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Decadal and Trend Analysis of Potential Evapotranspiration in Oluyole, LGA, Oyo State Nigeria

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Abstract: *Variability of potential evapotranspiration due to climate change is presently causing alterations in the global hydrological cycle with devastating effect on the water requirements of crops. This study evaluated the trend and decadal variability of the potential evapotranspiration in Oluyole Local Government Area for one climatic period ranging between 1991 and 2020. Meteorological data, which include the maximum and minimum temperature, were obtained from the NASA Langley Research Center POWER Project portal. These data were applied to estimate the potential evapotranspiration of the study area using the Thornthwaite equation. Thereafter normality test was performed using a coefficient of skewness and kurtosis, trend assessment was performed using the Mann Kendal method, while the significance of decadal variability was assessed using the One-sample t-test and Analysis of Variance (ANOVA). The results reveal that the annual trend of potential evapotranspiration for the period of 1991 and 2020 was accepted as indicative of normality at 95% confidence level, while a positive non-significant ($p > 0.05$) trend was observed during the study period. The study further unravelled that potential evapotranspiration in the first decade was lesser than the long-term mean average of 1498.64 mm, while the proceeding decades recorded slightly higher average values. The t-test and ANOVA revealed that the variations from the long-term average were not statistically significant in the study period. There is the need to pay critical attention to these alterations in order to satisfy crop water requirements.*

Keywords: *Climate Variability, Potential Evapotranspiration, hydrologic alterations, crop water requirement, trend analysis*

INTRODUCTION

Climate change which is a global environmental challenge influences the availability of water and several other climatic parameters. It has been reported that Africa will face increasing water scarcity and stress leading to increase in water conflicts due to climate change [1]. Reduced agricultural productivity and shorter growing seasons were also predicted in the continent due to the dependence of the sector on rainfall. Potential evapotranspiration is the evapotranspiration that occurs when the ground is completely covered by actively growing vegetation and there is abundant water available for the evaporation requirements of plants. Potential evapotranspiration (PET) is important in assessing water requirements for crops that influence the agricultural activities in an area. Future climate changes would affect the hydrological cycle components such as PET, soil moisture storage, surface water flow, and water yield, which determines the availability of water in a region [2]. [2] also noted that mean air temperature rise has an impact on PET. The variation of evapotranspiration had been used to assess the agricultural water needs of crops, hydrological cycles and ecological changes as solar radiation provides its primary source of energy [3].

The trends in PET has been of interest to researchers [4-6]. [7] Reported the need to analyze the influence of PET on crop yield at different stages in the growth of the crops. Changes in PET affect precipitation and the hydrological cycle, which directly influence the water requirements of crops. These alterations have resulted in crop failures in several areas, especially in Nigeria. This makes it imperative to know the impact of climate change on evapotranspiration and use it to develop adaptations in water use and management. There are limited studies on the impact of climate change on PET in Nigeria. Some of the studies have been on the climatic water balance and aridity in the western lithoral hydrologic zone of Nigeria [8] and the performance of PET models [9].

Trends and decadal variability of PET have not been well investigated in Nigeria and most especially in the study area. This study intends to contribute to knowledge in this area because two research institutes whose output depend on the availability of water are located in the area. These are the Forestry Research Institute of Nigeria which has a forest reserve in the area and the Cocoa Research Institute of Nigeria which is involved in cultivating tree crops. The study's objective is to evaluate the trend and decadal variability of the potential evapotranspiration in Oluyole Local Government Area for a climatic period of 1991- 2020.

THE STUDY AREA

The study was carried out in the Oluyole Local Government Area of Oyo State. The area lies between latitudes 7° 00 and 7° 20' N and longitudes 3° 53' E and 4° 00' E (figure 1). The area enjoys the west African Monsoonal climate marked by a distinct seasonal shift in the wind pattern. Two wind systems influence the climate. These are the moist maritime southwest winds from the Atlantic Ocean and the dry dust-laden harmattan winds from the Sahara Desert. The mean annual rainfall is between 1,200 mm and 1,500 mm. Temperatures are fairly uniform throughout the year with a mean annual temperature of about 27° C [10]. The annual potential evapotranspiration is estimated at between 1600 mm and 1900 mm. However, due to human activities such as urbanization, deforestation, the climate is rapidly being modified. The area falls within the Basement complex of Southwestern Nigeria, consisting of granites, gneisses and schist. It has been reported that gneisses underlie an area considerably larger than that occupied by schist [11]. The area is dominated by three major landform units: hills, plains, and river valleys [12]. The plains are the most extensive features, with an elevation of between 180 m and 210 m above sea level. The area is drained by the Ona and Awun Rivers. The soils belong to the Egbeda Association described by Smyth and Montgomery [13].

