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Comparative Study of Evapotranspiration Variation and its Relationship with Other Climatic Parameters in Asaba and Uyo

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Abstract— This study was carried out to assess the variations of Reference Evapotranspiration (ET_0 also denoted with RET) calculated using FAO-56 Penman Monteith model of two locations Asaba and Uyo and evaluate its relationships with the variations of other climatic parameters. Meteorological data of forty one years (1975-2015) and thirty five years (1981-2015) period for Asaba and Uyo, respectively gotten from Nigeria Meteorological Agency, Abuja were used. It was observed that the variations of Evapotranspiration (ET) in both locations were in line with two seasons (rainy and dry) normally experienced in Nigeria having its highest value in March (4.8 mm/day) for Asaba and for Uyo in February (4.5 mm/day); and its lowest value in August (3.1 mm/day) for Asaba and in July (2.9 mm/day) for Uyo. ET variation when compared with other climatic variables in both locations was observed to have the same trend with maximum temperature, solar radiation and sunshine hours. It also has the same variation with minimum temperature though with slight deviation. It was observed that ET variation is inversely proportional to the variation relative humidity. Wind speed displayed relatively small variation in its trend over the study period and is not in line with the variations of ET.

Keywords— Evapotranspiration, Climatic Variables, FAO Penman-Monteith Model, Variations

1 INTRODUCTION

Evapotranspiration (ET) is the combination of two separate processes evaporation and transpiration. These two processes in practice occur simultaneously, in regards, there is no easy way of distinguishing between them. Evaporation is the process in which liquid water is converted to water vapour from an evaporating surface such as wet soils, oceans, rivers or lakes; while transpiration is the process in which water is respired to the atmosphere predominantly from small openings on leaf surface called stomata which are connected to vascular plant tissues. According to Linsley et al. (1975), three-fourth of total precipitation on the land areas of the world is lost to the atmosphere through evapotranspiration. In Agriculture, water is naturally supplied to crops through precipitation and subsurface moisture, but when these supplies are inadequate for crop use, most farmers resort to irrigation.

Most water losses during irrigation occur primarily due to evapotranspiration. Thus, total crop water requirement is directly proportional to evapotranspiration (Jayasinghe, 2012; Anyanwu et al., 2016). It is one of the most important components of the hydrological cycle and changes in it affect all other components of the cycle significantly. This is so because of its dependence on different climatic parameters which include temperature, solar radiation, relative humidity, sunshine hour, wind speed etc., which is one of the reasons why evapotranspiration can be computed from climatic or weather data. For these reasons, it is paramount to have in-debt knowledge on the rate at which evapotranspiration occurs in a given region for proper study of water resources. The knowledge is needed for proper irrigation scheduling, for planning, designing, operating and maintaining of irrigation and soil and water conservation structures. It is needed in estimation of moisture loss from reservoirs and river basins and for accurate estimation of daily water use.

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Reliable and accurate estimate of evapotranspiration rates can be done using direct or indirect methods of measurement. The direct method of measurements which include the use of lysimeters (Obioma et al., 2015), pan evaporimeters (Bloemen, 1978), atmometers (Diop et al., 2015) etc. are not usually feasible because they are time consuming, expensive and complex which is brought about by their dependence on soil condition and plant physiology, (Ejieji, 2011). Thus, evapotranspiration estimation is normally done using the indirect method of measurement which is basically the use of empirical models that depend primarily on climatic factors. These models range from simple expressions which relate evapotranspiration to temperature or radiation to models having extensive data requirement.

The model universally acceptable which has been standardized by the Food and Agriculture Organisation is the FAO – 56 Penman – Monteith model. It is considered the best because it compasses the physical parameters that govern the exchange of aerodynamic, energy and physiological aspects of culture affecting ET (Obioma et al., 2015) and when compared with other models, it has a better performance in many regions of the world (Ilesanmi et al., 2014). Although being the best model for ET estimation, it can only be applied when all the required data are available and reliable.

