# DETERMINATION OF MONTHLY REFERENCE EVAPORTRANSPIRATION FOR UMUDIKE, NIGERIA USING FAO-56 PENMAN-MONTEITH METHOD.

***Abarikwu, O. I. and Akanimo E. E.**
Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike.
*hikeng4christ@yahoo.com; (+2348030960103)

***ABSTRACT***

*Crop evapotranspiration ($ET_c$) could be determined from reference evapotranspiration ($ET_o$) if the crop coefficient is known. FAO-56 Penman-Monteith (PM) method normally gives accurate and consistent $ET_o$. For a developing country like Nigeria, food sufficiency could only be achieved through irrigation in addition to rainfed agriculture and irrigation requires the detemination of precise crop water requirment or crop evapotranspiration for efficient water utilisation. In this study 10 years, 1996 – 2005, climatic and meteorological data were obtained from Umudike Meteorological Station, Nigeria, and the data were used in computing $ET_o$ using the FAO – 56 PM method. The average monthly $ET_o$ obtained from January to December were 13.0, 13.1, 10.7, 7.8, 7.2, 6.1, 5.3, 5.0, 5.9, 6.1, 7.3, and 9.8 mm/day, respectively. The results were compared to the studies by other researchers using a lysimeter for crop evapotranspiration at Umudike. The results of $ET_o$ obtained in this study is recommended for computing $ET_c$ for an irrigation project and water management in this area of Nigeria.*

***Keywords**: Reference Evapotranspiration, FAO – 56 Penman-Monteith Method, Crop Water Requirement, Crop Evapotranspiration, Umudike.*

## 1. INTRODUCTION

The value of evaporatranspiration (ET) is of importance to many disciplines: irrigation concept designers, irrigation schedulers, hydrologists, drainage system studies, project planners and environmentalists. Improved techniques are needed for accurate quatification of ET on a field, watershed and on regional scales to enhance efficient use of water resources and sustainability of agricultural production and protect water quatity. Accurate quantification of ET is crucial in water allocation, irrigation management, evaluating the changing land use, water yield and ground water quatity and quality (Irmark, 2010)

Reference evapotranspiration ($ET_o$) is a representation of the environmental demand for evapotranspiration and represents the evaporation rate of a reference surface, not short of water. FAO. doc. Allen *et al.* (1998). For agricultural production, reference evapotranspiration ($ET_o$) is of prime importance in evaluation of crop evapotranspiration, $ET_a$ for each crop and state of growth. It is a product of $ET_o$ and the crop coefficient $K_c$, (Wikipedia, 2016). Crop water requirement can be computed at various location or in different seasons, using the reference evapotranspiration when water and environment stress factors are applied, which are the $ET_c$ and $ET_{c\ adj}$ as given in equations 1 and 2 below.

$$ET_o \times K_c = ET_c \quad (1)$$

$$ET_o \times K_c \times K_s = ET_{c\ adj} = ET_a \quad (2)$$

Where:-

$ET_a$ = actual crop evapotranspiration, (cm)

$ET_c$ = crop evapotranspiration, (cm)

$ET_{c\ adj}$ = actual crop evapotranspiration, (cm)

$K_c$ = crop coefficient

$K_s$ = stress factor

Direct measurement of crop evapotranspiration, $ET_a$, using lysimeters, atmometers, energy balance or pan evapotimeters, is not usually feasible because of its relative high expense and time consuming nature (Echiegu, *et al.,* 2016). In the indirect methods, many models could be used, such as the Blaney-Morin-Nigeria, (BMN), Priestly-Taylor, Hargeaves-Samani or Jensen-Haise Models. These models are adjudged to be site or location speciifc by reseachers, (Echiegu, *et al.,* 2016). However, the FAO 56 Penman-Montheith (PM) method, an indirect method, has been recommended by the Food and Agriculture Organisation (FAO) as the sole standard method for evaluating $ET_o$, (Isikwue, *et al.* 2015 and Ilesanmi and Umego, 2016). The FAO 56- PM model is the best estimator of $ET_o$ to be used if all climatic and meteorological data are availale (Allen, *et al.,* 1998; Alexandiris *et al*., 2008).This study; (a) evaluates the reference evapotranspiration ($ET_o$) for the National Root Crop Research Station (NRCRI), Umudike, Nigeria, using the FAO56 Penman-Monteith (PM) Method with climatic and meterological data for the period, 1996 – 2005, of the station, (b) compares the result with crop water requirement, $ET_c$, of waterleaf, using a weightable lysimeter in Umudike for a period of the year, from another research, to validate the $ET_o$ values evaluated at the Umudike station.

