

# **Evaluation of Seasonal and Annual Variations of Evapotranspiration with Climatic Parameters in Ibadan, Nigeria**

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## **Abstract**

Evapotranspiration (ET) is a major component of hydrological cycle and the rate of ETo is mostly affected by climatic parameters. This research work evaluates the seasonal and annual variations of ETo with climatic parameters in Ibadan from 1977 - 2010. The climatic data used were obtained from International Institute of Tropical Agriculture, Ibadan. FAO-56 Penman-Monteith method was used in estimating ETo. The results show that the monthly mean ETo varies in the same pattern with solar radiation, air temperature, sunshine hour, evaporation and slightly with wind speed, but varies in opposite direction with relative humidity. Hence, low ETo were obtained in rainy season when it was cool, cloudy and humid while high ETo were obtained when it was hot, sunny and dry. Annually, the gradient of variation of ETo with evaporation, solar radiation, wind speed, and relative humidity in the area within the period under study is positive, implying an increase in these parameters, while ETo have negative gradient with sunshine hour and temperature. This variation may be due to the location of Ibadan in the tropical rain forest. The results obtained can help agriculturists and engineers for effective irrigation planning and management.

**Keywords:** Climatic parameters, evaporation, climatic condition, Ibadan, Nigeria.

## **1 Introduction**

Evapotranspiration (ET) is one of the most important components of hydrological cycle because it represents a loss of usable water from the hydrological supply for agriculture, natural resources and municipalities. Evaporation is the primary process of water transfer in the hydrological cycle [1]. ET is a complex phenomenon because it depends on several climatological factors, such as temperature, humidity, wind speed, solar radiation, and type and growth stage of the crop. ET can be either directly measured using lysimeter or water

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balance approaches, or estimated indirectly using climatological data. However, it is not always possible to measure ET using a lysimeter because it is a time-consuming method and needs precise and carefully planned experiments [2], [3].

Reference crop evapotranspiration, denoted as  $ETo$ , is the evaporative power of the atmosphere and represents the evapotranspiration from a standardized vegetated surface. Being an important component of the hydrologic cycle, the estimation of evapotranspiration is important for irrigation engineering applications and for studies relating to hydrologic water balance, water resource planning and management and land use planning [4].  $ETo$  is known to be dependent upon climatic factors and hence, climatic change is having an effect on evapotranspiration. Hence, this research work hopes to investigate the seasonal and annual variations of  $ETo$  with climatic parameters in Ibadan from 1977-2010 due to the recent report on climate change.

Ibadan, having a total area of about 1,190 sq mi (3,080 km<sup>2</sup>) is located at latitude 3°55' E and longitude 7°23' N. It is the capital city of Oyo State and the third largest metropolitan area, by population, in Nigeria, after Lagos and Kano, with a population of over 3 million. Ibadan is located in south-western Nigeria, 128 km inland northeast of Lagos and 530 km southwest of Abuja, the federal capital, and is a prominent transit point between the coastal region and the areas to the north [5].

Ibadan has a tropical wet and dry climate, with a lengthy wet season and relatively constant temperatures throughout the course of the year. Ibadan's wet season runs from March through October, though August sees somewhat of a lull in precipitation. This lull nearly divides the wet season into two different wet seasons. November to February forms the city's dry season, during which Ibadan experiences the typical West African harmattan. The mean total rainfall for Ibadan is 1420.06 mm, falling in approximately 109 days. There are two peaks for rainfall, June and September. The mean maximum temperature is 26.46 °C, minimum 21.42 °C and the relative humidity is 74.55% [5].

A lot of researches have been carried out on evapotranspiration using empirical models such as FAO-24 Penman, FAO-24 Radiation, FAO-24 Blaney-Criddle, Priestley-Taylor, Turc, and FAO-56 Hargreaves and FAO-56 Penman-Monteith [6]. The FAO-56 Penman-Monteith method is considered as a worldwide standard method for estimating ET and it has been used by many researchers [7], [8], [9], [4], [10]. The effect of temperature and solar radiation on evapotranspiration has also been studied [4], [1], [7]. However, no research works have been found carried out on the seasonal and annual variations of  $ETo$  with climatic parameters in Ibadan.

