Sub-Sahara African Academic Research Publications
March, 2021, Editions

JECM
Journal of Environmental Design and Construction Mgt.
Vol.19, No.4, ISSN 2292-7733

POTENTIAL EVAPOTRANSPIRATION IN SUDANO-SAHELIAN REGION OF NIGERIA: A CASE STUDY OF YOBE STATE

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Abstract
Potential evapotranspiration is a major controlling factor in hydrological processes and plays a vital role in the water balance of any place, river bodies or basin on the earth. This study assessed Potential evapotranspiration in Yobe State over the period (1956-2015). The study used mean monthly air temperature data collected from the archives of the Nigerian Meteorological Agency (NIMET) for Nguru and Potiskum in Yobe State. The entire data were subjected to Thornthwaite's method to estimate the monthly Potential Evapotranspiration (PE) over the period. The result indicated that the long-term mean monthly PE for Nguru varies from 167mm in January to as high as 191.7mm in June and from 170mm in January to as high as 191.8mm in May in Potiskum. Finding further revealed that the long-term annual mean PE for Nguru and Potiskum over the period were 2260mm and 2203mm respectively. On a general note, there were upward trends in PE during the period. Likewise, there is a significant relationship between PE and Temperature in Nguru ($F = 61.515$, $df = 1$, $p = .000$) and Potiskum ($F = 97.464$, $df = 1$, $p = .000$). The study concluded that potential evapotranspiration was very high in the area due to high rate of temperature and it is suggested that irrigation schemes be expanded and intensified in the area to boost crop production. More trees should be planted to contain the high temperature, which will in turn curtail the higher rate of potential evapotranspiration

Keywords: *potential, Evaporation, Transpiration, Potential evapotranspiration (PE) and Water balance*

INTRODUCTION

Potential evapotranspiration is a major factor in hydrological processes and plays a vital role in the water balance of any place, river bodies or basin on the earth. It is also one of the estimates to assess the impacts of Climate Change because with the increasing global temperature, there is a strong tendency of increasing rate of potential evapotranspiration. High potential evapotranspiration beyond the precipitation in a place leads to water deficit. Evapotranspiration is a combined process of water loss from a bare soil, water bodies and vegetated surfaces. While evaporation is a process of water loss from the bare soil, oceans, streams, rivers, basins etc, transpiration on the other hand is the process of water loss from the leaves and stomata of plants. Therefore, Potential evapotranspiration (PE) is considered the rate at which water will be lost from both the soil and the vegetated surfaces into the atmosphere if water is not a limiting factor. Hence, potential evapotranspiration could be considered as water demand based on the environmental condition.

Potential evapotranspiration is difficult to determine except through the methods of estimation such as that of Thornthwaite (1948) which pioneered the estimation of potential evapotranspiration in order to study the water balance. Other methods used include Priestley-Taylor method, Makkink method, Turc method, Hargreaves-Samani, Blaney-Criddle and Penman Monteiths. Among these methods, Thornthwaite's method is the easiest and widely used method of estimating PE because it involves less data set unlike others. With only temperature data, PE can be calculated.

Yobe State is in the Sudano-Sahelian region of Nigeria and has been characterized by inadequate water for agriculture and other purposes as a result of low rainfall and hot climatic condition due to high temperature. This area is far from the sea and has close proximity to the Sahara desert. This region has witnessed dramatic reduction in mean annual rainfall (Dai *et al*, 2004; Ekpoh and Nsa, 2011). It was also reported that, Northeastern Nigeria particularly Yobe State has witnessed dramatic climatic anomalies in the form of droughts, high water deficit, PET, and decrease in rainfall over the years (Buttu, 2019; Bulama, 2018, Kehinde, 2017; Kehinde and Umar, 2018). In a place that is characterized by inadequate rainfall and the majority of the population, practice rain-fed agriculture the solution is to protect the little available water in the soil for optimum crop production. The assessment of PE is very crucial with a view to ascertaining how much water will be lost from the available water in the soil at different time of the year. This will serve as a panacea to design alternative farming techniques to assist farmers in the state to cope with the problem of water shortage.

MATERIAL AND METHODS

Yobe State is a State located in the Northeastern Nigeria. Yobe State lies approximately between Latitude 12°00'N and 12.000°N of the equator and between Longitude 11°30'E and 11.500°E of the Greenwich Meridian. It occupies a total landmass of 45, 502km^2 with a total population of 2, 321,339 (NPoC, 2006). The estimated population growth as at 2011 was 2, 757,000. The State borders four States: Bauchi, Burno, Gombe and Jigawa. It borders to the north by Diffa and Zinder Regions of Niger. Because the State lies in the Sahel Savanna belt, the weather conditions are hot and dry for most of the year, except in the Southern part of the State which has more annual rainfall (Yobe State in Wikipedia).

Fig. 1: Yobe State

The climate is characteristically marked by two seasons namely: dry and wet season. The rainy season starts in May or June in the southern part and June or July in the northern flank and peaks in August and finishes quite rapidly in September or October. The rainfall in the state is mostly influenced by the migration of the Inter-Tropical Discontinuity (ITD).

