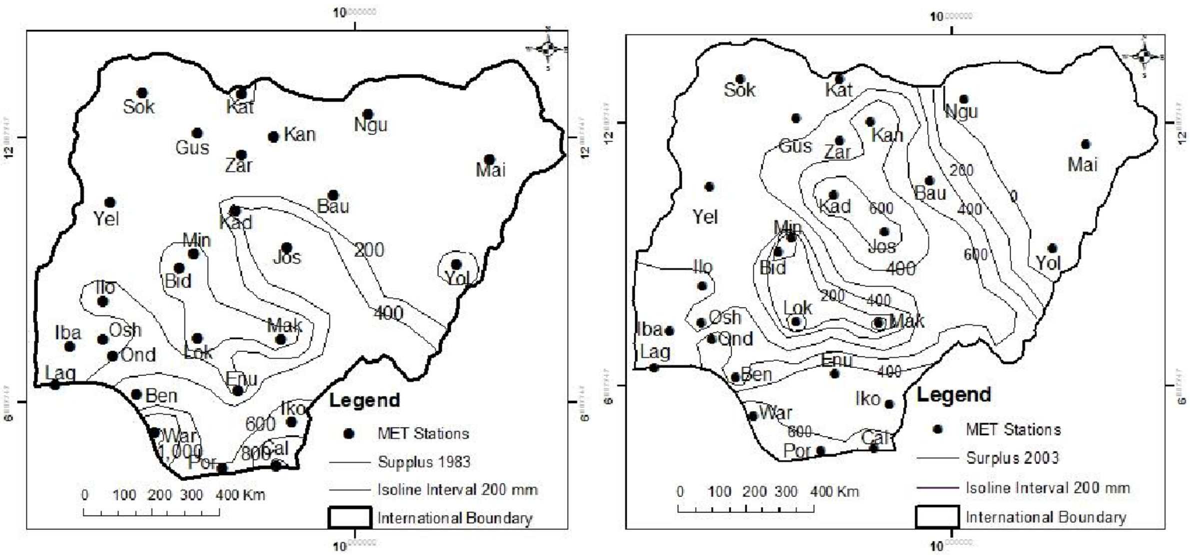

Figure 5.1. Spatial Pattern of Annual Water Surplus for 1983 and 2003 in Nigeria.
Source: Author's Compilation, 2017.

Table 5. Summary of Annual Water Surplus (mm) for 1983 and 2003 in Nigeria.

Station	S 1983	S 2003
Port/H	389	638
Calabar	870	669
Warri	1029	828
Ilkom	589	586
Benin	299	235
Lagos	6	170
Enugu	75	360
Ondo	118	351
Ibadan	0	276
Makurdi	0	0
Lokoja	12	0
Oshogbo	0	95
Ilorin	183	192
Bida	0	0
Yola	0	0
Minna	0	38
Jos	529	475
Kaduna	165	628
Yelwa	0	146
Bauchi	0	89
Maiduguri	0	0
Zaria	0	192
Kano	0	409
Gusau	0	149
Nguru	0	0
Katsina	0	0
Sokoto	0	22

Source: Author's Computation, 2017.

149mm, 146mm 89mm, and 38mm accordingly. See Figure 5.1 for the spatial pattern of annual water surplus for 1983 and 2003 in Nigeria.

The major factors responsible for the spatial variations of water surplus of any place on the earth's surface are the amount of precipitation received; the rate of potential

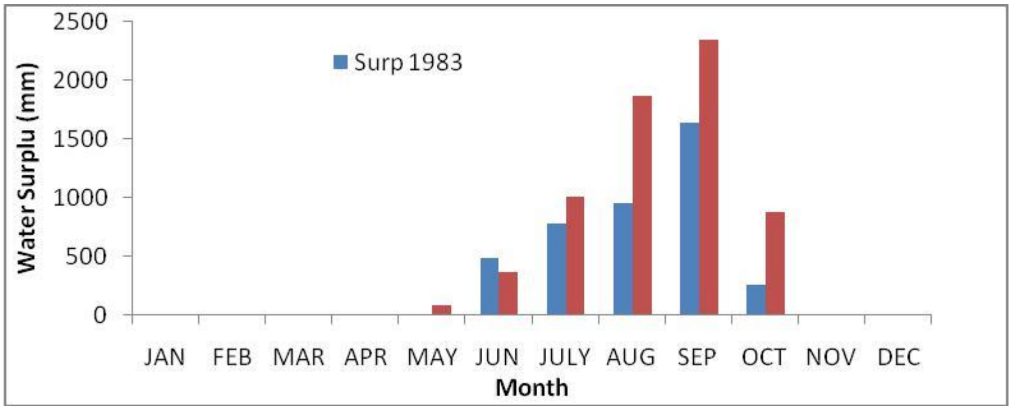

Figure 5.2. Temporal Pattern of Water Surplus for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