In Nigeria and other developing countries, the meteorological data required for calculation of ET using FAO 56 Penman-Monteith are typically not readily available. This could be as result of failure of instrumentations required for measurement of essential data input or absence of the personnel involved from duty (Ejieji, 2011; Echiegu et al., 2016). In situations like this, the use of simpler ET models such as temperature-based models whose data requirements are less vigorous to generate than that of FAO 56 PM becomes important (Ahaneku, 2011; Ewemoje and Okanlawon, 2015). This research therefore aims to study the variations of evapotranspiration over the study period and evaluate its relationships with the variations of other climatic parameters in Asaba and Uyo.

2 Materials and Method

2.1 Location and Description of the Study Area

Two locations Asaba and Uyo (Fig. 1) were considered in this study. Asaba, capital of Nigeria's Delta State with coordinates 6°11′52.23″N and 6°43′42.48″E lies approximately 60 degrees north of the equator and about the same distance east of the meridian; about 160 kilometers north of where the River Niger flows into the Atlantic Ocean and 55 m above sea level. The greater Asaba occupies an area of about 300 square kilometers. It maintains an average tropical temperature of 32 °C during the dry season and an average fertile rainfall of 2,700 millimeters during the rainy season.

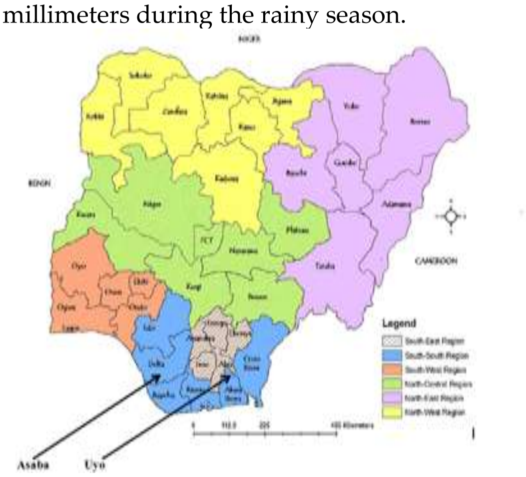

Fig. 1: Map of Nigeria showing location of Asaba and Uyo

Uyo, the capital of Akwa-Ibom State of Nigeria with coordinates 5°2′N and 7°55′E is located within the equatorial region. It is located about 60 kilometers from the coast of Atlantic Ocean. The rainfall is of the double maxima regime with a break occurring in August. Mean annual rainfall stands at about 2400 mm. Uyo is characterized by a uniform temperature all through the year with a mean high of about 28°C recorded between March/April and a mean low of about 25°C is recorded around August. Relative humidity is equally high with a seasonal variation component, the lowest relative humidity of about 54% is recorded in January and it keeps increasing to about 84% in July.

2.2 Data Source

Records of climatic variables solar radiation, maximum and minimum temperature, relative humidity, sunshine hours and wind speed; all in monthly average were collected from Nigeria Meteorological Agency (NIMET), Abuja. For Asaba station with elevation of about 97.6 m, 41-years (1975 – 2015) record was obtained and for Uyo with elevation 38.0 m, 35-years (1981 - 2015) record was obtained.

2.3 Evapotranspiration calculation

ETo for this study was computed using the FAO-56 Penman-Monteith model which was adjudged by the Food and Agricultural Organisation to be the best estimator of reference evapotranspiration.

Step by Step Calculation of FAO-56 PM Model

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (1)$$

The above equation is divided into two parts: radiation part using equation (2) and aerodynamic part using equation (3) which their summation gives the ETo of the FAO-56 PM model.

$$ET_o rad = \frac{0.408\Delta(R_n - G)}{\Delta + \gamma(1+0.34u_2)} \quad (2)$$

$$ET_o aero = \frac{\gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \quad (3)$$

where:

ET_o	Reference evapotranspiration in mmday^{-1}
R_n	Net radiation at the crop surface in MJm^{-2}day^{-1}
G	Soil heat flux density in MJ m^{-2} day^{-1}
T	Mean daily air temperature at 2 m height in °C
u_2	Wind speed at 2 m height in ms^{-1}
e_s	Saturation vapour pressure in kPa
e_a	Actual vapour pressure in kPa
$e_s - e_a$	Saturation vapour pressure deficit in kPa
Δ	Slope vapour pressure curve in kPa∘C^{-1}
γ	Psychrometric constant kPa∘C^{-1}

As proposed by Allen et al., (1998) and Zotarelli et al., (2015),

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2} \quad (4)$$

$$e(T_{max}) = 0.610 exp\left(\frac{17.27T_{max}}{237.3+T_{max}}\right) \quad (5)$$

$$e(T_{min}) = 0.610 exp\left(\frac{17.27T_{min}}{237.3+T_{min}}\right) \quad (6)$$

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e(T_{max}) + e(T_{min})}{2}\right] \quad (7)$$

$$\Delta = 4098\left[\frac{0.6108 exp\left(\frac{17.27T}{273.3+T}\right)}{(273.3+T)^2}\right] \quad (8)$$

$$\gamma = 0.665 \times 10^{-3} P \quad (9)$$

$$P = 101.3\left(\frac{293 - 00056Z}{293}\right)^{5.26} \quad (10)$$

where:

Z Elevation of the station above sea level (m)

P Atmospheric Pressure (kPa)

If wind speed is not measured at 2m height, equation 11 is used.

$$u_2 = u_z \frac{4.87}{In(67.8h - 5.42)} \quad (11)$$

where:

u_z measured wind speed above the ground surface (ms^{-1})

h height of the measurement above the ground surface (m)

$$R_n = (1-a)R_s - \sigma\left[\frac{(T_{max}+273.16)^4+(T_{min}+273.16)^4}{2}\right](0.34-0.14\sqrt{e^a})\times\left(1.35\frac{R_s}{R_{so}}-0.35\right) \quad (12)$$

where:

σ Stefan Boltzmann constant = 4.903×10-9 MJk^{-4}m-2day^{-1}

ɑ Albedo which is given as 0.23

R_s Incoming solar radiation (MJ m^{-2} day^{-1})

R_{so} Clear-sky solar radiation given by:

$$R_{so} = (0.75 + 2E^{-5}Z)R_a \quad (13)$$

Ra Extraterrestrial radiation (MJ m^{-2} day^{-1}), given as:

$$R_a = \frac{24(60)}{\pi}G_{sc}d_r[(\omega_s sin\varphi sin\delta) + (cos\varphi cos\delta sin\omega_s)] \quad (14)$$

where:

G_{sc} Solar constant = 0.0820MJ m^{-2} min^{-1}

d_r Inversely relative distance Earth-sun

δ Solar declination

φ Latitude (radians)

ω_s Sunset hour angel (radians)

$$d_r = 1 + 0.033cos\left[\frac{2\pi}{365}J\right] \quad (15)$$

$$\delta = 0.409sin\left[\frac{2\pi}{365}J - 1.39\right] \quad (16)$$

$$\omega_s = arcos[-tan(\varphi)tan(\delta)] \quad (17)$$

$$\varphi(Radians) = \frac{\pi}{180}\varphi(decimal\ degrees) \quad (18)$$

To convert latitude, 6^{o}14N to decimal = (6+14)/60 = 0.333

But if it is 5^{o}30S to decimal = ((-5) + (-30))/60 = 0.583

3 Results and Discussions

The curves showing the variations of monthly mean ETo for Asaba and Uyo are presented in Figs. 2 and 9 respectively. The values of the calculated FAO-56 PM ETo were compared with monthly mean values of maximum air temperature, monthly mean values of minimum air temperature, monthly mean values of relative humidity, monthly mean values of solar radiation, monthly mean values of sunshine hours and monthly mean values of wind speed.