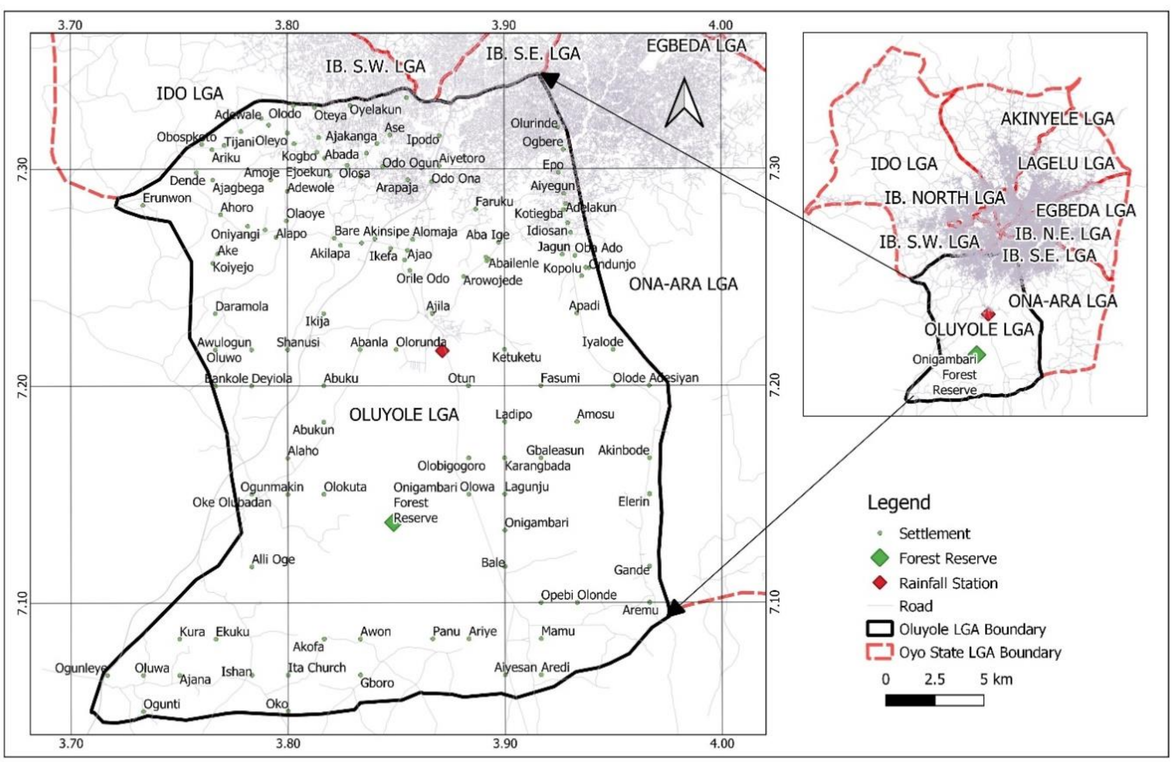

Figure 1: Map of the Study Area

MATERIALS AND METHODS

Meteorological data for this study were obtained from the NASA Langley Research Center POWER Project funded through the NASA Earth Science Directorate Applied Science Program. Maximum and minimum temperature, which were required for the computation of potential evapotranspiration were obtained for the period between 1991 and 2020. Descriptive statistics such as the mean, standard deviation and range were used to describe the computed potential evapotranspiration used for the study to provide concise information.