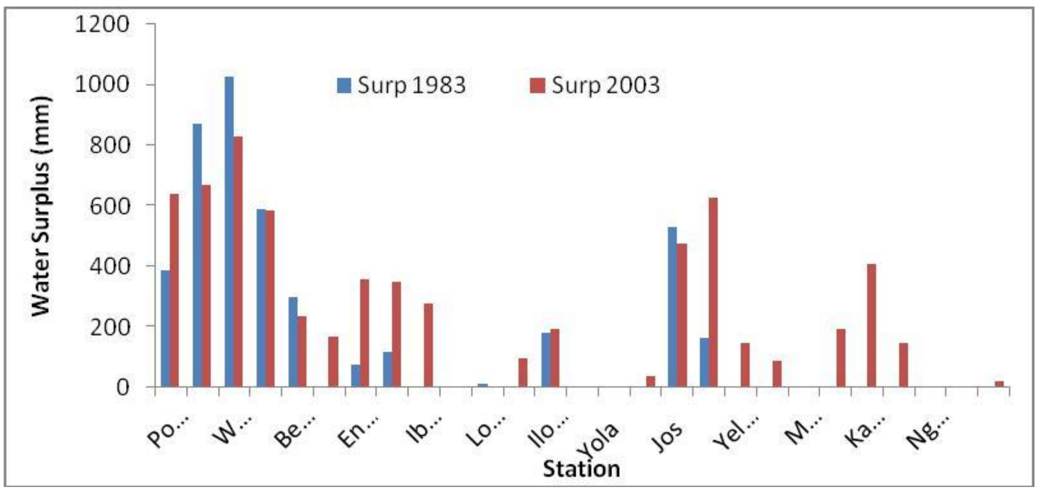

Figure 5.3. Comparison between the Annual Water Surplus for 1983 and 2003 in Nigeria.
Source: Field Work, 2017.

evapotranspiration in that particular place and the soil's water storage capacity. Some stations could not record any surplus because their PE is higher than their precipitation and their soil could not attain their water full storage capacity. On the contrary, some of the stations, especially those located in the Southern part of Nigeria were able to record water surplus because the amounts of precipitation received is higher than the amounts of potential evapotranspiration and their soil's attained their water holding capacity of 250mm used for this study.

Temporal Pattern of Water Surplus in Nigeria

The result from Figure 5.2 showed that the amount of water surplus varies monthly in Nigeria in both 1983 and 2003. It could be observed from Figure 5.2 that the amount and number of stations that recorded water surplus increases from as low as 0mm in January to as high as 1639mm and 2347mm in September in 1983 and 2003 in Nigeria. It is obvious from Figure 5.2 that water surplus was recorded only during the months of May, June, July, August, September October in both 1983 and 2003. Apart from September, the months that followed in terms of the higher water surplus in both years are August, July and October. All other months recorded no water surplus of any amount. See the details in (Figure 5.2).

It is important to note that the factors that are responsible for the spatial variations of the water surplus on earth are the same factors responsible for the variations of water surplus over time. Stations with records of monthly water surplus recorded water surplus in those months where the amount of precipitation received exceeds the amount of water demand for evapotranspiration (PE). On the contrary, some stations could not record water surplus in some months either, because there was no rainfall or the

Table 6. Paired Sample Statistics for Spatio-Temporal Pattern of Water Balance Indices for the year 2003 and 1983 in Nigeria.

Water balance indices	mean	N	std. deviation	std error Mean
2003	5759.37	26	958.95	184.55
1983	5227.7	26	1052.4	202.52

Source: Author's Computation, 2017

Table 7. Paired Sample Test for Spatio-Temporal Pattern of Water Balance Indices for the year 2003 and 1983 in Nigeria.

		Paired difference					t	df	Sig. (2tailed)
		Mean	Std.deviation	Std. error	95% confidence interval levelof difference				
					Lower	upper			
Water Balance Indices 2003&1983		531.66	674.85	129.87	264.70	798.63	4.094	26	.000

Source: Field Work, 2017.

amount of rainfall recorded was less than the water demand for evapotranspiration and as such, the soil was not saturated. The temporal pattern of monthly water surplus in Nigeria could be related to that of the quarterly soil moisture condition, compilation of *Agromet DEKAD* by the Nigerian Meteorological Agency (NIMET, 2012 and 2013). It means if the water surplus persists and there is further addition of water in form of precipitation, runoff will occur in those places.

Comparison between the Annual Water Surplus for1983 and 2003 in Nigeria

The result in Tables 5 showed that the amount and number of stations that recorded water surplus is higher in 2003 compared to 1983. Stations like Benin, Jos, Warri and Calabar are exceptional to have recorded annual water surplus of 299mm, 529mm, 1029mm and 870mm accordingly, higher than that of 2003. While only thirteen stations recorded water surplus in 1983, virtually all the weather stations in Nigeria recorded water surplus in 2003 except Maiduguri, Yola, Nguru, Katsina, Lokoja, Makurdi and Bida. See Figure 5.3 for the annual comparison of water surplus for 1983 and 2003 in Nigeria. The result in Figure 5.3 showed that many stations experienced annual surplus in 2003 compared to 1983. The reason for higher water surpluses recorded in 2003 when compared to that of 1983 could be ascribed to the higher rainfall received in the year 2003. The year 2003 was the year Nigeria began to recover from 1980s droughts as pointed out by Umar, (2013). On the other hand, there was low record of rainfall in 1983 to the extent that some Southern stations that were known for high rainfall in the like Lagos, Enugu and Ibadan recorded low rainfall below 1000mm. This is because the year 1983 has been reported to be one of those years bedeviled with droughts of 1980s of varied magnitudes (Umar, 2013).

With reference to Table VII, .000 is less than ∝ (0.05) therefore, "paired sample t test reveals a statistical mean difference between spatio-temporal pattern of water balance indices for 2003 (M=5759.37, s=958.95) and 1983 (M=5227.7, s=1052.4) in Nigeria. t (26) =4.094, p =.000, ∝0 .05. This means there is a significant difference in the water balance indices across the weather stations in Nigeria and over the years 2003 and 1983.

CONCLUSION AND RECOMMENDATIONS

This study concludes that there is variation in the spatial and temporal patterns of water balance indices in Nigeria and over the two years with contrasting moisture condition. It is recommended that Government should expand the existing irrigation scheme across different locations in Nigeria and establish more irrigation projects even in some part of the Southern Nigeria where there are very low rainfall, high potential evapotranspitation and high water deficit to boost crop production throughout the year. Places with high rainfall, water surpluses should be properly managed to forestall severe soil erosion and flooding.

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