The economy of the State is majorly agriculture. It is also rich in mineral deposit, including gypsium and kaolin in Fune Local Government and very rich in agricultural resources as well. The State agricultural produce includes gum Arabic, groundnut, beans and cotton. The State also has the biggest cattle markets in West Africa, located in Potiskum. The major ethnic groups living in Yobe State are the Kanuri and Fulani, while other major ethnic communities include Bolewa, Ngizim, Karai-Karai, Bade, Hausa, Ngamo, Shuma, Bura, Margi and Manga (Yobe State in Wikipedia).

Type and Source of Data

This study used mean monthly air temperature data that were collected from the archives of the Nigerian Meteorological Agency (NIMET). The data were collected with respect to Nguru and Potiskum, which are the two synoptic weather stations located in Yobe State. The data covered a climatological period of 60 years (1956-2015). Due to different changes in climatic variables such as rainfall, air temperature unfolded by earlier studies with respect to the area, this study decided to split the period into two period (1956-1979 and 1980-2015) with a view to determining how better the PE has changed over the years.

Calculation of Potential Evapotranspiration (PE)

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

$$ET_0 = 16 \times \left(\frac{10Ti}{I}\right)^{a} \left(\frac{N}{12}\right)\left(\frac{1}{30}\right) \quad (1)$$

$$I = \sum_{I=1}^{12} \left(\frac{Ti}{5}\right) 1.514 \quad (2)$$

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.

However, for efficiency and accuracy, this study use an excel template for computing Potential evapotranspiration using Thornthwaite's method. The

Software was developed by Dr. Andre, Department of Geology, Humboldt State University in 1994.

After estimating the monthly PE over the years under review, the study used descriptive statistic and measure of dispersion such as mean, standard deviation and variance for better analysis. The results were also presented in Tables and Charts for better understandings.

Result and Discussion

Monthly Potential Evapotranspiration in Yobe State

The estimated monthly PE for the entire period was divided into two climatological periods (i.e. 1956-1979 and 1980-2015). The results of monthly Potential Evapotranspiration (PE) for Nguru for the period of 1959-2015 in Yobe State are contained in Table 1a and Table 1b. Table 1a contained the estimated PE for 1956 to 1979 while Table 1b contained the monthly PE for the period 1980 to 2015 for Nguru. It is obvious from the tables that the monthly PEs varies from as low as 47mm in January in 1983 to as high as 192mm from March to October in most of the years. The values of PE were higher in June compared to any other month where the PE values for virtually all the years were above 190mm.

Table 1a: Monthly Potential Evapotranspiration for Nguru (1956-1979)

Yea	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	170	191	191	190	189	192	179	158	182	190	190	172
1957	172	181	192	190	192	189	180	176	185	192	192	184
1958	183	185	191	187	190	191	176	171	187	192	192	186
1959	176	185	191	190	190	192	188	165	180	191	188	178
1960	172	185	192	189	191	192	180	178	184	191	185	187
1961	172	168	188	190	189	191	177	183	184	191	183	162
1962	162	186	191	191	190	190	183	169	185	192	191	185
1963	184	191	190	191	191	192	186	178	188	190	180	184
1964	172	181	191	188	190	191	181	164	183	192	184	182
1965	183	191	191	191	188	190	185	175	186	192	181	175
1966	178	181	192	192	191	191	189	178	183	191	188	176
1967	160	187	190	188	189	192	184	173	181	190	183	185
1968	166	187	192	192	192	189	181	182	188	190	187	185

1969	168	191	188	190	190	191	188	178	187	191	186	187
1970	180	184	192	191	190	191	188	177	182	191	183	172
1971	164	187	187	191	189	192	185	171	185	189	184	166
1972	171	187	192	191	191	191	190	188	191	191	179	179
1973	178	189	192	190	191	191	189	179	189	191	176	181
1974	151	182	192	188	191	192	179	174	182	191	184	158
1975	145	181	192	189	189	191	182	175	180	189	188	171
1976	169	187	191	191	191	190	183	179	184	190	187	181
1977	171	179	188	191	190	192	186	169	188	189	181	159
1978	164	186	192	191	190	190	175	180	184	191	182	176
1979	177	187	192	191	191	190	183	179	187	191	190	163

Source: Authors' Fieldwork, 2021

Table 1b: Monthly Potential Evapotranspiration for Nguru (1980-2015)