## 2 Sources of Data and Method of Analyses

Secondary data were used for this research work. The data was collected from the International Institute of Tropical Agriculture, Ibadan (1977-2010). In this study, the FAO-56 Penman-Monteith method was used in estimating  $ETo$ . The  $ETo$  was calculated by strictly following the procedures and equations recommended by the FAO, irrigation and drainage paper 56 [11]. The daily average reference evapotranspiration ( $ETo$ ) is given in (mm/day) according to this equation as,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

$ET_0$  - reference evapotranspiration ( $\text{mm day}^{-1}$ ),  $R_n$  - net radiation at the crop surface ( $\text{MJm}^{-2}\text{day}^{-1}$ ),  $G$  - soil heat flux ( $\text{MJm}^{-2}\text{day}^{-1}$ ),  $T$  - mean daily air temperature at 2 m height ( $^{\circ}\text{C}$ ),  $U_2$  - wind speed at 2 m height ( $\text{ms}^{-1}$ ),  $e_s$  - saturated vapour pressure (kPa),  $e_a$  - actual vapour pressure (kPa),

$e_s - e_a$  - saturated vapour pressure deficit (kPa),  $\Delta$  - slope of vapour pressure curve (kPa) and

$\gamma$  - psychrometric constant ( $\text{kPa } ^{\circ}\text{C}^{-1}$ ).

The mean saturated vapour pressure derived from air temperature is given by [11] as:

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2} \quad (2)$$

where

$$e(T_{min}) = 0.610 \exp\left(\frac{17.27T_{min}}{T_{min} + 237.3}\right) \quad (3a)$$

$$e(T_{max}) = 0.610 \exp\left(\frac{17.27T_{max}}{T_{max} + 237.3}\right) \quad (3b)$$

The actual vapour pressure derived from relative humidity was computed using the expression:

$$e_a = \frac{RH_{mean}}{100} \left[ \frac{e(T_{max}) + e(T_{min})}{2} \right] \quad (4)$$

The slope of saturated vapour pressure curve was calculated using the relation:

$$\Delta = 4098 \left[ \frac{0.6108 \exp\left(\frac{17.27T}{T+273.3}\right)}{(T+273.3)^2} \right] \quad (5)$$

The psychrometric constant is related to the atmospheric pressure  $P$  as:

$$\gamma = 0.665 * 10^{-3} P \quad (6)$$

Where

$$p = 101.3 \left( \frac{293 - 0.0056 Z}{293} \right)^{5.26} \quad (7)$$

$Z$  is the station elevation above sea level. For Kano,  $Z = 287$  m.

The net radiation,  $R_n$  was computed using the equation (8):

$$R_n = R_{ns} - R_{nl} \quad (8)$$

$R_{ns}$  and  $R_{nl}$  are the net shortwave and net longwave radiation calculated according to the FAO Irrigation and Drainage paper No 56 (Allen *et al.*, 1998). The wind speed data obtained from meteorological state measured at 10 m was converted to the 2 m required for agrometeorology according to [11].

Finally, ETo was computed by substituting the values of  $e_s$ ,  $e_a$ ,  $\Delta$ ,  $\gamma$ , and  $R_n$  calculated from equations (2), (4), (5), (6) and (8) respectively and the values of the mean temperature,  $T$  and the converted values of wind speed,  $U_2$  into equation (1).

### 3 Results

The variation of daily mean monthly ETo in Ibadan from 1977-2010 is presented in Figure 1 while Figures. 2 – 7 show the variation of daily mean monthly ETo with evaporation, sunshine hour, air temperature, solar radiation, wind speed and relative humidity respectively. The trend in variation of monthly mean annual ETo, evaporation, sunshine hour, air temperature, solar radiation, wind speed and relative humidity from 1977 – 2010 is presented in Figures. 8 - 14 respectively.