In this study, potential evapotranspiration was estimated using the Thornthwaite equation [14] provided below:

$$PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T_d}{I}\right)^{\alpha} \qquad 1$$

where PET is the estimated potential evapotranspiration (mm/month), T_d is the average daily temperature (degrees Celsius; if this is negative, use 0) of the month being calculated, N is the number of days in the month being calculated, L is the average day length (hours) of the month being calculated, α was computed based on equations 2 and 3 below:

$$\alpha = (6.75 \times 10^{-7})I^3 - (7.71 \times 10^{-5})I^2 + (1.792 \times 10^{-2})I + 0.49239 \qquad 2$$

$$I = \sum_{i=1}^{12}\left(\frac{T_{m_i}}{5}\right)^{1.514} \qquad 3$$

I is a heat index which depends on the 12 monthly mean temperatures T_{m_i}

A normality test was conducted on climatic data to ascertain whether its distribution is normal or not, which determined the type of inferential statistics used. To test for normality of the estimated potential evapotranspiration, the study adopted the standard coefficient of skewness (Z_1) and the standard coefficient of kurtosis (Z_2), respectively defined in equation 4 and 5 [15].

$$Z_1 = \frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{s}\right)^3 \qquad 4$$

$$\frac{n(n+1)}{(n-1)(n-2)(n-3)}\frac{\sum_{i=1}^{n}(x_i-\bar{x})^4}{s^4} - \frac{3(n-1)^2}{(n-2)(n-3)} \qquad 5$$

where, Σ = summation of variate, s is the standard deviation.

$\bar{x}$ is the long term mean of x_i samples and n is the total number of samples

These statistics were used to test the direction of sampled population with a normal distribution. If Z_1 or Z_2 is greater than 1.96, a significant deviation from the normal curve is indicated at 95% confidence level. In order to identify decadal variability, the computed potential evapotranspiration time series was divided into three periods (1991 – 2000, 2001 – 2010 and 2011 - 2020). The means of each 10-year interval were then statistically compared with the long-term mean of the study period (1991 - 2020).

Trend analysis of the estimated potential evapotranspiration was computed using the Mann Kendall test [16-17] based on the following equations:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sig}(X_j - X_i) \qquad 6$$

$$\text{sgn}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases} \qquad 7$$

$$Z = \begin{cases} V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right], \\ \frac{S-1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S > 0 \\ \frac{S+1}{\sqrt{\mathrm{VAR}(S)}} & \text{if } S = 0 \\ \text{if } S < 0 \end{cases} \quad 8$$

In these equations, X_j and X_i are the time series observations in chronological order, n is the length of time series, t_p is the number of ties for Pth value, and q is the number of tied values. Positive Z values indicate an upward trend in the potential evapotranspiration time series; negative Z values indicate a negative trend. The null hypothesis is rejected and a statistically significant trend exists in the time series when $|Z| > Z_{1-\frac{\alpha}{2}}$,. The critical value of $Z_{1-\frac{\alpha}{2}}$ for a P-value of 0.05 from the standard normal table is 1.96. This was used to test for significance of trends in the study.

The analysis of data was aided using inferential statistics such as one sample t-test and Analysis of Variance (ANOVA) that were further used to test the significance of decadal variability of PET.

RESULTS AND DISCUSSION

Description of Average Monthly Potential Evapotranspiration (1991 – 2020)

The statistical summary of the monthly mean potential evapotranspiration distribution in Oluyole LGA is presented in Table 1. The table shows that a mean potential evapotranspiration of 116. 47±14.24 mm was observed in January with a maximum of 143.08 mm and a minimum of 88.65 mm. In February, the mean potential evapotranspiration observed was 140.23±10.72 mm, while the maximum was 159.78 mm and the minimum was 114.42 mm. A mean potential evapotranspiration of 147.37 mm with standard deviation of 8.09 mm was observed respectively however the maximum and minimum potential evapotranspiration observed in March were 159.78 mm and 134.02 mm. In April, mean potential evapotranspiration of 142.95 ± 6.99 mm with maximum potential evapotranspiration of 125.98 mm, and minimum potential evapotranspiration of 161.51 mm was observed.