Yea	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	179	184	192	190	191	191	181	177	189	191	186	165
1981	151	184	192	190	191	191	179	182	187	191	177	178
1982	170	178	192	189	190	192	187	174	187	191	179	176
1983	47	186	186	188	187	192	188	183	187	190	187	179
1984	160	181	191	190	190	192	186	189	189	191	187	163
1985	178	176	192	191	191	191	181	179	184	190	188	164
1986	166	190	192	186	190	192	182	179	183	191	187	162
1987	174	188	192	192	187	192	191	183	189	191	187	176
1988	165	183	192	189	189	191	181	169	183	190	187	164
1989	148	167	191	190	192	192	185	175	187	190	185	169
1990	178	173	187	187	189	191	183	183	189	192	190	188
1991	166	191	192	190	191	192	184	176	190	191	185	172
1992	158	176	192	191	191	192	182	174	185	192	181	174
1993	152	184	192	190	190	192	188	178	187	192	191	170
1994	167	180	191	190	190	192	181	166	181	190	186	160
1995	162	178	191	190	189	192	187	181	186	191	184	181
1996	183	190	191	191	190	191	189	177	186	190	180	179
1997	179	170	191	191	192	192	188	183	189	192	191	174
1998	174	188	189	187	187	192	190	181	181	191	190	179
1999	176	183	189	190	190	191	184	169	181	190	189	187
2000	164	164	191	187	189	192	185	183	187	190	188	171
2001	169	177	192	191	190	191	186	175	184	189	192	183
2002	153	182	192	188	186	192	188	182	186	191	189	179
2003	177	191	191	189	188	190	188	176	186	192	189	174
2004	176	183	191	188	190	192	186	182	189	192	189	183
2005	166	175	190	189	190	191	186	180	189	192	188	185
2006	177	192	192	190	189	191	190	184	184	191	182	166
2007	162	189	191	188	190	192	187	182	186	192	191	181
2008	150	181	191	191	190	192	184	179	187	191	189	183

2009	181	191	192	187	187	191	189	184	190	192	187	183
2010	185	189	192	186	187	191	185	178	184	191	191	179
2011	170	191	191	190	189	191	189	180	186	191	188	172
2012	173	190	192	186	191	191	182	174	185	191	191	180
2013	174	185	186	191	188	192	187	172	187	191	191	181
2014	179	185	191	188	190	192	188	176	186	192	190	176
2015	166	187	192	192	185	191	190	181	186	192	187	154

Source: Authors' Fieldwork, 2020

Tables 2a and 2b contained the monthly PEs for Potiskum from 1956 to 2015. While Table 2a contained the monthly PEs for 1956 to 1979, Table 2b contained that of 1980 to 2015 in the area.

Table 2a: Monthly Potential Evapotranspiration for Potiskum (1956-1979)

Yea	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	171.1	192.2	192.2	192.2	192.2	190.8	172.3	152.6	176.7	188.1	188.3	171.7
1957	171.1	180.6	191.0	192.0	191.0	186.0	172.3	171.7	180.6	190.8	192.1	183.9
1958	183.9	185.3	192.1	190.3	192.2	188.3	170.5	167.4	182.3	191.6	191.2	186.6
1959	178.7	185.7	191.3	191.5	192.1	191.0	184.2	159.6	174.6	191.4	186.6	179.7
1960	175.7	185.0	192.2	190.8	192.2	190.5	175.1	174.6	179.2	191.0	183.1	187.2
1961	174.6	169.9	188.3	192.1	192.0	189.7	170.5	178.2	179.2	190.5	179.7	163.3
1962	165.3	186.3	192.2	192.2	192.2	187.5	177.7	165.3	180.1	190.3	189.9	184.6
1963	183.9	192.2	189.7	192.2	192.2	191.4	178.7	171.7	184.2	187.2	178.7	182.3
1964	174.0	180.6	192.2	191.4	192.2	188.8	174.6	159.6	177.7	190.1	181.0	179.7
1965	181.0	190.5	190.5	192.1	192.2	187.5	180.6	168.0	182.3	190.5	178.7	175.7
1966	178.2	181.0	192.1	192.1	191.7	188.6	186.0	172.9	179.2	189.7	186.9	175.7
1967	163.3	186.6	190.1	190.7	192.1	189.7	177.7	168.0	176.7	188.6	181.0	185.3
1968	168.6	187.2	192.2	191.5	192.0	184.2	176.2	178.2	183.5	188.3	185.7	181.9
1969	169.9	191.0	190.7	191.4	192.1	187.8	186.9	173.5	182.7	188.3	184.2	187.2
1970	181.0	185.0	192.1	192.1	191.9	191.9	183.9	172.3	176.7	189.5	183.1	172.3
1971	172.9	188.1	192.2	192.2	192.0	189.1	186.0	185.0	187.2	187.8	181.0	178.2
1972	172.9	188.1	192.2	192.2	192.0	189.1	186.0	185.0	187.2	187.8	181.0	178.2
1973	179.7	189.1	191.9	191.8	192.2	192.0	186.3	173.5	184.2	190.7	175.7	181.9
1974	155.8	180.6	191.9	191.0	192.1	191.4	171.1	167.4	176.7	189.5	179.7	158.9
1975	150.0	181.9	192.2	191.4	191.9	186.9	174.6	168.6	174.0	187.2	185.7	171.7
1976	171.7	180.6	191.2	192.2	191.6	186.6	176.2	173.5	178.2	187.2	186.3	181.0
1977	172.3	178.2	187.2	192.2	192.1	191.5	180.6	161.8	183.1	186.9	177.2	159.6
1978	167.4	186.3	192.2	192.2	192.1	187.8	170.5	176.7	178.7	190.1	183.1	177.2
1979	179.2	186.3	192.1	192.2	192.1	185.3	175.1	171.7	183.5	190.5	189.7	169.3

Source: Authors' Fieldwork, 2021

It could be inferred from Tables 2a and 2b that the rate of PE varies monthly based on the environmental condition specially the level of the temperature. The PE is higher in the month of May in Potiskum where many years recorded PE values above 190mm. The tables further showed that the rate of PEs were low during the months of January over the period in Potiskum where many years recorded PE below 150mm.