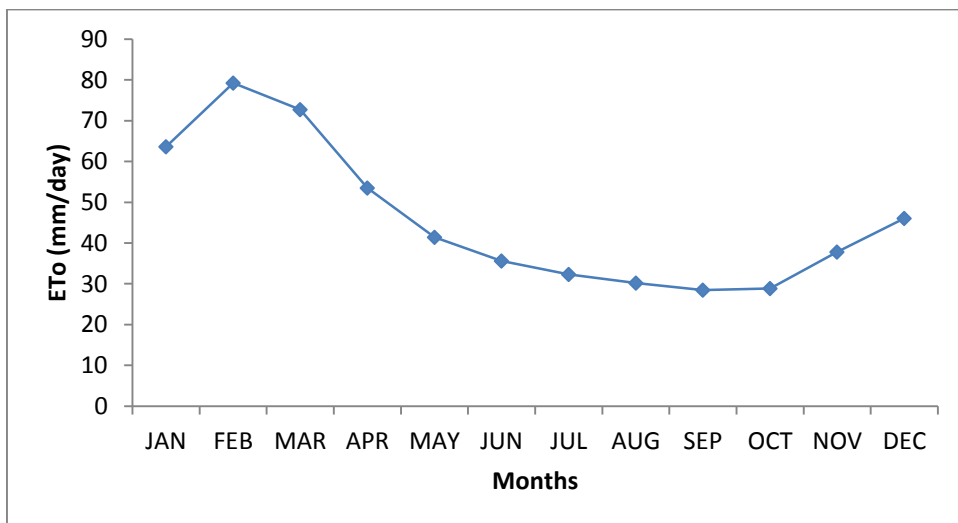


Figure 1: Variation of monthly mean ETo in Ibadan from 1977-2010

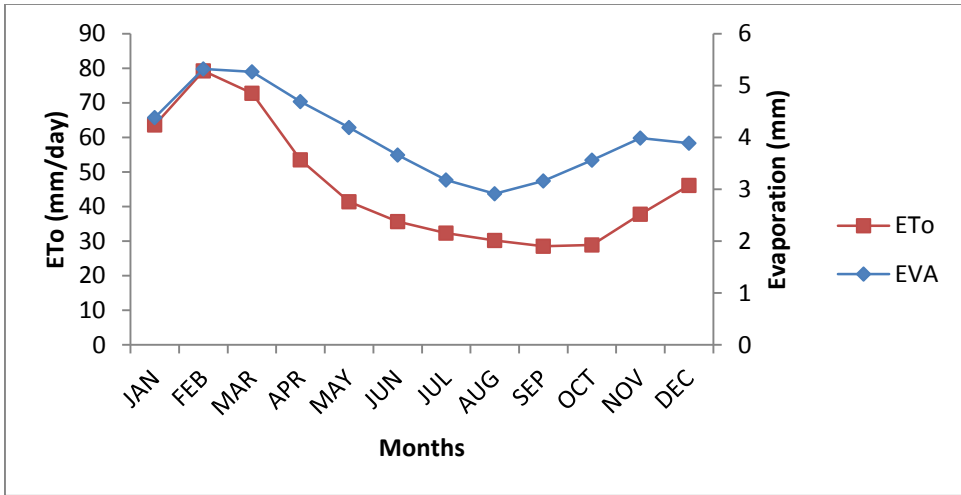


Figure 2: Variation of monthly mean ETo with evaporation

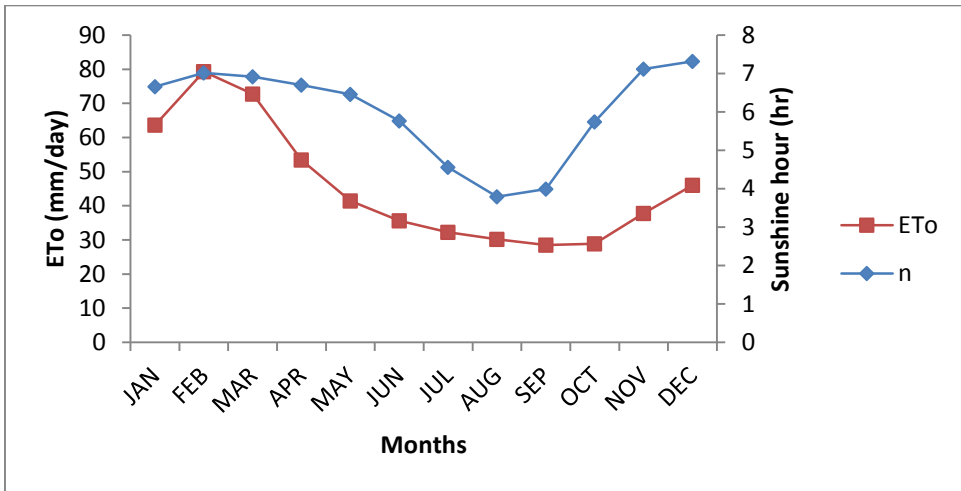


Figure 3: Variation of monthly mean ETo with sunshine hour

