International Journal of Science and Technology Volume 3 No. 11, November, 2014

Evaluation of Evapotranspiration using FAO Penman-Monteith Method in Kano Nigeria

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ABSTRACT

This work evaluated the reference evapotranspiration ET_o for Kano (lat. 12.0^0N, long. 8.3^0E at an altitude of 472.45m above sea level) using the FAO Penman-Monteith Method, for effective irrigation planning and management due to the location of Kano within the semi-arid Sudan savannah zone of West Africa about 840 kilometers from the edge of the Sahara desert, with little rainfall. The climatic data used were obtained from International Institute for Tropical Agriculture, Ibadan (1977-2010). The results show that the lowest ET_o (60.406 mm/day), was obtained in rainy season (August) due to the high humidity of the air and the presence of clouds, while the highest ET_o (125.08mm/day) was obtained in dry season (February) as a result of hot dry weather due to the dryness of the air and the amount of energy available. Among the climatic factors affecting ET_o, it was observed that solar radiation has highest effect on ET_o since it provide the energy needed for evapotranspiration to take place.

Keywords: *evapotranspiration, FAO Penman-Monteith Method, Kano.*

1. INTRODUCTION

Evapotranspiration (ET) is the combination of two separate processes, evaporation and transpiration; whereby water is lost from the soil surface by evaporation and from the crop by transpiration. Evaporation and transpiration occur simultaneously and it is not easy to distinguish between the two processes. When the crop is small, water is predominately lost from the soil surface by evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics (Allen et al. 1998).

ET is typically known as the crop water requirement since total crop water requirement is directly proportional to ET. In irrigation schemes, water losses occur mainly due to ET. The knowledge of ET is very important in the design and maintenance of irrigation schemes as it helps to predict whether there would be any deficit or excess in demand for water, hence, the required amount of water can be estimated and necessary precautions can be taken earlier (Ramirez and Harmsen, 2011). According to (Allen et al. 1998), reference evapotranspiration (ET_o) is an important agro-meteorological parameter for climatological and hydrological studies, as well as for irrigation planning and management.

Evaporation and transpiration are affected by weather parameters, crop characteristics, management and environmental conditions (Łabędzki.L *et al*. 2011). The major factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. The principal weather parameters affecting evapotranspiration are solar radiation, air temperature, humidity and wind speed (Trajković and Živković 2009)..

Evapotranspiration can be measured with field lysimeters, which measure mass balance variables like rainfall, percolation, runoff and soil moisture changes. This direct method in practice presents some difficulties to be used, basically because of the high cost of acquisition and keeping of the instruments (Ramirez and Harmsen, 2011). Hence, there is need to use empirical method to estimate evapotranspiration.

There are many analytical and empirical equations that are currently used to calculate reference evapotranspiration (ETo) involving one or more climatic data. The Food and Agricultural Organization (FAO) Penman-Monteith method is recommended as the sole standard method (Allen et al. 1998). Several researchers have used the FAO Penman-Monteith Method to estimate evapotranspiration (Buttafuoco et al. 2010; McVicar *et al*. 2007; Ram and Anju 2012). Working on the usability of the Penman-Monteith equation for calculating reference and grassland evapotranspiration in Central Poland, (Labedzki, 1999), found a good agreement between the values computed using the FAO Penman-Monteith method and the one measured using lysimeters. Using this method and working in the climatic conditions of Poland, Łabędzki *et al*. (2011) calculated the growing season ETo to range from 480 - 560 mm in an average year. Also, they discovered that the ET_o ranges between 500 - 620 mm in a hot and dry year and 460 - 520 mm in cold and wet year. Other researchers have used the FAO Penman-Monteith method in relation to other methods in calculating reference evapotranspiration (Maulé et al. 2006; Paltineanu et al. 1999).

