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DETERMINATION OF POTENTIAL EVAPOTRANSPIRATION USING THE PENMAN-MONTEITH MODEL FOR OWERRI

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ABSTRACT
The determination of the potential evapotranspiration using the Penman-Monteith model for Owerri has been carried out. Potential evapotranspiration represents the environmental demand for evapotranspiration for a location which reflects the energy available to evaporate water from the ground into the lower atmosphere.The data for this work were collected from the Nigeria Meteorological Agency, Owerri which is at altitude 160 m, latitude 50º 00′ N and longitude 06º 05′ E. The result of this work shows that the maximum potential evapotranspirationoccurs from January to March, then drops considerably from April to September and then rises from October to December. This result is useful to farmers and horticulturalists in determining when to farm and to irrigate the farms and gardens.

Keywords: Energy, farmers, Owerri, Penman-Monteith model, potential evapotranspiration

1. Introduction

Evapotranspiration is a key indicator for water management and irrigation performance, it is the sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. Potential evapotranspiration is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop completely shading the ground of uniform height and with adequate water status in the soil profile. It is a reflection of the energy available to evaporate water and of the wind available to transport water vapour from the ground into the lower atmosphere. Evapotranspiration could be estimated using the equation of water balance for a drainage basin:

$$ET = P - \Delta S - Q - D \quad (1)$$

Where ET is evapotranspiration, P is the precipitation,ΔS is the change in water stored in the basin,Q is the stream flow and$D$ is the ground water drainage. Since it is difficult to develop equation for estimating evaporation rate for various crops on different condition, reference evapotranspiration scheme was developed(Manik*et al*., 2017). Reference ET is the rate of evapotranspiration from an extensive area of 0.08–0.15 m high, uniform, actively growing, green grass that completely shades the soil and is provided with unlimited water and nutrients (Bakhtiari*et al*., 2011).There are several models used for determining the reference evapotranspirationbut the most general and widely used is the Penman-Monteith model recommended by the Food and Agriculture Organization (FAO) (Allen *et al*., 1998).The FAO Penman-Monteith (FAO-56 PM) method is recommended as the standard method for determining ET_0 as it is physically based and explicitly incorporates both physiological and aerodynamic parameters (Tomar, 2015).A large number of empirical models have been developed over the years by numerous scientists and specialists to estimate potential evapotranspiration from different climate variables(Blaney and Criddle, 1950; Makkink, 1957; Priestley and Taylor, 1972; Hargreaves and Samani, 1982; Allen *et al.*, 1998; Sumner and Jacobs, 2005; Yoder*et al.*, 2005; Schneider*et al.*, 2007; Adeboye*et al.*, 2009: Rácz*et al.*,2013). But testing the accuracy of the methods under new set of conditions is laborious, time consuming and costly, and yet potential evapotranspiration data is frequently needed at short notice for project planning or irrigation scheduling designs. Users with different data variability can be accommodated by using any of the following models to calculate the reference crop evapotranspiration (ET_o): Solar Radiation, Temperature, Blaney-Criddle, Makkink, Jensen-Haise, Linacre, HargreavesSamani, Thornthwaite, Camargo, Priestley-Taylor, Original Penmanand the modified Penman-Monteith models. Some of the models are presented and the Penman-Monteith model is used in the study.The modified Penman-Monteith method was considered to offer the best result in predicting ET_o in a wide range of locations and climates with minimum possible error in relation to a living grass reference crop. The aim of this study is to determine the potential evapotranspiration using the Penman-Monteith Modelfor Owerri. Some models are presented:

Radiation Baesd Model (Makkink−FAO-24:Makkink, 1957)

$$ET_o = a_2 + b_2\left(\frac{\Delta}{\Delta+\gamma}\right)\frac{R_g}{\lambda} \quad (2)$$

$$a_2 = -0.3$$

$$b_2 = c_0 + c_1 RH + c_2 u_{2d} + c_3 RHu_{2d} + c_4 RH^2 + c_5 u_{2d}$$

where a_2, b_2 are parameters of the equation (2), c_0,c_1 – c_5 are coefficients of the equation (2), Δ is slope of the vapor pressure curve (kPa°C^{-1}), γ is psychrometric constant (kPa°C^{-1}), R_g *is*global radiation (MJm^{-2}day^{-1}), λ is latent heat of vaporization (MJkg^{-1}), *RH* is daily mean relative humidity (%) and u_{2d} is mean wind speed of daylight hours at 2 m height (ms^{-1}).