## 2. DATA, MATERIALS AND METHOD OF ANALYSIS

### *2.1 Location of Study, Z.*

Umudike town in Abia State, Nigeria is located on 8 km East of Umuahia-Ikot-Ekpene road in Eastern Nigeria. It is 140 km North of Port-Harcourt International Airport and 80 km East of Owerri Airport. It is situated on latitude (05° 29'N, 07° 33'E) with geographical elevation of 122 m (above mean sea level as altitude), (Chukwu and Mbanaso, 1999). The town has two notable national institutions, Michael Okpara University of Agriculture, (MOUAU) and National Root Crop Research Institute, (NRCRI). Both are Federal Government of Nigeria Agencies, and adjacently located. The NRCRI has a history of over half a century with very good and reliable equipment in the meteorological station and have records for that long, that are accurate and reliable for $ET_o$ computation using the FAO 56 PM method.

### *2.2 Data Source*

A ten year data of daily records, were extracted from the Agriculture and Meteorological Unit (Agromet) of the NRCRI for the years 1996 to 2005, of radiation, sunshine duration, maximum and minimum air temperature, maximum and minimum air humidity, wind speed and rainfall. The data were analyzed for monthly average values for each year, and recorded in Table 1.

### *2.3 Meteorological Parameters*

***Solar Radiation and Sunshine Hours:***

Solar radiation gives the largest potential amount of energy source that can reach the evaporating surface and is determined by its location and time of the year, (Allen *et al.,* 1998). It was measured by Campbell-Stocks Sunshine Recorder. The instrument was also used to measure the sunshine duration in hours at the station.

***Air Temperature***

The wet and dry bulb thermometer in a Stevenson Screen, set 2.0m above the ground was used to obtain maximum and minimum temperature indicating the solar radiation absorbed by the atmosphere and the heat emitted by the soil.

***Relative Humidity RH%***

The relative humidity describes the amount of water vapor in a mixture of air and water vapor, was measured using the wet bulb thermometer in the Stevenson Screen from the equation

$$RH\ (\%) = 100\left(\frac{(e_a)}{e^o\ (T)}\right) \quad (3)$$

Where:

RH (%) = relative humidity in % saturated pressure

($e_a$) = actual vapor pressure at the temperature T

$e^o(T)$ = saturation vapor pressure at temperature T

The values obtained in equation 3, are used in calculating the actual vapour pressure in equation 6.

***Wind Speed, $u_2$***

The wind speed was measured by an anemometer set at the height of 2.0 m above the ground at the Agromet Station of NRCRI, Umudike. The $u_2$ values are substituted in equation 14 for evaluating the $ET_o$.

### *2.4 Atmospheric Parameters*

***Atmospheric Pressure (P);*** the pressure exerted by the weight of the earth's atmosphere is calculated by

$$P = 101.3\left(\frac{293-0.0065Z}{293}\right)^{5.26} \quad (4)$$

Where: P= atmospheric pressure ($kP_a$)

Z = elevation above sea level (m)

This value is constant and a function of the altitude of the location. It is substituted in equation 8 to obtain the psychometric constant, γ.

***Actual Vapor Pressure ($e_s$):*** The saturation vapor pressure is related to air temperature and is calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperature. That is

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \quad (5)$$

Where:

$$e^o\ (T_{max}) = 0.6108 \exp\ [(17.27)(T_{max})/(T_{max} + 273.3)]\ ^0kP_a \quad (5a)$$

And

$$e^o\ (T_{min}) = 0.6108 \exp\ [(17.27)(T_{min})/(T_{min} + 273.3)]\ ^0kP_a \quad (5b)$$

***Actual Vapor Pressure from relative Humidity***: is used in the calculation using the equation below:-

$$e_a = [(e^o\ (T_{min})(RH_{max}/100) + (e^0T_{max})(RH_{min}/100)]/2 \quad (6)$$

Where:

$e_a$ = actual vapor pressure ($kP_a$)

$e^0(T_{min})$ = saturation vapor pressure at daily minimum temperature ($kP_a$)
$e^o (T_{max})$ = saturation vapor pressure at daily maximum temperature ($kP_a$)
$RH_{max}$ = maximum relative humidity (%)
$RH_{min}$ = minimum relative humidity (%).
The values of $e_a$ and $e_s$ are substituted in equation (14) to determine the $ET_o$.