3.1 The Variations of ET_0 with Climatic Parameters in Asaba

The deviation of ETo detected from Fig. 2 is in line with the two seasons (dry and rainy) normally experienced in Asaba and in Nigeria as a whole. It could be observed that ETo is high during dry season having its highest average value (4.8 mm/day) in March whereas it is low during rainy season having lowest value (3.1 mm/day) in August. This is so because ET demand is usually high in hot dry weather as a result of dryness of the air and more so, the amount of energy available as direct solar radiation and latent heat of vapourisation is high. Under these conditions, ample water vapour can be stored in the air while wind may promote the transportation of water allowing more water vapour to be taken up. On the other hand, under humid weather conditions, the high humidity of the air and the presence of clouds cause the evapotranspiration rate to be lower. This is in line with the observation made by Singh and Bala (2012), on monitoring of evapotranspiration in major districts of Haryana using FAO-56 PM method and also by and Isikwue et al., (2014), on evaluation of ET using FAO-56 PM in Kano Nigeria.

From Fig. 3, it could be observed that the variation of monthly mean ETo with maximum temperature demonstrate the same trends (Edoga and Suzzy, 2008). This implies that the higher the maximum temperature, the higher the evapotranspiration rate. Both trends decreases during the rainy season (May – October) having their lowest values in July and August and increases during dry season. The variation of mean monthly minimum temperature showed slight similarity with the variation of ETo. It shows that maximum and minimum temperature does not evolve similarly. Minimum temperature does not play an important role on the amount of ETo as maximum temperature. This phenomenon was also reported in the third IPCC (2007), as well as by some authors like Malekinezhad (2012) and Mansour et al., (2017).

It could be observed from the variation of monthly mean ETo with relative humidity (Fig. 5), that the trend of relative humidity is inversely proportional to that of ETo. ET increases with increase in temperature as a result of low relative humidity in the atmosphere which will result to more water loss from the plant tissues as well as surface. This agrees with Edoga and Suzzy, (2008) that ET increases with decrease in relative humidity.

From the variation of monthly mean ETo with solar radiation (Fig. 6), it could be observed that the solar radiation trend has the same behaviour with maximum temperature and ETo trends. It is high during dry period and low during rainy period. Its minimum values are in July and August just as observed in ETo and maximum temperature. For ET to take place, energy is required to change the state of the molecules of water from liquid to vapour. This energy is provided by solar radiation incident on the Earth's Surface. It can then be said that, ETo is directly proportional to solar radiation (Isikwue et al., 2014). From Fig. 7, sunshine hour has similar trend with ETo maximum temperature and solar radiation though a little deviation in the months of January, March and April. From Fig. 8, it could be observed that the variation of monthly mean wind speed is relatively small, having it maximum in February. These findings were also observed by Isikwue et al., (2014). It can be stated that the effect of wind speed on ETo is less compared to the other climatic factors. This is in line with Rim, (2004) who noted that wind speed was the least sensitive meteorological factor that affects ETo.