Table 2b: Monthly Potential Evapotranspiration for Potiskum (1980-2015)

Yea	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	181.0	184.6	192.1	191.8	192.2	189.9	179.7	172.9	185.7	189.9	185.7	166.7
1981	155.0	186.0	192.0	191.4	192.0	189.5	171.1	179.2	182.7	189.3	178.2	177.7
1982	171.1	179.7	191.9	191.4	192.2	191.4	182.3	168.0	182.7	188.6	179.2	177.2
1983	66.1	186.9	187.2	190.0	190.5	190.5	182.7	180.1	182.3	189.1	186.6	178.7
1984	165.3	183.5	192.2	192.1	192.1	191.1	181.4	186.0	185.0	189.7	188.8	165.3
1985	178.7	177.7	192.2	191.5	192.1	189.5	175.1	173.5	178.2	189.5	187.5	163.3
1986	169.9	191.0	192.2	189.3	192.1	191.6	174.6	174.0	177.7	190.5	187.5	161.8
1987	178.2	189.1	192.1	192.2	191.4	191.7	189.7	177.7	184.6	189.3	187.8	176.7
1988	170.5	186.0	192.2	191.0	191.6	188.6	175.1	161.8	175.7	188.8	187.5	165.3
1989	157.4	171.7	191.1	191.6	191.9	191.1	179.7	170.5	181.9	187.2	186.3	170.5
1990	182.3	178.2	186.6	189.8	192.1	192.0	175.1	177.2	185.0	190.8	189.5	185.7
1991	168.6	191.5	192.0	191.9	189.5	191.4	180.1	168.6	187.8	190.3	184.2	173.5
1992	162.6	177.7	192.1	192.1	192.2	190.1	176.2	166.0	179.7	190.5	181.4	175.1
1993	158.9	184.2	192.2	191.8	192.2	191.5	183.5	170.5	181.9	191.4	190.5	172.3
1994	170.5	181.4	191.9	191.9	192.2	190.5	175.7	158.1	176.2	189.1	188.6	164.0
1995	168.0	179.2	192.1	191.9	191.8	191.0	182.7	174.6	181.4	190.1	183.9	181.4
1996	183.9	190.8	191.7	192.1	192.1	188.8	185.7	172.9	179.7	188.6	179.2	178.7
1997	180.1	172.3	190.7	192.2	192.0	189.9	183.5	178.7	186.6	191.7	190.7	174.6
1998	179.7	186.3	190.0	191.4	192.2	191.7	180.1	164.7	175.1	187.8	188.6	190.1
1999	168.6	167.4	191.5	190.0	191.7	190.8	181.9	179.7	182.7	188.1	187.5	171.1
2000	168.6	167.4	191.5	190.0	191.7	190.8	181.9	179.7	182.7	188.1	187.5	171.1
2001	172.3	179.2	192.2	191.9	192.2	189.7	181.0	169.3	177.2	185.7	191.5	182.3
2002	155.0	182.3	192.2	191.3	189.5	191.6	184.6	177.2	180.1	189.7	187.5	178.2
2003	178.2	191.4	191.0	191.3	191.7	186.3	183.1	170.5	181.0	191.6	188.8	173.5
2004	177.2	183.5	191.1	190.5	192.0	191.4	181.9	177.2	185.3	191.5	188.3	183.1
2005	168.0	182.7	191.4	191.0	192.2	188.1	182.3	174.0	185.3	190.7	187.8	184.2
2006	178.2	191.9	192.2	191.7	192.1	192.2	186.3	179.2	179.7	189.9	182.3	167.4
2007	167.4	189.5	192.0	190.3	192.2	190.3	183.1	175.7	182.3	192.1	190.7	182.3
2008	159.6	181.9	191.9	192.2	192.2	191.5	179.2	174.0	181.9	189.9	187.5	181.4
2009	182.3	191.4	192.2	190.1	191.3	192.1	184.6	180.6	186.0	190.7	186.9	183.1
2010	186.0	188.8	192.2	188.6	191.3	192.1	180.1	174.0	178.2	190.1	190.3	179.2
2011	173.5	190.7	192.0	191.8	191.9	190.7	186.0	176.2	181.4	189.9	186.6	174.0
2012	173.5	190.7	192.0	191.8	191.9	190.7	186.0	176.2	181.4	189.9	186.6	174.0
2013	172.3	185.3	188.9	192.2	191.4	191.7	181.9	164.7	181.4	188.6	189.9	179.7
2014	179.7	185.7	192.2	191.1	192.2	191.9	184.6	169.3	181.4	190.7	188.3	175.1
2015	168.0	187.2	192.2	192.2	190.0	191.8	187.8	176.7	181.0	191.7	187.2	155.8