The table also shows that a mean potential evapotranspiration of 134.42±5.56 mm, was observed in May with a maximum of 149.66 mm and a minimum of 125.37 mm. The mean potential evapotranspiration of 120.81±3.35 mm was observed in June while the maximum was 127.64 mm with a minimum of 113.75 mm. In July, the mean potential evapotranspiration observed was 109.69±4.75 mm with a maximum of 118.91 mm and a minimum of 102.55 mm. The mean potential evapotranspiration of 106.73±4.59 mm was observed in August while the maximum and minimum were 117.65 mm and 97.57 mm respectively. Furthermore, a mean potential evapotranspiration of 114.32±6.9 mm was observed in September while the maximum was 122.23 mm and the minimum was 105.38 mm. In October, the mean potential evapotranspiration was 121.32±5.64 mm. However, a maximum of 130.65 mm and a minimum of 106.88 mm were observed. The mean potential evapotranspiration observed in November was 127.38±7.56 mm, with a maximum and minimum of 139.75 mm and 111.5 mm respectively. In December the last month of the year, the mean potential evapotranspiration was 116.97±11.42 mm while the maximum and minimum were 137.07 mm and 85.32 mm respectively.

From the distribution, it was observed that March recorded the highest mean evapotranspiration, while the lowest mean evapotranspiration was observed in August. This may be as a result of low cloudiness in March and high cloudiness in August. This result is in agreement with [18], who stated that evapotranspiration in Ibadan is strongly negatively correlated with humidity and cloudiness. In addition, [19] reported that evapotranspiration in Nigeria is low in August. It was also observed that the highest maximum and minimum evapotranspiration was observed in March. The high values of evapotranspiration in the month of March could be correlated to the high temperature observed during the month, as reported by [20], who investigated temperature variabilities in Nigeria using observations of air temperature. Their findings showed that temperature was observed to increase southward during January to March, with temperature ranging from 21.1^{o} C to 30^{o} C and decreasing in August and October in Southwest Nigeria.

Table 1: Statistical Summary of Monthly Mean Potential Evapotranspiration in Oluyole between 1991 and 2020

Month	Mean	Min	Max	Standard Deviation
JAN	116.47	88.65	143.08	14.24
FEB	140.23	114.42	159.78	10.72
MAR	147.37	134.02	165.79	8.09
APR	142.95	125.98	161.51	6.99
MAY	134.42	125.37	149.66	5.56
JUNE	120.81	113.57	127.64	3.35
JULY	109.69	102.55	118.91	4.75
AUG	106.73	97.57	117.65	4.59
SEPT	114.32	105.38	122.23	3.89
OCT	121.32	106.88	130.65	5.64
NOV	127.38	111.5	139.75	7.56
DEC	116.97	85.32	137.07	11.42

Description of Average Annual Potential Evapotranspiration (1991 – 2020)

The summary of descriptive statistics of the average annual evapotranspiration in the study area between 1991 and 2020 (Table 2), shows that for the period of study, the minimum potential evapotranspiration of the study area was 1426.71 mm, the maximum potential evapotranspiration was 1596.93 mm and mean annual evapotranspiration was 1498.64 mm. Furthermore, since the statistics of Skewness and Kurtosis, as could be observed in Table 2 were less than 1.96, the annual series of evapotranspiration was accepted as indicative of normality at 95% confidence level. This implies that the annual evapotranspiration and consequently the resultant long term mean and standard deviation are representative values of potential evapotranspiration for the study period.

Trend Analysis of Annual Potential Evapotranspiration

The trend of the annual mean potential evapotranspiration for the study period is depicted in Figure 2. The figure shows that the lowest annual potential evapotranspiration was observed in the year 2012, while the highest annual mean potential evapotranspiration was observed in the year 2016. The 3-years moving average observed in Figure 2 shows the general increase in the trend of evapotranspiration. An increase in the trend could have been a result of the general increase in temperature. The Mann Kendall tau values of potential evapotranspiration of the study area for the study period (Table 3) are 0.18 and 0.05 for annual and monthly series, respectively. Since their p-values are greater than 0.05, the null hypothesis which states that there is no significant trend in potential evapotranspiration in Oluyole Local Government Area, is accepted. Therefore, it can be inferred that both annual and monthly potential evapotranspiration had a low positive, none significant trend for the thirty years.