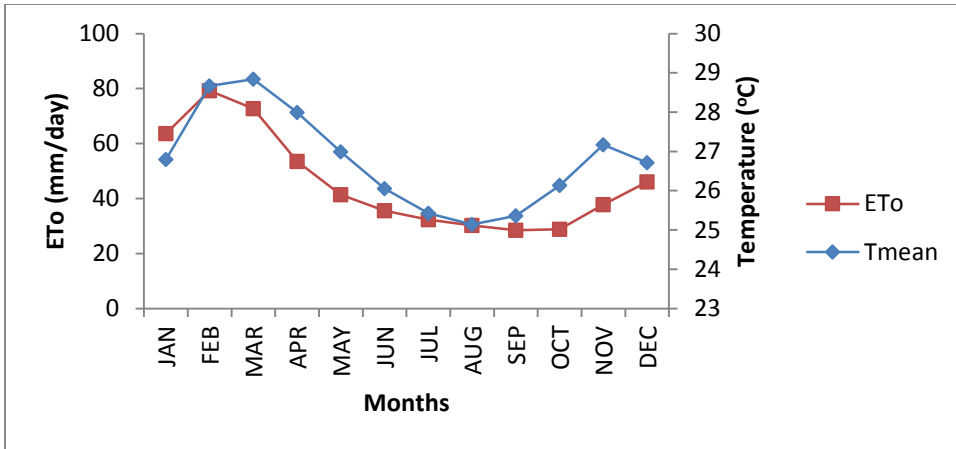


Figure 4: Variation of monthly mean ETo with air temperature

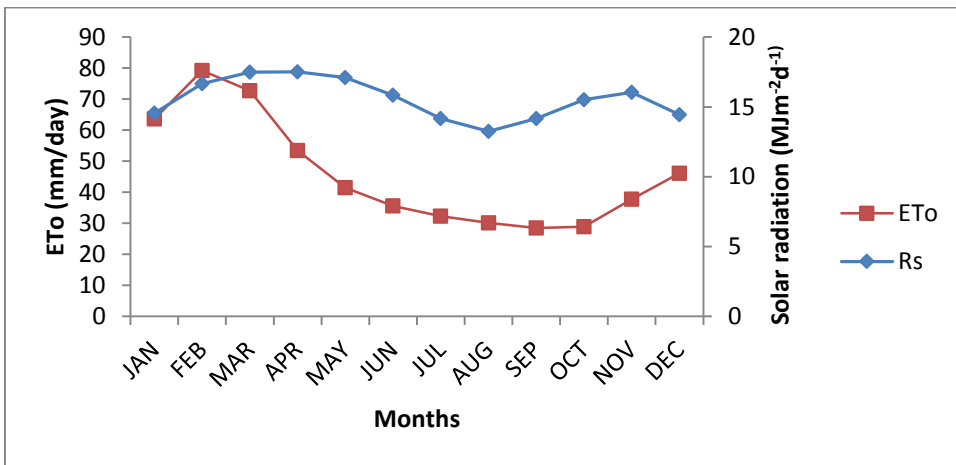


Figure 5: Variation of monthly mean ETo with solar radiation

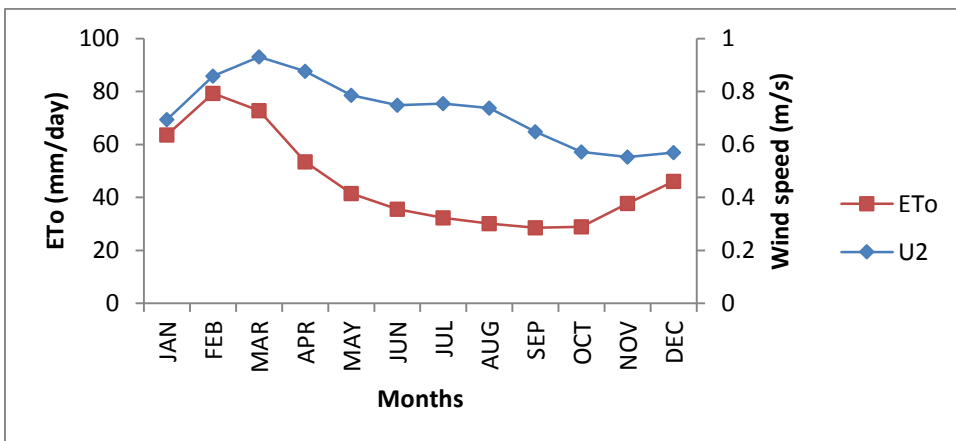