Source: Authors' Fieldwork, 2021

The result in Figure 2 showed that the month of May recorded the highest long-term mean monthly PE of 191.8mm. This implies that the rate of potential evaporanspiration is higher in the month of May compared to other months in the area over the period. It is also evident from Figure 2 that the lowest long-term mean PE value of 170.3mm was recorded in January. This implies that the rate of PE was low in January in all the years between 1956 and 2015 in

Potikum. The lowest PE recorded in Potiskum during the months of January is also attributed to the influence of harmattan wind, which makes the environment very cold during the period. When the temperature is low, there would not be potential for the water to be drawn from the earth's surface.
It could be seen from Figure 2 that the month of June recorded the highest long-term mean monthly potential evapotranspiration of 191.7mm in Nguru while the highest mean monthly PE of 191.8mm was recorded in Potiskum in May. This implies that the rate of PE was higher during the month of June and May in the area between 1956 and 2015. The results in Figure 2 also revealed that January recorded the lowest long-term monthly mean of 167.9mm and 170.3mm in Nguru and Potiskum respectively. This indicates that the rate of PE is usually low in January in the area. This could be attributed to the influence of harmattan wind, which temperature very cold to draw water from the earth's surface. When the temperature is cold, the potential to draw water from the earth's surface is limited. According to Kimberly Research and Extension Center (2016), Potential evapotranspiration is higher in summer, on less cloudy days and closer to the equator, because of higher level of solar radiation that provides the energy for evaporation. This finding is in line with the finding of Kehinde (2017); Kehinde and Umar (2018) which found that the monthly PE for Nguru was as low as 24mm in January and as high as 192mm in April.

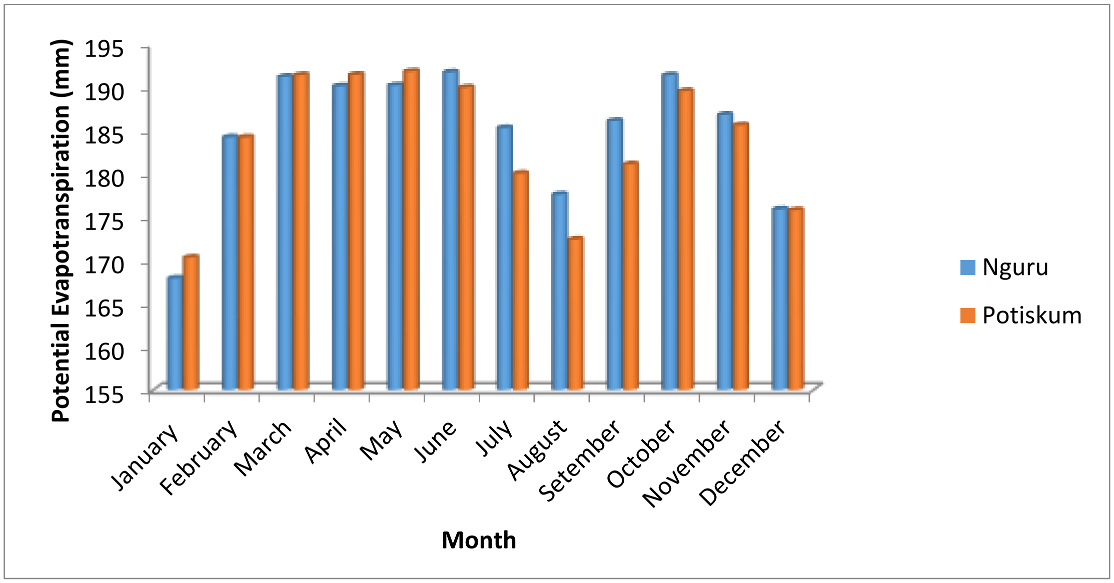

Fig. 2: Mean Monthly Distribution of PE in Yobe State
Source: Authors' Fieldwork, 2021

Annual Potential Evapotranspiration in Yobe

The result in Table 3 revealed that the long-term annual mean potential evapotranspiration between 1956 and 2015 in Nguru was 2218.65mm and that indicates that the amounts of PE in most of the years in Nguru within the period were higher (above 2000mm). The table equally showed that the standard deviation was 25.39 and the variance was 644.3.This implies the rate of PE in the area is variable within the period in Nguru. It could be observed in Table 3 that the highest annual PE of 2260.29mm was recorded in Nguru in 2009 while the lowest PE of 2105.91mm was recorded in the year 1983. This implies that the year 2009 recorded the highest rate of water loss probably because the year was the hottest year during period in the 21st century.