Slope ofvapour pressure curve (Δ) (Xu and Singh, 2002) is given as

$$\Delta = \frac{4098 e_s(T_a)}{(T_a+237.3)^2} = \frac{2504\left(\frac{17.27T_a}{T_a+237.3}\right)}{(T_a+237.3)^2}, \quad (3)$$

where Δis slope of vapour pressure curve (kPa C^{-1}) andT_a is air temperature (°C).

Latent Heat of Vaporization (λ) (Xu and Singh, 2002) is given as

$$\lambda = 2.501 - (2.361 \times 10^{-3})T_a \ , \quad (4)$$

where λ is latent heat of vaporization (MJ kg^{-1}) and T_a is air temperature (°C).

Psychrometric Constant (γ) (Xu and Singh, 2002) is given as

$$\gamma = \frac{C_P P}{\varepsilon \lambda} \times 10^{-3} = 0.00163 \frac{P}{\lambda}, \quad (5)$$

where γ is psychrometric constant (kPa C^{-1});C_P is specific heat of moist air = 1.013 (kJ kg^{-1}°C^{-1});P is atmospheric pressure (kPa);ε is ratio molecular weight of water vapour/dry air = 0.622 and λ is latent heat of vaporization (MJ kg^{-1}).

Temperature Based Model(Blaney−Criddle-model: Blaney−Criddle, 1950)

$$ET_o = a_1 + b_1[p(0.46T + 8.13)] \quad (6)$$

$$a_1 = 0.0043RH_{min} - \left({}^{n}/_{N}\right) - 1.41$$

$$b_1 = 0.82 - 0.0041RH_{min} + 1.07\left({}^{n}/_{N}\right) + 0.066u_{2d} - 0.006RH_{min}\left({}^{n}/_{N}\right) - 0.0006RH_{min}u_{2d}$$

where a_1, $b_1$are parameters for equation (3),p is the mean daily percentage of annual daytime hoursfor the used period (daily or monthly) out of total daytime hours,T is daily mean temperature at 2 m height (°C), RH_{min} is daily minimum of relative humidity (%),$\left({}^{n}/_{N}\right)$is relative sunshine duration,

Pan coefficient-based methods (FAO-56: Allen *et al.*, 1998)

$$ET_o = E_{pan} - K_p \quad (7)$$

$$K_p = 0.51206 - 0.000321u_2 + 0.0422ln(F) + 0.1434ln(RH) - 0.000631[ln(F)]^2 ln(RH)$$

where$F$ is the fetch distance above the reference surface (m), E_{pan} is class A Pan evaporation (mm/day) and K_p is pan coefficient.

Methods based on mass-transfer(Mahringer-model:Mahringer, 1970)

$$ET_0 = 0.1572.\sqrt{3.6u_2}.(e_s - e_a) \quad (8)$$

where u_2 is daily mean wind speed at 2 m height (km day^{-1}), e_s is saturation vapor pressure (kPa) and e_a is actual vapor pressure (kPa).

Penman−Monteith−FAO-56-model (Allen *et al.*, 1998):

The FAO Penman-Monteith model for calculating potential evapotranspiration (ET_o) (Allen *et al.*, 1998) can be written as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (9)$$

where $ET_o$is reference evapotranspiration(mm/day),Δ is slope of vapour pressurecurve (kP_a/°C), R_n is net radiation at crop surface (MJ/m^2/day), G is soil heat flux density (MJ/m^2/day), γ is psychrometric constant (kP_a/°C), *T* is mean daily air temperature at 2m height (°C), U_2 is wind speed at 2mheight (m/s), e_s is saturated vapour pressure (kP_a), e_a is actual vapour pressure (kP_a) and e_s-e_a is saturated vapour pressure deficit (kP_a).