Figure 6: Variation of monthly mean ETo with wind speed

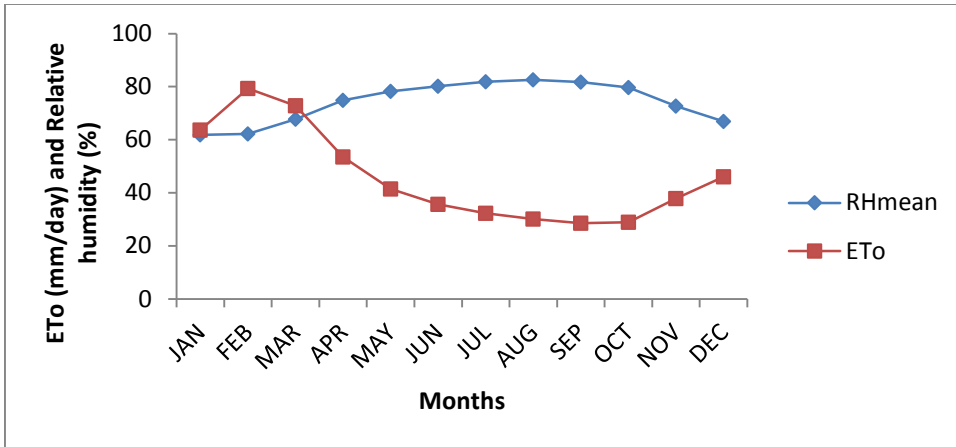


Figure 7: Variation of monthly mean ET<sub>0</sub> with relative humidity

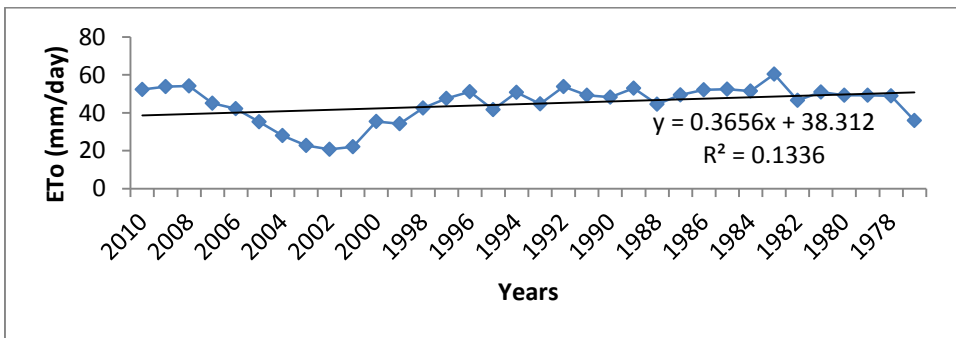


Figure 8: Variational trend of annual mean evapotranspiration in Ibadan (1977-2010)