The result in Table 3 further revealed that the long-term annual mean potential evapotranspiration in Potiskum during the period (1956-2015) was 2203.81mm, which indicates that virtually all the years recorded annual PE above 2000mm. The standard deviation, annual range and variance of PE were 24.98, 140.47 and 624.3. This indicates that the amount of annual PE is variable in Potiskum over the period (1956-2015). Similarly, the result in Table 3 showed that the highest annual PE (2251.19mm) was recorded in the year 2009 while the lowest PE of 2110.72mm was recorded in 1983 in Potiskum. The highest annual PE recorded in the year 2009 might not be unconnected with the fact that the year 2009 has been described as the hottest year in the 21st century in Nigeria. This finding is in agreement with Kehinde (2017); kehinde and Umar (2018) that revealed that the annual PE of Nguru, Northeastern Nigeria was above 1900mm in 1983 and above 2000mm in 2003.

Table 3: Descriptive Statistics on the Potential Evapotranspiration in Yobe State

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
PE for Nguru	60	154.91	2105.38	2260.29	2218.65	25.39	644.93
PE for Potiskum	60	140.47	2110.72	2251.19	2203.81	24.98	624.30
Valid N (listwise)	60						

Source: Authors' Fieldwork, 2021

Trend in Potential Evapotranspiration in Yobe State

The result in Figure 3a revealed a downward trend in annual PE in both Nguru and Potiskum between 1956 and 1979 while it showed an upward trend in both

Nguru and Potiskum between 1980 and 2015. The regression trendline equations in the figures revealed that the annual PE was decreasing at rate of -0.646mm per annum and -15.50mm between 1956 and 1979 in Nguru. The trendline equation for Potiskum showed that the rate of annual PE was decreasing at the rate of -0.563mm per annum which means the amount of PE has decreased by -13.512mm over the period (1956-1979).

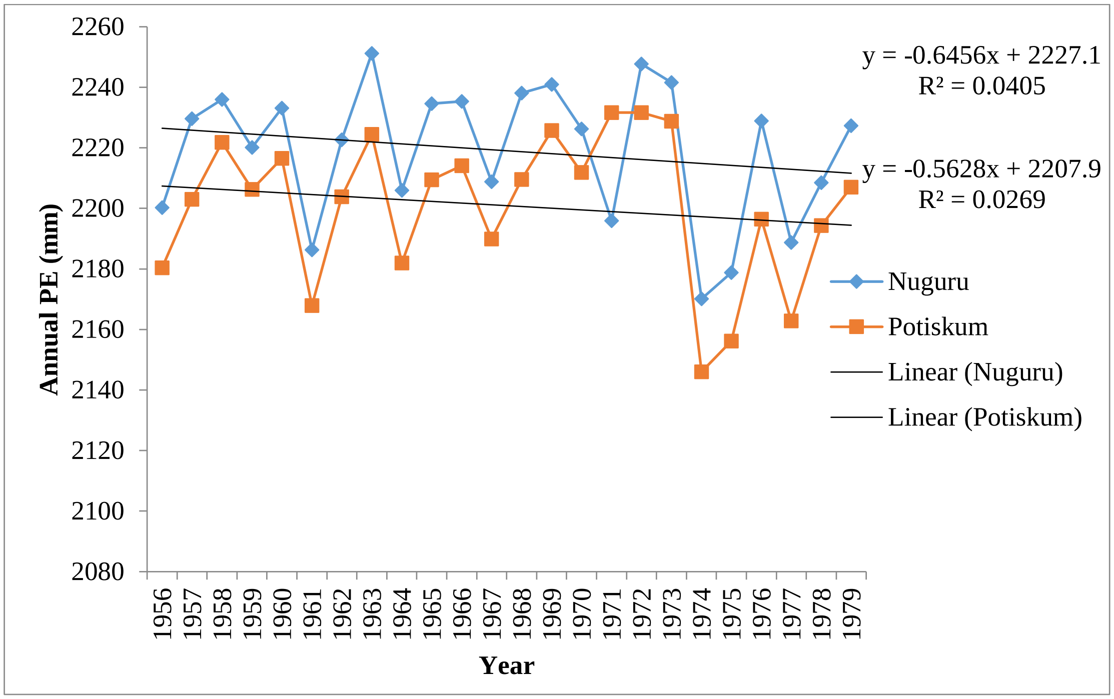

Fig. 3a: Short-term Annual Trend of PE in Yobe State (1956-1979)
Source: Authors's Fieldwork, 2021

The results in Figure 3b revealed that there were upward trends in the amount of annual PE in both Nguru and Potiskum between 1980 and 2015. The trendline equation showed that the PE was increasing at the rate of 1.2196mm per annum in Nguru and it was increasing at the rate of 1.1759mm per annum in Potiskum during the same period. The trendline equations in Figure 3b implies that the amount of annual PE has increased by 43.91mm in Nguru and 51.63mm in Potiskum over the period (1980-2015).