2. Materials and Method

The data for the determination of potential evapotranspiration for Owerri was obtained from the Nigeria meteorological agency Owerri, which is at latitude 50º 00′ N, longitude 06º 05′ Eand altitude 160 m. The data was from the year 2004 to 2008 and include; temperature, rainfall, humidity, relative humidity, mean monthly temperature, sunshine hours, mean monthly wind speed and solar radiation.The Penman-Monteith Model was used for the determination of the potential evapotranspiration for Owerri.

3. Results and Discussion

The data obtained and results for the potential evapotranspiration (ET_o) for Owerri using the Penman-Monteith Model are presented in Tables 1 and 2 respectively. The monthly averages of the ET_o using Penman-Monteith Model from 2004 – 2008 are presented in Table 3.

Table 1: Monthly Potential Evapotranspiration Data for 2004

Month	T_{mean} /°C	Humidity %	Wind Speed /km/day	Radiation MJ/m^2/day	Δ	$e^o \times$ (T_{max})	$e^o \times$ (T_{min})
JAN	32.4	31	54.8	3.0	0.2739	6.1635	1.9217
FEB	43.3	60	60.6	5.2	0.4567	5.4634	2.1175
MAR	32.5	59	60.0	3.4	0.2753	6.4817	2.2686
APR	33.0	78	57.3	2.5	0.2821	4.8101	2.8486
MAY	31.5	75	56.4	1.8	0.2621	4.2510	2.7468
JUN	30.1	77	98.8	1.6	0.2446	4.7015	2.6291
JUL	28.5	80	63.6	1.3	0.2257	4.6982	2.9049
AUG	27.1	85	66.4	1.1	0.2102	3.7053	2.5369
SEP	28.2	84	98.5	1.1	0.2223	4.9284	2.6740
OCT	30.2	83	59.7	1.4	0.2458	5.3220	2.6276
NOV	31.3	80	45.9	1.6	0.2596	4.5698	2.7147
DEC	32.2	81	53.5	2.8	0.2713	4.1764	1.7359

Table 2: Determination of Monthly ET_o using Penman-Monteith Model for 2004

e_s	e_a	e_s-e_a	G	P	γ	$0.408\Delta \times (R_n\text{-}G)$	$\gamma\left(\frac{900}{T+273}\right) \times U_2(e_s - e_a)$	$\Delta + \gamma(1 + 0.34U_2)$	ET_o
4.043	1.234	2.809	4.45	101.2	0.067	0.0277	30.4835	1.5934	19.15
3.790	2.243	1.548	1.53	101.2	0.067	0.5169	17.9670	1.9109	9.67
4.555	2.648	1.907	-1.51	101.2	0.067	0.5293	22.6889	1.7156	13.53
3.829	2.901	0.928	0.07	101.2	0.067	0.2222	10.5193	1.6599	6.47
3.499	2.569	0.930	-0.21	101.2	0.067	0.9637	10.4314	1.6200	7.03
3.665	2.783	0.882	-0.20	101.2	0.067	0.1792	17.4149	2.5215	6.84
3.802	3.012	0.789	-0.22	101.2	0.067	0.1496	10.0761	1.7469	5.85
3.121	2.602	0.519	-0.20	101.2	0.067	0.1112	6.9457	1.7950	6.50
3.801	3.126	0.675	0.15	101.2	0.067	0.1130	13.3596	2.5415	7.80
3.969	3.203	0.767	0.28	101.2	0.067	0.0923	9.1326	1.6773	8.80
3.642	2.846	0.796	0.15	101.2	0.067	0.1743	7.2721	1.3766	12.50
2.956	2.325	0.631	0.13	101.2	0.067	0.3071	6.6953	1.5617	11.80

Table 3: Monthly Averages of the ET_o using Penman-Monteith Model from 2004 – 2008