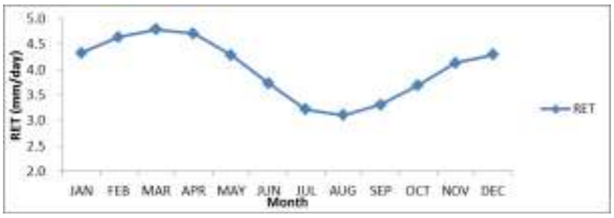

Fig. 2: The trend in variation of monthly ET_o in Asaba

Fig. 3: Variation of monthly ET_o with max. temperature in Asaba

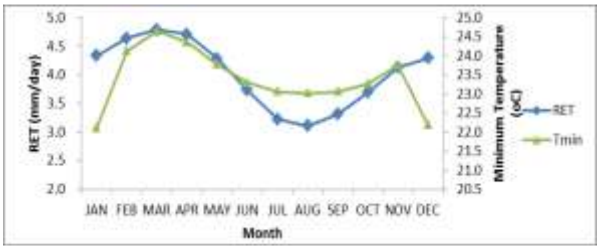

Fig. 4: Variation of monthly ET_o with min. temperature in Asaba

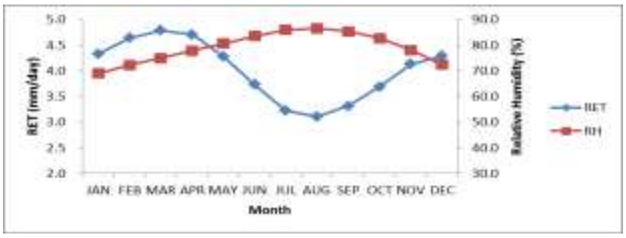

Fig. 5: Variation of monthly ET_o with relative humidity in Asaba

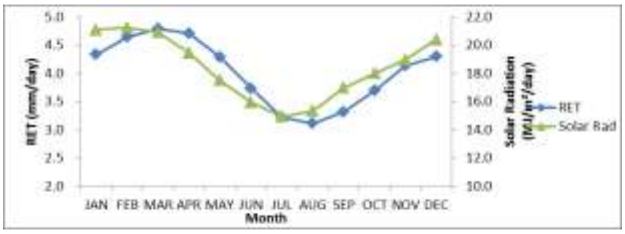

Fig. 6: Variation of monthly ET_o with solar radiation in Asaba

Fig. 7: Variation of monthly ET_o with sunshine hour in Asaba

Fig. 8: Variation of monthly ET_o with wind speed in Asaba

3.1 THE VARIATIONS OF ET0 WITH CLIMATIC PARAMETERS IN UYO

The monthly variation of ETo in Uyo as detected from Fig. 9 is as well in line with the two periods usually experienced in Nigeria which is same as Asaba. During the dry period, ET is usually high having its highest values in February and March (4.5 mm/day and 4.3 mm/day respectively) while during rainy period, low ET is experienced with lowest values in July and August (2.9 mm/day and 3.0 mm/day respectively).

The deviation of monthly mean ETo with maximum temperature follows the same pattern. This agrees to the fact that maximum temperature plays a very important role in rate and amount of reference evapotranspiration. As observed in Fig. 10 the higher the maximum temperature, the higher the ETo rate. Both trends decreases during the rainy season (May – October) having lowest value between July and August, and increases during dry season (November – March) with highest values in February. For mean monthly minimum temperature, the trend is just as observed in Asaba, slight similar with the variation of ET.

The variation of monthly mean relative humidity as shown in Fig. 11, is inversely proportional to the trend of RET (Edoga and Suzzy 2008). This is in line with the observation made in Asaba which implies that ET decreases with increase in relative humidity. Both solar radiation and sunshine hour have similar trends with ETo though sunshine hour showed a slight deviation in the month of August. They both have their maximum values in February and minimum values in July which also applies to ETo.

Wind speed as stated earlier and as observed by Isikwue et al., (2014) usually display relatively small variation in its trend. This also is shown in Fig. 14, where the deviation is between values of 1.8 m/s and 2.5 m/s. As observed both in Asaba and Uyo, the variation of wind speed do not follow a particular pattern, it is not in line with the two seasons observed in both locations. Thus, wind speed when compared with other climatic parameters, has little role to play in evapotranspiration rates.