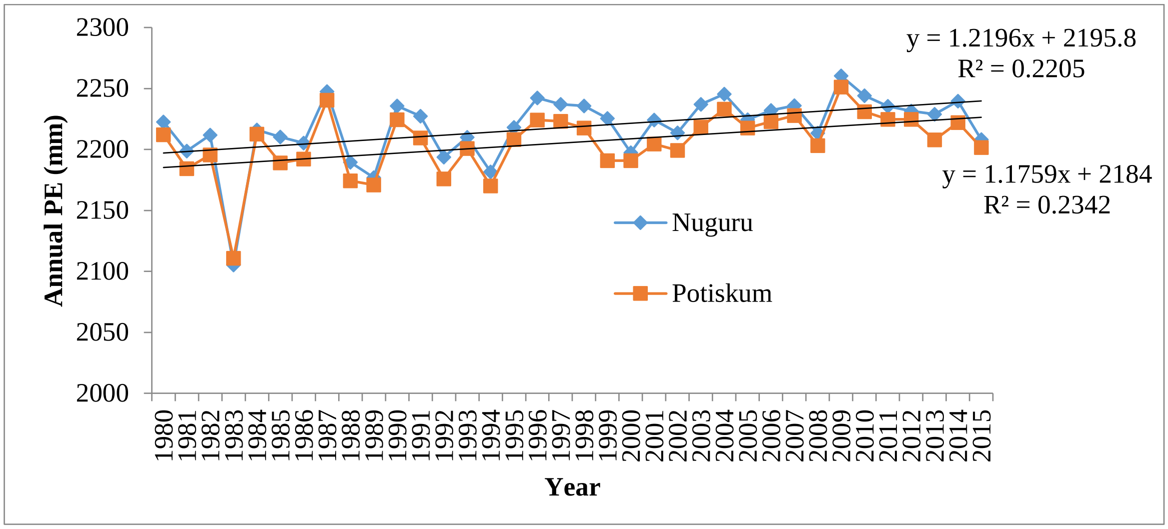

Fig. 3b: Short-Term Annual Trend of PE in Yobe State (1980-2015)
Source: Authors' Fieldwork, 2021

The results in Figure 4 revealed that the amount of PE showed upward trends in both Nguru and Potikum over the entire period (1956-2015). Further analysis from Figure 4 indicates that the amount of PE had increased by 12.38mm in Nguru and by 20.05mm in Potiskum over the entire period (1956-2015). From the foregoing, it is obvious that rate of PE is increasing in Yobe State over the years and it is a clear indication of increasing dryness in the place. As the rate of potential evapotranspiration is higher than the precipitation, there will be water deficit. This in turn affects agriculture, hydrological and ecological processes in an area. This finding corroborates with the finding of Butu (2019) which revealed that there was upward trend in PE between 1978 and 2012 in the northeastern Nigeria. The study further stressed that the rate of PE increased both annually and seasonally.

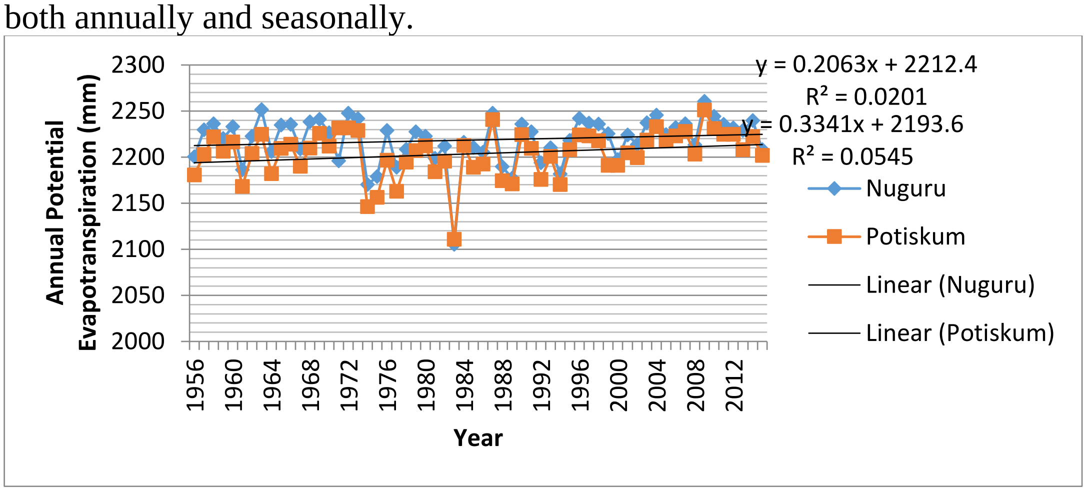

Fig. 4: Long-Term Annual Trend of Potential Evapotranspiration (1956-2015 in Yobe State
Source: Authors' Fieldwork, 2021

Relationship between potential evapotranspiration and Temperature in Yobe State

The result in Table 4 revealed that the adjusted R square for Nguru is .506 and that of Potiskum is .620. This implies that the independent variable entered into the model contribute significantly in predicting the variations in the dependent variable (PE) by 50.6% and 62.0% for Nguru and Potiskum respectively. This further implies that temperature contributes significantly in determining the amount of potential evapotranspiration by 50.6% and 62.0% in Nguru and Potiskum respectively.