Month	ET_o2004	ET_o2005	ET_o 2006	ET_o 2007	ET_o 2008	ET_o Average
JAN	19.15	12.50	7.46	11.40	13.37	13.84
FEB	9.67	21.60	9.60	10.21	11.17	12.72
MAR	13.53	20.02	12.77	9.24	13.01	12.34
APR	6.47	6.90	10.94	6.67	7.93	6.54
MAY	7.03	6.67	5.92	3.62	5.56	5.10
JUN	6.84	5.70	4.75	3.50	4.66	4.99
JUL	5.85	4.03	2.64	3.66	3.99	4.31
AUG	6.50	3.87	4.25	3.54	2.44	4.29
SEP	7.80	5.13	4.04	4.10	4.36	5.96
OCT	8.80	8.66	5.09	6.25	5.26	8.03
NOV	12.50	9.82	8.40	7.46	6.81	9.00
DEC	11.80	10.12	11.16	9.39	12.19	10.93

The results of the monthly averages of the ET_o using FAO Penman-Monteith Model from 2004 – 2008 for Owerri are presented in Figs. 1-7. From the figures, the rate of potential evapotranspiration is generally high from January to March and drops from April to September with a little rise from October to December, which is in accordance with the intensity of solar radiation pattern for the year.

The maximum temperature of 43.3 °C and radiation of 5.2 MJ/m^2/day occurred in February while the minimum temperature of 27.1 °C and radiation of 1.1MJ/m^2/day occurred in August. Generally, February is the driest while August is the wettest month of the year at Owerri. This is similar to the work of De Meloand Fernandes,(2012). According to Rácz*et al.*, (2013), the value of ET_0 increases with the increase of global radiation.Potential evapotranspiration data are useful to farmers, gardeners, hydrologists and horticulturists for predicting drought patterns and determining when to farm and to irrigate the farms and gardens in the locality of Owerri. ET_0 values help farmers to maintain, improve crop yields and quality; boost profits, reduce energy costs and ecological degradation.