In this work, the FAO Penman-Monteith Method will be use to estimate reference evapotranspiration for Kano, Nigeria. Kano State is located in North-Western Nigeria with its capital as Kano. Kano city is located on latitude 12.0^0N and longitude 8.3^0E within the semi-arid Sudan savannah zone of West Africa about 840 kilometers from the edge of the Sahara desert. Kano has a mean height of about 472.45m above sea level (Ibrahim, 2006). It is the largest State of the Nigerian Federation having a land mass of about 20,131 km^2 with a population of 9,383,682 according to the 2006 census. Agriculture is one of the most important pillars of the State's economy with above 75% of the total working population engaged directly or indirectly in this activity (Ezenekwe *et al*. 2013). The principal food crops cultivated in abundance are Millet, Cowpeas, Sorghum, Maize and Rice for local consumption while Groundnuts and Cotton are produced for export and industrial purposes. Other exportable commodities grown in Kano State include Sesame, Soya Beans, Garlic, Gum Arabic and Chilli Pepper. Kano State contributes over 20% of Nigeria's non-oil export revenue (Ibrahim, 2006).

The temperature of Kano usually ranges between a maximum of 33^0C and a minimum of 15.8^0C although sometimes during the harmattan, it falls down to as low as 10^0C. Kano has two seasonal periods which consist of four to five months of wet season (May - September) and a long dry season lasting from October to April. The average rainfall is between 63.3mm $\pm$ 48.2mm in May and 133.4mm $\pm$ 59mm in August, the wettest month. Most of the farming activities in this area are done through irrigation system (Ibrahim, 2006). The objective of this work is to evaluate evapotranspiration in Kano using the FAO Penman-Monteith method which will be an important tool in effective irrigation and management.

2. SOURCES OF DATA AND METHOD OF ANALYSIS

The climatic data such as maximum and minimum temperature, maximum and minimum relative humidity, solar radiation and wind velocity used in this work were collected from International Institute for Tropical Agriculture, Ibadan. The period under focus is from 1977 to 2010.

The ET_o was computed using the P-M model for the ETo estimation recommended by the FAO-56 paper (Allen et al. 1998) and standardized by the American Society of the Civil Engineers-ASCE (Allen *et al.* 2005) given as:

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

where

ET_o - reference evapotranspiration ($mmday^{-1}$), R_n - net radiation at the crop surface ($MJm^{-2}day^{-1}$), G - soil heat flux ($MJm^{-2}day^{-1}$), $\bar{T}$ - mean daily air temperature at 2 m height (°C), U_2 - wind speed at 2 m height (ms^{-1}), e_s- saturated vapour pressure (kPa), e_a - actual vapour pressure (kPa), $e_s - e_a$ saturated vapour pressure deficit (kPa), Δ - slope of vapour pressure curve (kPa) and γ -psychrometric constant (kPa $°C^{-1}$). According to (Łabędzki.et al. 2011), soil heat flux can be ignored and assumed to be zero since it is small compared to R_n.

In this study, e_s, e_a, Δ, γ and R_n were calculated as proposed by the FAO (Allen et al. 1998). Mean saturated vapour pressure derived from air temperature is given by (Allen et al. 1998) as:

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

where

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

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

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:

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

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

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

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 = 479 m.

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

$R_n = (1-\alpha)R_s - \sigma\left[\frac{(T_{max}+273.16)^4+(T_{min}+273.16)^4}{2}\right](0.34 - 0.14\sqrt{e_a}) * (1.35\,\frac{R_s}{R_{so}} - 0.35)$ (8)

Where
σ is the Stefan Boltzmann constant, $\sigma = 4.903\, x\, 10^{-9} MJk^{-4}m^{-2}day^{-1}$, α is the albedo given as 0.23 (Allen *et al.* 1998). R_{so} is the clear sky solar radiation given as:

$R_{so} = (0.75 + 2\, x\, 10^{-5}Z)\, R_a$ (9)

R_a is the extraterrestrial radiation and was 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 (Allen et al. 1998).

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

3. RESULTS

The curve showing the variation of monthly mean evaluated evapotranspiration is presented in Figure 1. The values of the calculated ET_o were compared with monthly mean values of relative humidity (Figure 2); monthly mean values of wind speed (Figure 3); monthly mean values of air temperature (Figure 4); and monthly mean values of solar radiation (Figure 5).