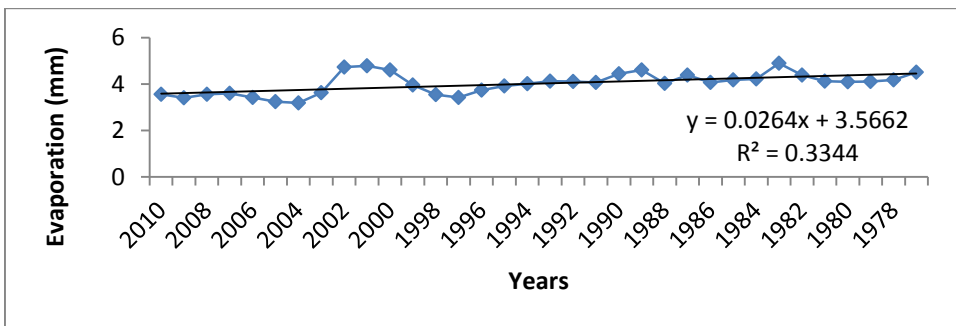


Figure 9: Variational trend of annual mean evaporation

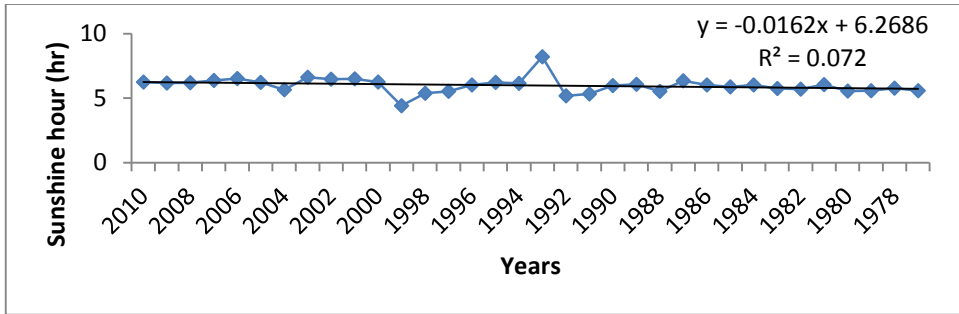


Figure 10: Variational trend of annual mean sunshine hour

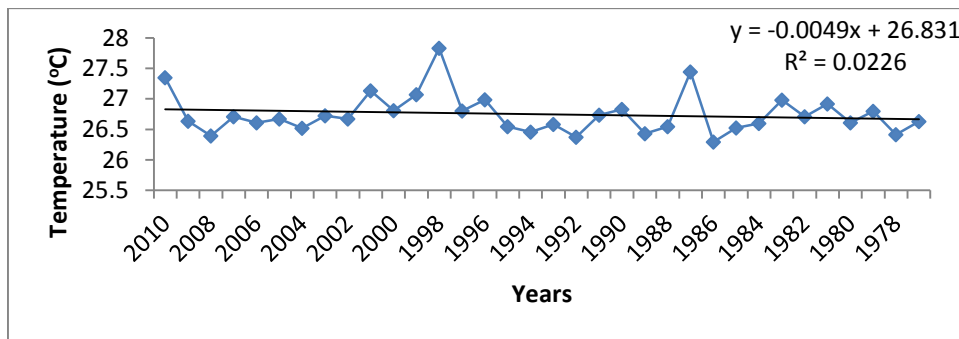


Figure 11: Variational trend of annual mean temperature

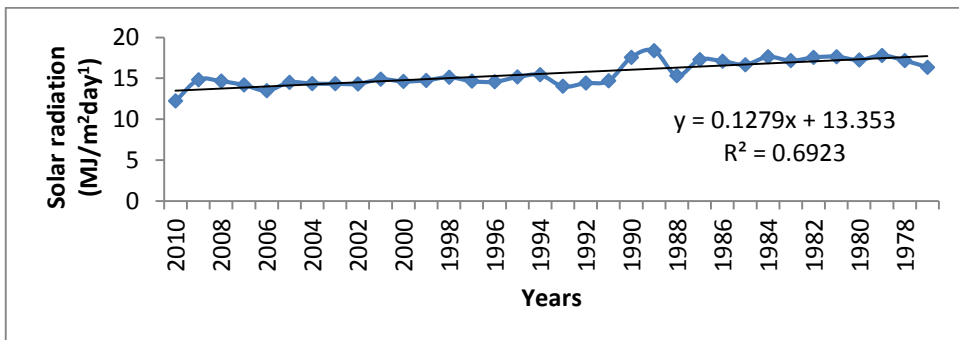


Figure 12: Variational trend of annual mean solar radiation

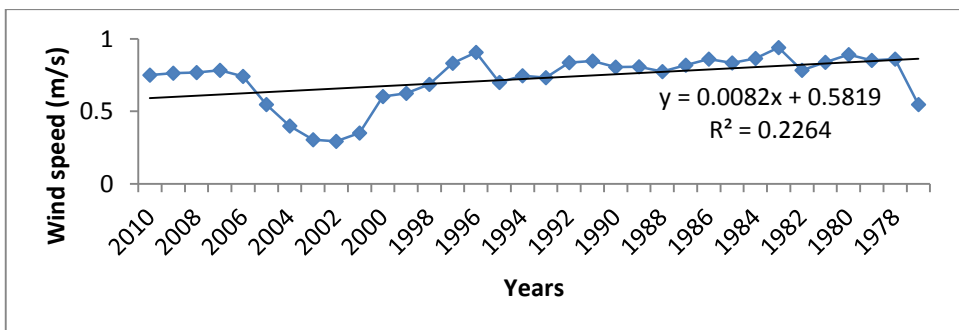


Figure 13: Variational trend of annual mean wind speed



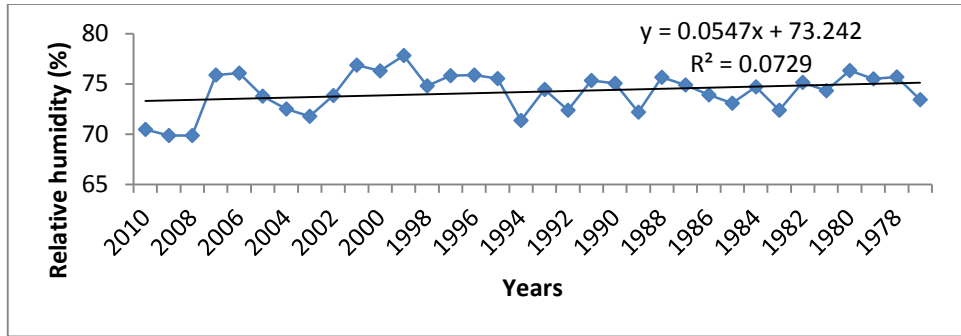


Figure 14: Variational trend of annual mean relative humidity

## 4 Discussion

From Figure 1, it could be observed that  $ET_o$  increases from January to its peak (79.26mm/day) in February. It then decreases steadily to its minimum (28.50mm/day) in September and increases again from October to December. The maximum  $ET_o$  occurred in dry season in February; the peak of dry season while the lowest  $ET_o$  was obtained in rainy season in September; the peak of cloud activity.

It could be observed from Figure 2 that the variation of monthly mean  $ET_o$  with evaporation follows the same trend; having their maximum in the dry season (November to February) and their minimum in the rainy season (March to October). This could be because both are affected by the same climatic parameters such as sunshine hour, air temperature, solar radiation, wind speed and relative humidity.

The variation of monthly mean  $ET_o$  with solar radiation, sunshine hour and air temperature are shown in Figures. 3 - 5 respectively. It could be observed that both  $ET_o$  and these parameters were very low in the rainy season while they were high in the dry season. This trend was due to the fact that the rate of  $ET_o$  depends mostly on the availability of solar radiation, sunshine hour and air temperature based on the observations made by [7], [12]. Gad and El-Gayar, (2010a); and Chegaar and Guachi (2009).

It could be observed from the variation of monthly mean  $ET_o$  with wind speed (Figure 6), that the variation of monthly mean wind speed is relatively small, having it maximum of 0.93 m/s in March. This variation may be due to the fact that the effect of wind speed on  $ET_o$  is less compared to the other climatic factors. This is in line with [10] and [4] who noted that wind speed was the least sensitive meteorological factor affecting  $ET_o$ .