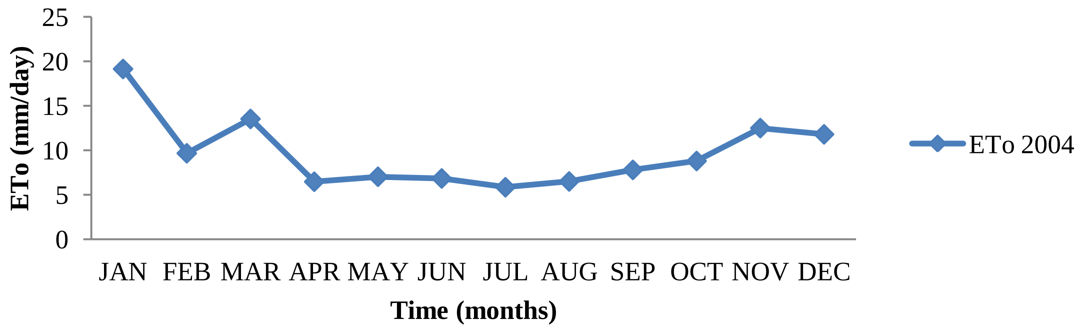

Fig. 1: ET_o using Penman-Monteith Model for 2004

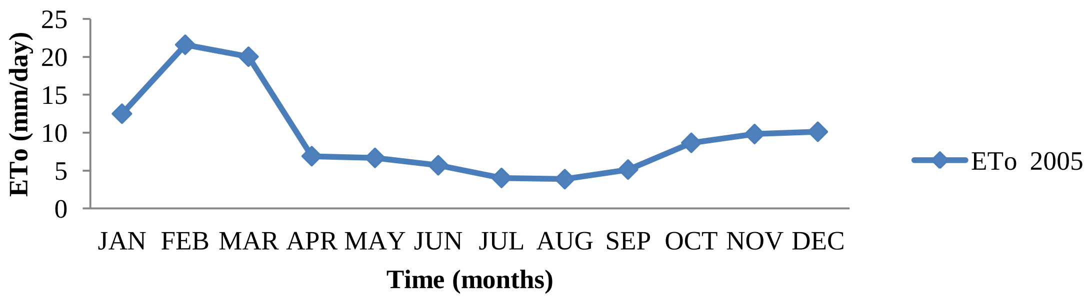

Fig. 2: ET_o using Penman-Monteith Model for 2005

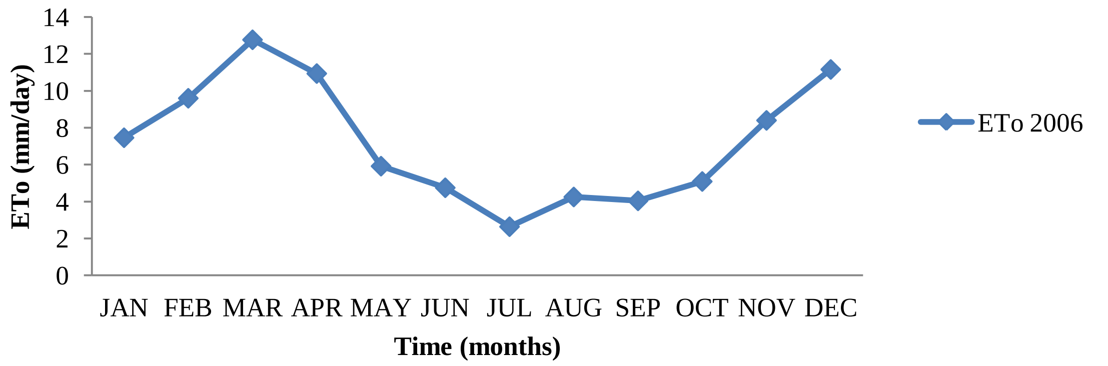

Fig. 3: ET_o using Penman-Monteith Model for 2006

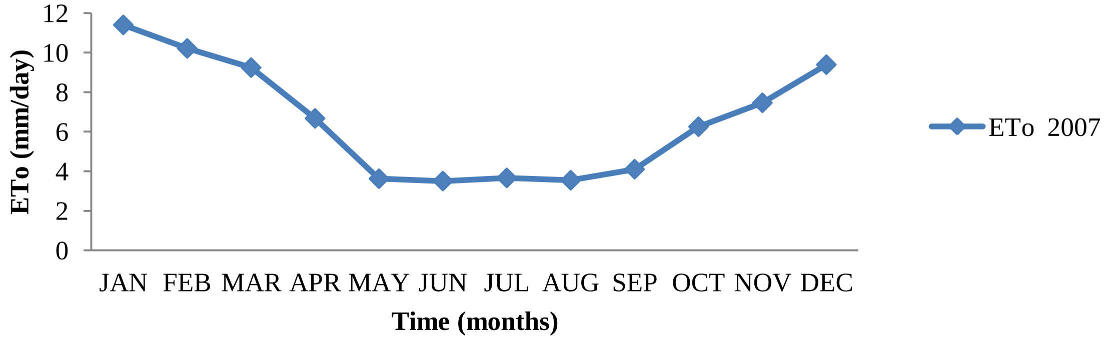

Fig. 4: ET_o using Penman-Monteith Model for 2007