***Slope of Saturation Vapor Pressure Curve (Δ)*** as it relates to temperature required for the calculation of reference evapotranspiration $ET_o$, in equation 14, is given by

$$\Delta = \frac{4098(0.6108 \exp\ [\frac{17.27T}{T+237.3}]}{(T+237.3)^2} \quad (7)$$

Where: Δ = slope of saturation vapor pressure curve at air temperature T ($kP_a\ {}^0C^{-1}$)
T = air mean temperature ($^0C$)
Exp $[\frac{17.27T}{T+237.3}]$ = 2.7183 (base of natural logarithm) raise to power $[\frac{17.27T}{T+237.3}]$

***Psychometric Constant,*** ϒ, is given by

$$\gamma = \frac{C_pP}{\varepsilon\lambda} = 0.665x10^{-3}P \quad (8)$$

Where ϒ = psychometric constant [$kP_a\ {}^0C^{-1}$]
P = atmospheric pressure [$kP_a$]
λ = latent heat of vaporization, 2. 45 [MJ $Kg^{-1}$]
$c_p$ = specific heat at constant pressure, $1.013x10^{-3}$ [MJ $Kg^{-1}\ {}^0C^{-1}$]
ε = ratio molecular weight of water vapor/dry air = 0.622.
The value is constant because it is the function of altitude and susbsituted in equation 14 for $ET_o$ determination.

***Net Radiation at the Crop Surface ($R_n$) (MJ $m^{-2}$ $day^{-1}$)***
Solar radiation can be measured with pyranameters, radiometers or solarimeters with sensors installed on a horizontal surface that measure intensity of total solar radiation. In our study it was measured by estimation of the duration of bright sunshine using Campbell-Strokes Sunshine Recorder.

Net Radiation is the balance between energy absorbed, reflected and emitted by the earth's surface or the difference between the incoming net shortwave ($R_{ns}$) and the net outgoing long wave ($R_{nl}$) radiation. That is:-

$$R_n = R_{ns} - R_{nl} \quad (9)$$

Where $R_n$ = net radiation ($MJm^{-2}d^{-1}$)
$R_{ns}$ = net short wave radiation
$R_{nl}$ = net outgoing long radiation,
$R_n$ value, equation 9, is substituted in equation 14 in determinig $ET_o$.

***Net Solar or Net Shortwave Radiation ($R_{ns}$) $MJm^{-2}d^{-1}$)***
This is the radiation resulting from the balance between incoming and reflected solar radiation and is given by

$$R_{ns} = (l - \alpha\ ) R_s \quad (10)$$

Where:
$R_{ns}$ = net solar or net shortwave radiation (MJ $m^{-2}d^{-1}$)
α = albedo or canopy coefficient, taken as 0.23 for the hypothetical grass reference crop, dimensionless
$R_s$ = incoming solar radiation ($MJm^{-2}d^{-1}$)
The $R_{ns}$ is substituted in equation 9 to obtain the net radiation at the crop surface $R_n$

***Net long wave radiation ($R_{nl}$) (MJ $m^{-2}d^{-1}$)***
This is the long wave energy flux leaving the earth's surface and is proportional to the absolute temperature of the surface raised to the fourth power, and is calculated by the equation,

$$R_{nl} = G\left\{\frac{T_{max}K^4 + T_{min}K^4}{2}\right\}\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{Rs}{R_{so}} - 0.35\right) \quad (11)$$

Where:
σ = Stefan Boltzmann constant ($4.903x10^{-9}MJK^{-4}m^{-2}day^{-1}$)
$T_{max\ K}$ = maximum absolute temperature during the 24 hours period [
K= $^0C$ + 273.16],
$E_a$ = actual vapor pressure [$kP_a$]
$R_s/R_{so}$ = relative shortwave radiation (limited to ≤ 1.0)
$R_s$ = measured or calculated solar radiation [MJ $m^{-2}$ $day^{-1}$]
$R_{so}$ = calculated clear sky radiation [MJ $m^{-2}day^{-1}$].
$R_{so}$ = (0.75 + $2x10^{-5}z$) Rs [MJ $m^{-2}day^{-1}$]
Z = station elevation above sea level (m).