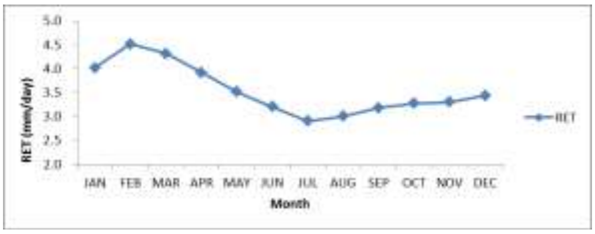

Fig. 9: The trend in variation of monthly ET_o in Uyo

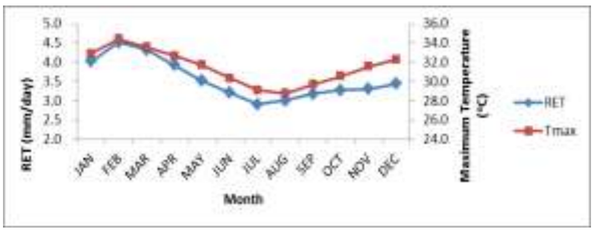

Fig. 10: Variation of monthly ET_o with max. temperature in Uyo

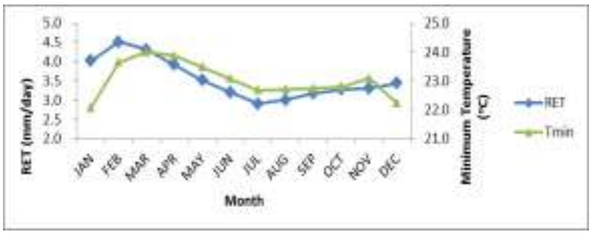

Fig. 11: Variation of monthly ET_o with min. temperature in Uyo

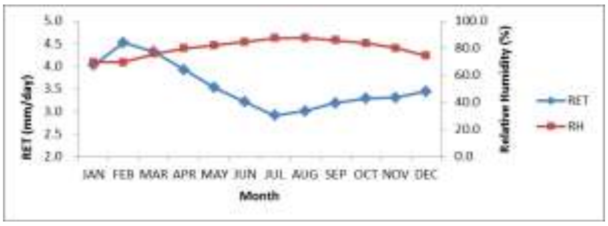

Fig. 12: Variation of monthly ET_o with relative humidity in Uyo

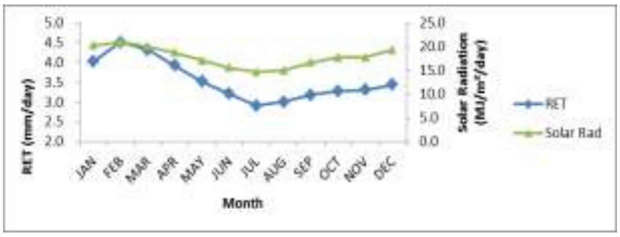

Fig. 13: Variation of monthly ET_o with solar radiation in Uyo

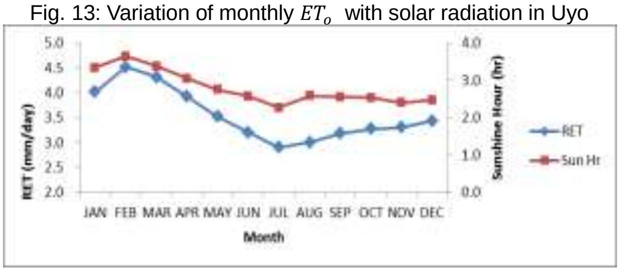

Fig. 14: Variation of monthly ET_o with sunshine hour in Uyo

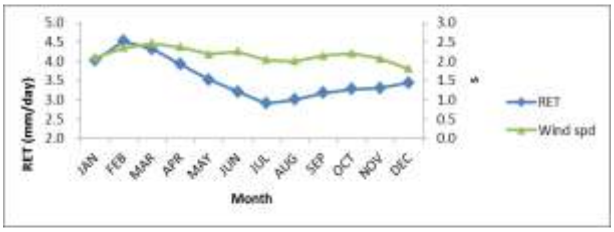

Fig. 15: Variation of monthly ET_o with wind speed in Uyo

4 Conclusions

The following conclusions were drawn from the study:

1. Variations of ET in both locations over the period of study are in line with the two seasons (rainy and dry) normally experienced in Nigeria. ET is high during dry season and low during rainy season.
2. The variation of ET in both locations and the variation of maximum temperature and solar radiation follow the same pattern, while minimum temperature and sunshine hour showed slight deviation in their variations when compared with ET variation.
3. Relative humidity trend is inversely proportional to the trend of ET, and
4. Wind speed displayed relatively small variation in its trend. In both locations, the variations of wind speed do not follow a particular pattern; they are not in line with the variations of ET.

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