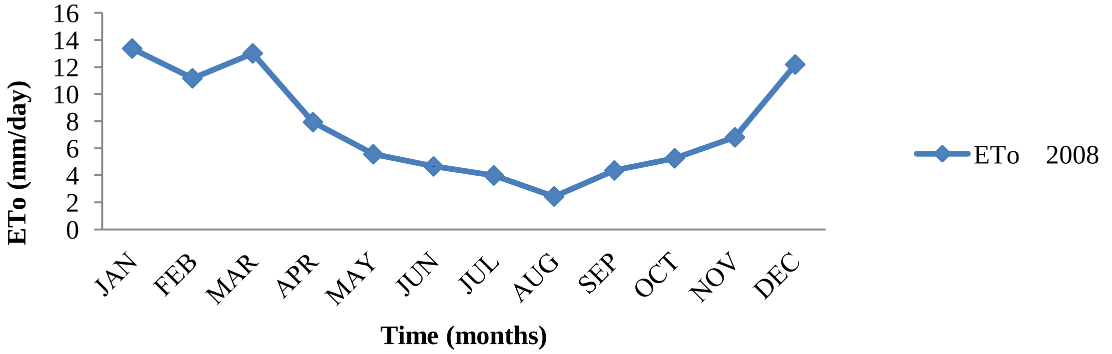

Fig. 5: ET_o using Penman-Monteith Model for 2008

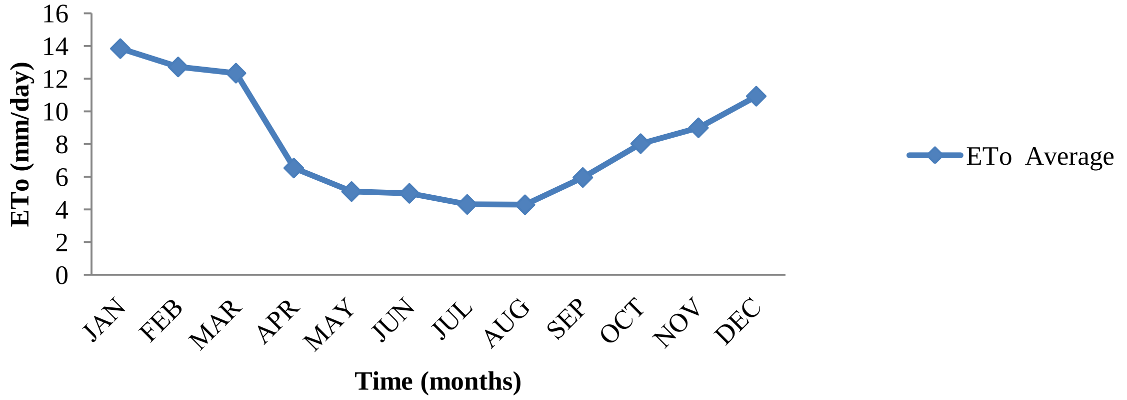

Fig. 6: Monthly Average ET_o using Penman-Monteith Model from 2004 - 2008

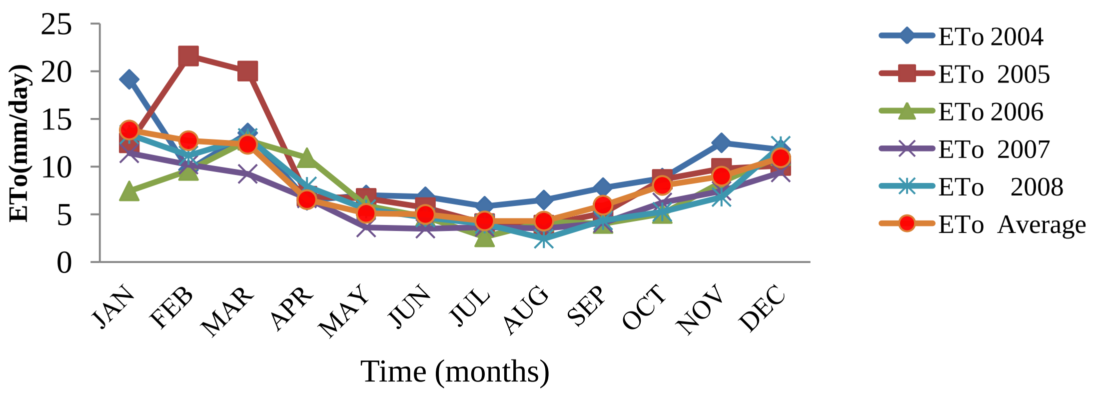

Fig. 7: Monthly Averages of *ETo* using Penman-Monteith Model from 2004 – 2008

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