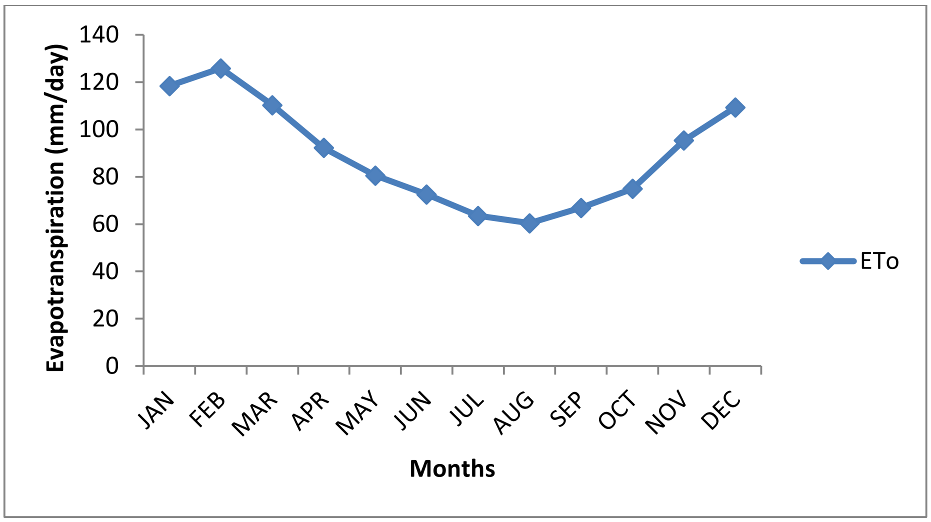

Figure 1: The trend in variation of evapotranspiration in Kano, Nigeria

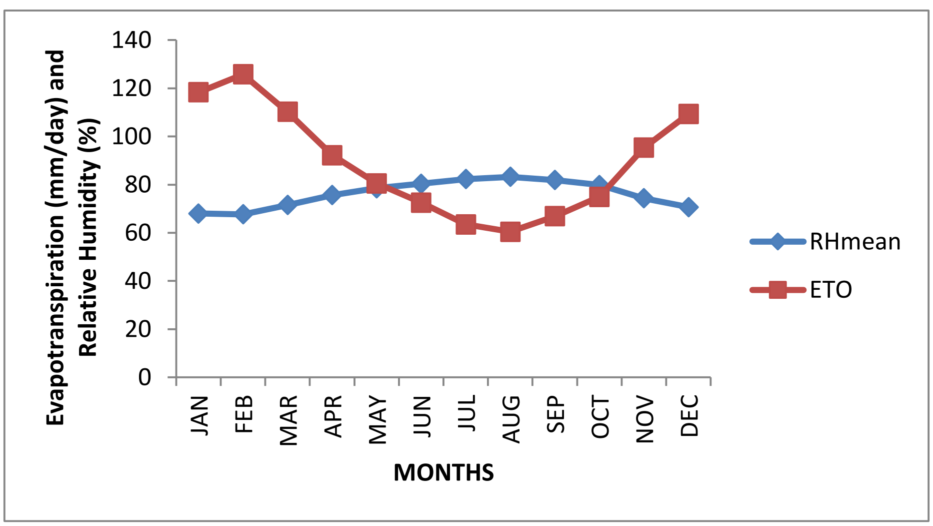

Figure 2: Variation of monthly mean relative humidity with evapotranspiration

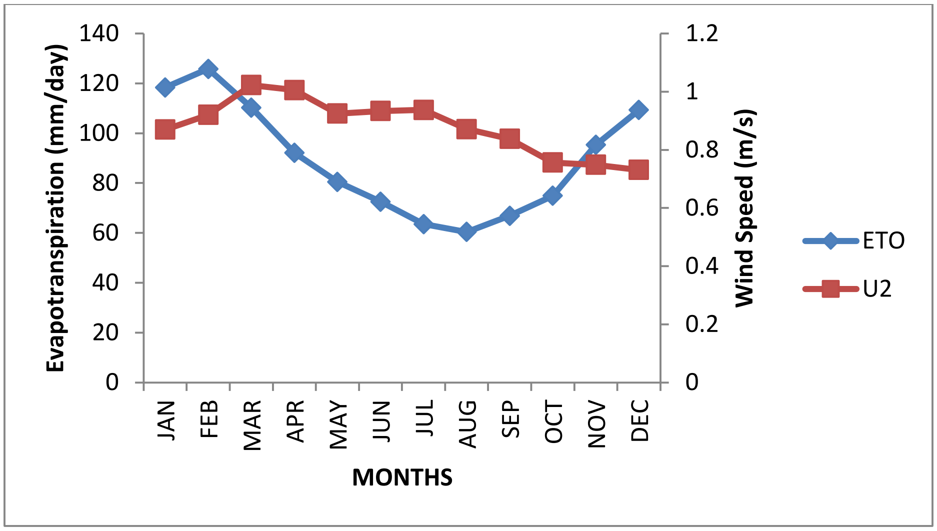

Figure 3: Variation of monthly mean wind speed with evapotranspiration

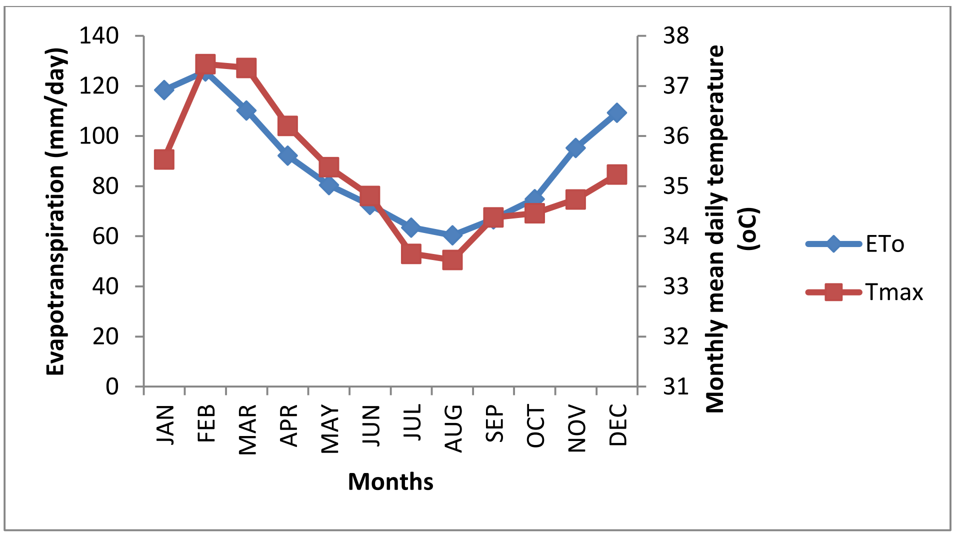

Figure 4: Variation of monthly mean air temperature with evapotranspiration

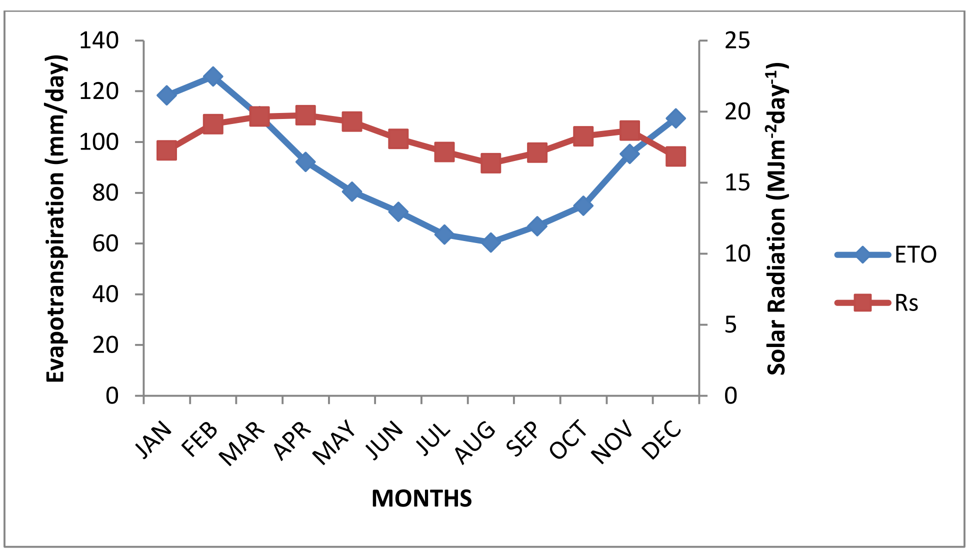

Figure 5: Variation of monthly mean solar radiation with evapotranspiration

4. DISCUSSION

The variation of evapotranspiration observed from Figure 1 is in line with the two seasons normally experienced in Kano. It could be observed that evapotranspiration is high during dry season with its highest value (125.08mm/day) in February while it is very low in rainy season having lowest value (60.406 mm/day) in August. This is because evapotranspiration demand is high in hot dry weather due to the dryness of the air and the amount of energy available as direct solar radiation and latent heat of vaporization. Under these circumstances, much water vapour can be stored in the air while wind may promote the transport 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 (Ram and Anju, 2012), on monitoring of evapo-transpiration in major districts of Haryana using Penman Monteith Method.