Table 2: Descriptive Statistics of Annual Potential Evapotranspiration in Oluyole LGA

Minimum	Maximum	Mean	Std. Deviation	Skewness			Kurtosis		
				Value	Std. Error	Z-value	Value	Std. Error	Z-value
1426.71	1596.93	1498.64	43.41	0.261	0.427	0.611	-0.538	0.833	-0.646

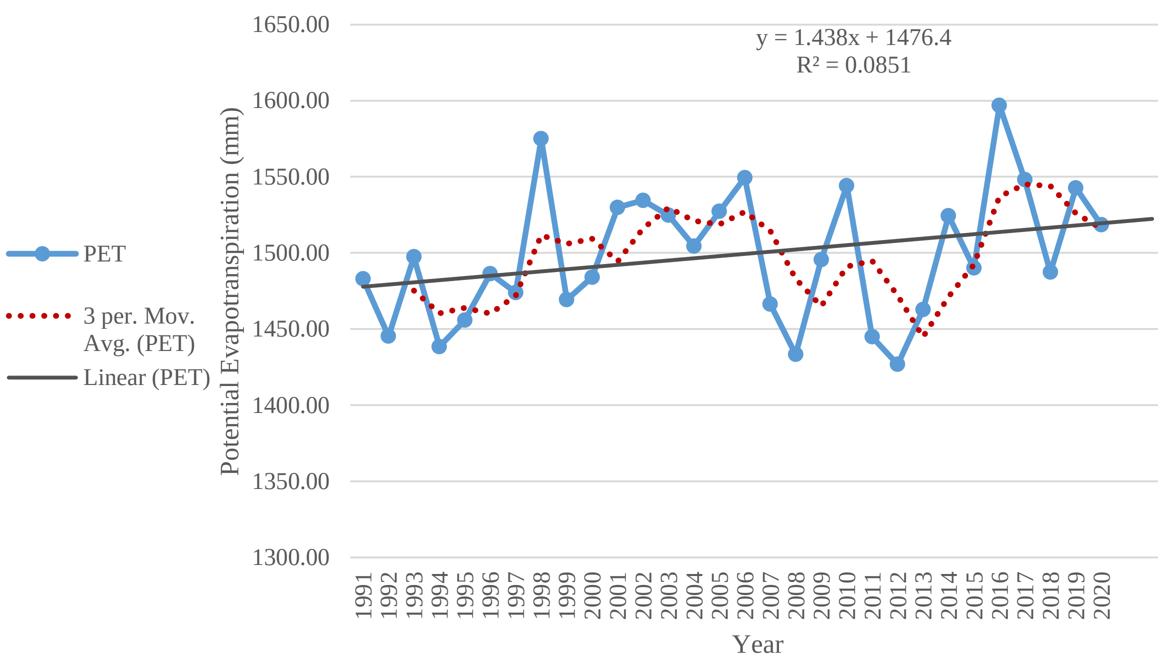

Figure 2: shows a positive trend for the annual Series (linear trend and 3-month moving average)

Table 3: Result of Mann Kendall Trend Test on Annual and Monthly Series

	Annual	Monthly
tau	0.18	0.05
2-sided pvalue	0.18	0.15

Decadal Variability of Potential Evapotranspiration

The decadal monthly mean of evapotranspiration in the study area (Figure 3). The figure shows that the monthly mean evapotranspiration varied in the three decades. Table 4 shows that monthly evapotranspiration generally increases from the first decade to the third. While the standard deviation confirms climate variability within the period of study.