The values of ($a_s$ + $b_s$), the fraction of extraterestrial radiation reaching the earth on clear-sky days (n-N) is not calibrated. Value $R_{nl}$ obtained from equation 11 is used in equation 9 for $R_n$, the net radiation.

***Soil Heat Flux (G)***
The soil heat flux, G, is the energy used in heating the soil. It is small when compared to the net radiation, $R_n$, particularly when the soil is covered with vegetation. However the quantity of heat conducted into the soil, G, can be measured with systems of soil heat flux plates, thermocouples or thermistors. The simple procedure used in calculating it is given by (Allen *et al.,* 1998) as:

$$G = C_S \frac{Ti - Ti-1}{\Delta t} \Delta z \quad (12)$$

Where: G = soil heat flux (MJ $m^{-2}$ $day^{-1}$)

$C_s$ = soil heat capacity (MJ $m^{-2}day^{-1}$)
$T_i$ = air temperature at time i ($^0$c)
$T_i$ = air Temperature at time i-l ($^0$C)
$\Delta_t$ = Length of time interval (day)
$\Delta_z$ = Effective soil depth (m)

For monthly periods and assuming a constant soil heat capacity of 2.1MJ $m^3$ $^0C^{-1}$ and an appropriate soil depth (Allen et al 1998) derived the G as

$G_{month, i} = 0.07\,(T_{month\ i+l} - T_{month\ i+l})$ (13)

or if $T_{month\ i+l}$ is unknown

$G_{month,\ i} = 0.14\,(T_{month,\ i} - T_{month\ i\text{-}l})$

Where: $T_{month\ i}$ = mean air temperature of month, í ($^0$C)
$T_{month\ i\text{-}l}$ = mean air temperature of previous month ($^0$C)
$T_{month\ i+l}$ = mean air temperature of next month ($^0$C)

In this study, soil heat flux is neglected as it is comparatively very small as also found by Isikwue *et al.* (2014).

### *2.5 Model Used and Analysis of Data*

The model used for the evaluation of the reference evapotranspiration $ET_o$ was FAO 56 Penman-Monteith (PM ) model, equation 14. The data obtained in Section 2.2 were them synthesied to conform to the imputs required in the FAO 56 PM model for $ET_o$ computation given the proceedure adopted in Allen *et al.* (1998) and Zotarelli *et al.* (2010). Determination of the FAO-56 Penman-Monteith reference evapotranspiration $ET_o$, was obtained by substituting the values of $e_s$, $e_a$, $\Delta$ ,γ , $R_n$, from equations 7, 8, 6, 5, 9, the mean temperature, T, and the wind speed $u_2$, into the equation 14.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (14)$$

Where: $ET_o$ = reference evapotranspiration, [mm $day^{-1}$]
$R_n$ = net radiation at the crop surface, (MJ $m^{-2}$ $day^{-1}$)
G = soil heat flux density, (MJ $m^{-2}$ $day^{-1}$)
T = air temperature at 2 m height, ($^0$C)
$u_2$ = wind speed at 2 m height, ($ms^{-1}$)
$e_s$ = saturation vapor pressure, (kPa)
$e_a$ = actual vapour pressure, (kPa)
$e_s$-$e_a$ = saturation vapour pressure deficit, ($kP_a$)
Δ = slope vapour pressure curve, ($kPa^0C^{-1}$)
ɣ = psychometric constant, (kPa $^0C^{-1}$)

### *2.6 Crop Evapotranspiration Study with Lysimeter*

A comparative study of crop evapotranspiration, $ET_a$, of waterleaf (Talium triangulare) plant using a weightabe lysimeter at Umudike, done by Obioma *et al.,* (2015) was reviewed. The growth period was 15th July to 18th August, and four methods; Blaney-Morin Nigeria, Blaney-Criddle, Modified Hargreaves-Samani and Pan Evapotranspiration, were compared with that of the lysimeter. Their report was compared with $ET_o$ results using FAO 56 Penman-Monteith method..