Table 4: Regression Model on the Relationship between potential Evapotranspiration and Temperature in Yobe State

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
Nguru	.717[a]	.515	.506	17.84	.515	61.515	1	58	.000
Potiskum	.792[a]	.627	.620	15.39	.627	97.464	1	58	.000
a. Predictors: (Constant), Temperature for Nguru									

b. Dependent Variable: PE for Nguru

The ANOVA test in Table 5 test whether the overall regression model is a good fit for the data used for the regression. The F-ratios (61.51and 94.46) for Nguru and Potiskum respectively in the table showed that the independent variable (temperature) significantly predicted the rate of potential evapotranspiration in Yobe State. This implies that this variable is good and appropriate for the regression model used for this study.

Table 5: ANOVA on the relationship between PE and Temperature in Yobe State

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	19584.891	1	19584.891	61.515	.000[b]

Nguru	Residual	18465.924	58	318.378		
	Total	38050.815	59			
Potiskum	Regression	23092.036	1	23092.036	97.464	.000[b]
	Residual	13741.857	58	236.929		
	Total	36833.893	59			
a. Dependent Variable: PE for Nguru						
b. Predictors: (Constant), Temperature for Nguru						

The coefficient of regression in Table 5 showed that the unstandardized "B" of the temperature is 36.68 and the significant level is ,000, which indicates that there is a positive significant relationship between potential evapotranspiration and temperature in Yobe State. It implies that for every 1℃ increase in Temperature there will be a corresponding increase in potential evapotranspiration by 36.6mm in Nguru and 41.2mm in Potiskum. Details of the relationship could also be seen in Figure 5.

Table 5: Coefficient of Regression

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
1	(Constant)	9333.957	163.815		5.701	.000
	Temperature for Nguru	36.684	4.677	.717	7.843	.000
	(Constant)	794.988	142.717		5.570	.000
	Temperature for Potiskum	41.202	4.174	.792	9.872	.000

a. Dependent Variable: PE for Nguru

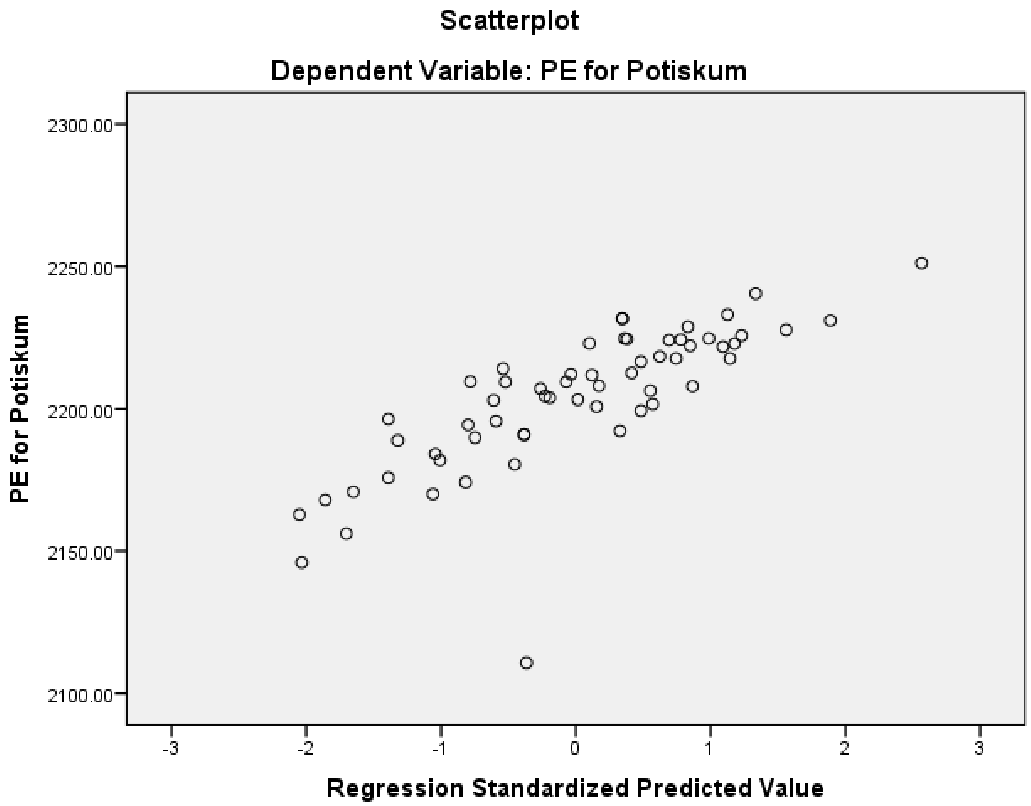

Figure 5: Scatter spot showing relationship between PE and Temperature in Yobe State
Source: Authors' Fieldwork, 2021

Conclusion and Recommendations

This study assessed potential evapotranspiration in Yobe State and concluded that potential evapotranspiration is very high in the area due to high rate of temperature. The study further concludes that the potential evapotranspiration is very low during the months of January over the period due to the influence of harmattan wind and that generally there was an upward trend in potential evapotraspiration over the period in the area. It is suggested that irrigation schemes be expanded and intensified in the area to boost crop production. More trees should be planted to contain the high temperature which will in turn curtail the higher rate of potential evapotranspiration.

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