It could be observed from the variation of monthly mean relative humidity with evapotranspiration (Figure 2), that the variation of relative humidity is relatively small. This shows that the effect of relative humidity on ET_o may not be as significant as other climatic factors. This variation may be due to the location of Kano in inland area. This agrees with (Rim, 2004) that ET_o sensitivity to humidity is less in the inland areas than in the coastal areas.

From Figure 3, it could be observed that the variation of monthly mean wind speed is relatively small, having it maximum in February. 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 (Rim, 2004) who noted that wind speed was the least sensitive meteorological factor that affects ET_o.

From the variation of monthly mean maximum temperature with evapotranspiration (Figure 4), it could be observed that air temperature and monthly mean evapotranspiration exhibit the same trends. It decreases during the rainy period (June – September) when air temperature is very low with minimum value in the month of August; the peak of rainy season. This may be probably due to rain bearing clouds which pervaded the sky.

From the variation of monthly mean solar radiation with ET_o (Figures 5), it could be observed that the solar radiation is high during dry season (October-May) but low during rainy season (June-September), with minimum value in the month of August. The low values of ET_o during the rainy season implies that the rate of ET_o is directly proportional to the solar radiation. This is because for evapotranspiration 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 could be observed that among the climatic factors affecting ET_o, solar radiation and temperature are the most important factors affecting ET_o as also observed by (Rim, 2004). This is obvious in the fact that the least ET_o was obtained in rainy season (August) when the sky is cloudy while the highest was observed in dry season (February) when the sky is cloudless. Cloudless condition allows a high percentage of solar radiation to reach the Earth surface, hence warmer temperature occurs. On the other hand, less solar radiation reaches the surface during cloudy sky and cooler temperature occurs. The variation of temperature with solar radiation is due to the fact that surface temperature is the reflection of both the duration and intensity of solar radiation (Isikwue *et al*. 2013).

5. CONCLUSION

- The FAO Penman-Monteith method as modified by ASCE has been used to evaluate the reference evapotranspiration for Kano. This will be a tool for effective irrigation planning and management.
- The results shows that the lowest ET_o (60.406 mm/day), was obtained in rainy season (August) due to the high humidity of the air and the presence of clouds while the highest ET_o (125.08mm/day) was obtained in dry season (February) as a result of hot dry weather due to the dryness of the air and the amount of energy available.
- Variation of ET_o with climatic parameters that affects it was carried out. It was observed that among the climatic parameters, solar radiation has highest effect on ET_o since it provide the energy needed for evapotranspiration to take place.

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