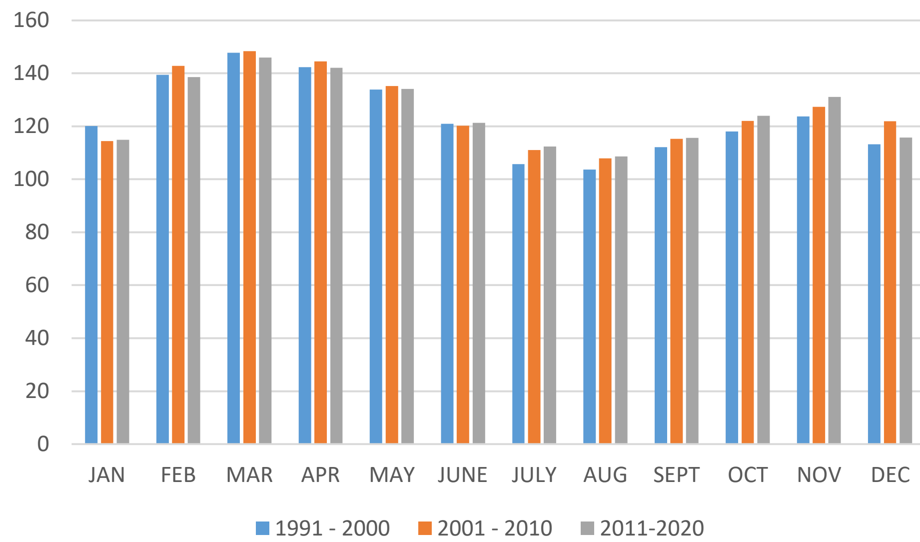

Figure 3: Decadal Variability of monthly Potential Evapotranspiration

Table 4: Variations of Decadal Annual and Monthly Potential Evapotranspiration

Decade	Annual Average PET (mm)	Standard Deviation (mm)	Monthly Average PET (mm)	Standard Deviation (mm)
1991 - 2000	1480.80	38.08	123.40	15.81
2001 - 2010	1510.93	36.90	125.91	15.33
2011-2020	1504.19	52.00	125.35	14.10

Table 5 tests whether the mean difference between average potential evapotranspiration of each decade and the long term mean for the study period (1991-2020) is significant at 0.05. The table shows that the average potential evapotranspiration in the first decade was 17.84 mm (Sig. > 0.05) lesser than the long-term mean of 1498.64 mm, the average potential evapotranspiration in the second decade was 12.29 mm (Sig. > 0.05) greater than the long-term mean of 1498.64 mm, while the average potential evapotranspiration in the third decade was 5.55 mm (Sig. > 0.05) greater than the long-term mean of 1498.64 mm. These deviations from the long term average were not significant at 0.05 significant level, since the significant p-value of each decade were greater than 0.05. Furthermore, the mean difference of each decade were within the 95% confidence intervals, as shown in table 5, which implies that the deviations from the long term average of potential evapotranspiration of the study area for the study period (1991 – 2020) has a 95% chance of occurring.

Table 5: Summary of Results of one sample t-test

Decades	Test Value / Climatic Mean = 1498.64 (mm)					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
1991 - 2000	-1.481	9	0.173	-17.83600	-45.0764	9.4044
2001 - 2010	1.053	9	0.320	12.28600	-14.1086	38.6806
2011 - 2020	.338	9	0.743	5.55300	-31.6472	42.7532

Since the sig. p-value in the ANOVA statistic presented in Table 6 is greater than 0.274, then second hypothesis which states that there is no significant difference between the decadal and the longer-term potential evapotranspiration in Oluyole Local Government Area was accepted. Consequently, it could be concluded that although there was an increase in the decadal evapotranspiration of the study area within the three periods, these disparities in the three decades were not significantly different from each other. This shows that mean annual evapotranspiration was changing in the study area, which is also in agreement with [18], who concluded that PET was constantly changing due to the dynamics of the tropical continental air mass.

Table 6: Analysis of Variance (ANOVA) Statistics

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4999.045	2	2499.522	1.360	0.274
Within Groups	49641.065	27	1838.558		
Total	54640.110	29			

CONCLUSION

Variability of potential evapotranspiration due to climate change is presently causing alterations in the global hydrological cycle with devastating effect on the water requirements of crops. This study has shown that the annual series of the potential evapotranspiration for the climate period follows a normal distribution at 95% confidence level. Non-significant ($p > 0.05$) positive trends for annual and monthly series have been established for the climatic period. The study has also revealed clear evidences of climate variability in the study area due to fluctuations in decadal means of potential evapotranspiration with respect to its long-term mean value. The findings of this study will be useful for agricultural planning. The efficient use of water resources is now a global concern due to anthropogenic and climate induced stress on fresh water. It is thus imperative to adequately understand the dynamics of evapotranspiration, which is a major component of the global water budget because information on trend and variability of potential evapotranspiration are applied in the optimization of irrigation schemes, water conservation planning and drought mitigations. The present study is limited to the use of satellite-based climate data due to the absence of conventional weather stations in the study area. The study therefore recommends that adequate synoptic weather stations should be installed in the study area to encourage spatial and temporal evaluation of the trend and variability of PET. There is also the need to carry out more studies to ascertain the impacts of climate change and variability on water resources components. There is therefore the need to pay critical attention to these alterations in order to satisfy crop water requirements and maximize agricultural output.

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