## 3. RESULTS AND DISCUSSIONS.

### *3.1 Computational Results.*

***Table 1: Monthly means of daily climatic data at NRCRI, Umudike, (1996-2005) and $ET_O$ by FAO-56 PM***

| (1) Month | (2) Max Temp (°C) | (3) min. temp (°C) | (4) Mean Temp (°C) | (5) max.Rel humidity (%) | (6) Min Rel humidity (%) | (7) Mean Rel humidity (%) | (8) Radiation(MJm-2day-1) | (9) Sunshine (hour) | (10) wind speed (ms-1day-1) | (11) rainfall (mm) | (12) ETo (mmday-1) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 32.5 | 21.5 | 27.0 | 57 | 38 | 47.5 | 3.8 | 4.8 | 27.9 | 9.1 | 13.0 |
| Feb. | 34.3 | 22.8 | 28.6 | 58 | 42 | 50.0 | 5.4 | 4.7 | 26.8 | 44.5 | 13.1 |
| Mar. | 33.9 | 23.4 | 28.7 | 70 | 53 | 61.5 | 4.9 | 4.2 | 30.7 | 86.6 | 10.7 |
| Apr. | 32.7 | 23.7 | 28.2 | 77 | 60 | 68.5 | 4.7 | 4.6 | 30.7 | 192.4 | 7.8 |
| May | 32.1 | 23.2 | 27.7 | 79 | 65 | 77.0 | 4.4 | 5.0 | 26.6 | 248.3 | 7.2 |
| Jun. | 30.4 | 23.0 | 26.7 | 82 | 69 | 75.5 | 3.3 | 4.0 | 27.9 | 325.4 | 6.1 |
| Jul. | 30.4 | 23.2 | 26.8 | 85 | 72 | 78.0 | 2.2 | 2.6 | 28.6 | 306.7 | 5.3 |
| Aug. | 28.6 | 22.5 | 25.6 | 85 | 74 | 79.5 | 2.1 | 2.6 | 35.4 | 346.7 | 5.0 |
| Sep. | 29.1 | 22.5 | 25.8 | 84 | 72 | 78.0 | 3.2 | 2.7 | 28.7 | 322.3 | 5.9 |
| Oct. | 30.6 | 22.6 | 26.6 | 79 | 70 | 74.5 | 3.2 | 3.7 | 23.6 | 273.3 | 6.1 |
| Nov. | 31.9 | 22.1 | 27.0 | 75 | 63 | 69.0 | 5.0 | 4.5 | 23.5 | 54.8 | 7.3 |
| Dec. | 30.9 | 22.8 | 26.8 | 69 | 49 | 59.0 | 4.3 | 5.3 | 26.1 | 4.3 | 9.8 |

***Table 2: Calculated $ET_o$ and Waterleaf Crop Evapotranspiration 15th July-18th August.***

| | |
|---|---|
| Calculated $ET_o$ with FAO 56 PM 15th July-18th August | 180.10mm |
| Lysimeter crop evapotranpiration $ET_a$ for waterleaf | 141.32mm |

$$K_c = \frac{ETa}{ETo} = 0.785 \quad (15)$$

***3.2 Overall Results.***

Table 1 shows the average monthly processed climatic parameters from January to December, in columns 1-11, and the average monthly calculated $ET_o$ values for Umudike using FAO-56 PM in column 12. The monthly average $ET_o$ values by FAO 56 Penman-Monteith (PM) method were 13.0, 13.1, 10.7, 7.8, 7.2, 6.1, 5.3, 5.0, 5.9, 6.1, 7.3, and 9.8 mm/day for January to December respectively. Table 2 gives the result of the research done at Umudike using a lysimeter to determine the crop evapotranspiration, $ET_a$ of waterleaf by Obioma *et al.* (2015). $ET_o$ and $ET_c$ are related by a crop coefficient (equations 1 and 2). The lysimeter evapotranspiration,$ET_a$, was 141.32 mm for the 35 days of growth, while calculated $ET_o$ from FAO 56 PM was 180.10mm