The variation of monthly means  $ET_o$  with relative humidity (Figure 7) depicts opposite relationship between the two parameters. The highest relative humidity of 81.73% was obtained in September with the corresponding lowest  $ET_o$  of 28.50 mm/day. On the other hand, the lowest relative humidity of 61.82% was obtained in January with the corresponding highest  $ET_o$  of 79.25 mm/day in February. This implies that low  $ET_o$  was observed in the rainy season when the air was cold and humid while high  $ET_o$  was observed in dry season when the air was hot and dry.

From Figure 8, the general mean of  $ET_o$  within the period under investigation is 44.71 mm/day. The values of  $ET_o$  in some years were closer to this mean value, while there were anomalous values of  $ET_o$  in other years which were either higher or lower than the mean.

The highest (60.47mm/day) and lowest (20.75mm/day) ETo in the period under study were obtained in 1983 and 2002 respectively.

Also, from the variational trend of annual mean evaporation (Fig. 9), the general mean obtained is 4.03 mm, with the maximum and minimum values of 4.91 mm and 3.19 mm in 1983 and 2004 respectively. The gradient of the variation observed in both Figs. 8 and 9 are positive, implying an increase in the variation of ETo and evaporation in the area within the period under study. This variation may be due to the change in the climatic factors affecting them as a result of climate change.

It could be observed from the variational trend of annual mean sunshine hour (Figure 10) and variational trend of annual mean temperature (Figure 11) that the gradients of this variations are negative, implying a decrease in the variation of sunshine hour and air temperature in the area within the period under study. However, the percentage of this variation are very small ( $R^2=7.2\%$  and  $2.2\%$  respectively). These variations may be due to the location of Ibadan in the Tropical rain forest. The general mean obtained for sunshine hour is 5.98 hrs, with the maximum and minimum values of 8.20 hrs and 4.40 hrs in 1993 and 1999 respectively. The general mean obtained for temperature is  $26.74\text{ }^\circ\text{C}$ , with the highest and lowest values of  $27.83\text{ }^\circ\text{C}$  and  $26.29\text{ }^\circ\text{C}$  in 1998 and 1986 respectively.

From the variational trend of annual mean solar radiation, it could be observed that the gradient of this variation is positive, implying an increase in the variation of solar radiation in the area within the period under study. The maximum and minimum values of  $18.37\text{ MJm}^{-2}\text{day}^{-1}$  and  $12.23\text{ MJm}^{-2}\text{day}^{-1}$  of solar radiation were obtained in 1989 and 2010 respectively while the general mean obtained was  $15.59\text{ MJm}^{-2}\text{day}^{-1}$ .

From the variational trend of annual mean wind speed (Figure 13) and variational trend of annual mean relative humidity (Figure 14). It could be observed that the gradients of these variations are positive, implying an increase in the variation of wind speed and relative humidity in the area within the period under study. The percentage of this variation are small ( $R^2 = 7.2\%$  and  $2.2\%$  respectively). These variations may be due to the location of Ibadan in the Tropical rain forest. The general mean obtained is  $74.19\%$ , with the maximum and minimum values of  $77.81\%$  and  $69.84\%$  in 1999 and 2008 respectively. The general mean obtained for temperature is  $0.73\text{ m/s}$ , with the maximum and minimum values of  $0.93\text{ m/s}$  and  $0.29\text{ m/s}$  in 1983 and 2002 respectively.

## 5 Conclusion

- Seasonally, the influence of solar radiation, air temperature wind speed and sunshine duration on ETo are greater during the dry season than that in rainy season, while the reverse occurs with the influence of relative humidity. Hence, ETo was greatest on hot, sunny and dry days and lowest on cool, cloudy and humid days.
- Annually, the gradient of variation of ETo with most of the climatic parameters in the area within the period under study is positive, implying an increase in these parameters, while ETo have negative gradient with sunshine hour and temperature. It implies that the climate of Ibadan and its environs have being cool and humid.
- The results obtained can help agriculturists and engineers for effective irrigation planning and management.

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