***3.3 Discussions.***

From the results in Table 1, it is observed that the $ET_o$ is high during the dry season from November to April with peak in February of 13.0 mm/day, while it is low during the rainy season, the lowest being in August with 5.0 mm/day. The mean air temperature, radiation and sunshine hours are high in the dry season when the $ET_o$ are high, and low in the rainy season and lowest in August when the $ET_o$ has the lowest value.

Winds transport water vapour thereby produce more storage of vapour in the vicinity. The highest wind speed of 35.4 $ms^{-1}day^{-1}$ (Table 1, column 10) occurs in August when the $ET_o$ attains its lowest value. Low windspeeds are witness in the dry season between October and March. The associated cooling effect of the wind as it accelarates, may lead to condensing of water vapour, cloud formation, reduction of sun shine and precipitation. High wind speeds could reduce $ET_o$, while low winds may enhance $ET_o$.The highest mean relative humidity of 79.5% (Table 1, column 7) occurs in August when the $ET_o$ of 5.0 $mmday^{-1}$; and its lowest of 47.5% and 50.0% in January and February with high $ET_o$ of 13.0 and 13.1 $mmday^{-1}$, respectively.. In the study, the highest mean monthly rainfall of 35.4 mm (Table 1, column11) occured in August. It could be the cause for the reduction of sunshine hours to its lowest , 2.6 hours and mean air temperature to 25.6 $^0$C, its lowest for the year. Rainfall therefore, has a reductive effect on the $ET_o$. Windspeed, humidity and rainfall are low when $ET_o$ are high, and the converse also..

The highest radiation of 5.4 $MJm^{-2}day^{-1}$ ( Table 1,column 8) occurs in Februrary and reduces to 2.1 $MJm^{-2}$ $day^{-1}$ in August. Solar radiation produces the heat energy for evaporation to take place from the earth's surface and the warming of the air temperature. Its high and low points correspond the the high and low of $ET^o$. The mean air temperature (Table 1, column 4 ) has the high points and low points in the same period as $ET_o$. The high occured in February and March of 28.6 $^0$C and 28.7 $^0$C respectively, while the low was 25.6 $^0$C in August. Mean monthly sunshine hours (Table 1, column 9) show similar pattern as radiation. Higher sunshine values, have high $ET_o$ values. The result in Table 1 show that increase in radiation, sunshine hours and air temperature leads to increase in $ET_o$. The three climatic parameters contribute to the reference evapotranspiration, $ET_o$ in the study area. Table 2, gives the result of a study done at Umudike by Obioma *et al.*(2015) to determine the crop evapotransspiratio, $ET_a$, of waterleaf from 15th July to 18th August using a lysimeter. $ET_o$ from our study, for the same period was 180.10 mm, while the crop water requirement was 141.32 mm. From equation 1 and 2, $ET_o$ is greater than $ET_a$. If there was no error in the development and calibration of the lysimeter, the crop coefficient, $K_c$, is 0.785 as in equation 15.

**4. CONCLUSION.**

From this study:

1. The average monthly $ET_o$ values obtained for Umudike, Nigeria, are 13.0, 13.1, 10.7, 7.8, 7.2, 6.1, 5.3, 5.0, 5.9, 6.1, 7.3, and 9.8.mm/day for January to December, repectively. The results indicate that the lowest average monthly $ET_o$ of 5.0 mm/day was in August, while Feburary has the highest $ET_o$ of 13.1mm/day.
2. The $ET_o$ values are high when radiation, sunshine hours and air temperature are also

high, their low values correspond to low $ET_o$ values. High values of humidity, windspeed and rainfall have low $ET_o$ values.

3. The comparative study with lysimeter in the same study area, indicates that the $ET_o$ values derived using FAO 56 (PM) method at Umudike, are practicable and usuable.
4. The results of $ET_o$ from FAO 56 PM method in this study, are recommended for computing $ET_c$ for irrigation projects in this location in Nigeria.

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