American Journal of Sciences and Engineering Research

E-ISSN -2348 – 703X, Volume 8, Issue 1, 2025

Assessment of Six Evapotranspiration Models for Umuahia Local Government Area, Abia State

Tom, Cyprian N.[1], Gam, Eunice N.[1] , Edet, Joseph A.[2]

[1]*Department of Agricultural and Environmental Engineering, Rivers State University, Portharcourt, Rivers State, Nigeria.*
[2]*Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.*

ABSTRACT: *Penman-Monteith (PM), Priestly Taylor (PT), Blaney-Morin Nigeria (BMN), Jensen-Haise (JH), Hargreaves-Samani (HS) and Thornthwaite (TH) models were used to estimate Reference Evapotranspiration (RET) for Umuahia, in South-Eastern Nigeria from 1997to 2017. The Penman-Monteithmodel was chosen as a standard for evaluating the other five empirical models. Good correlation was found between the RET values, estimated by each of the five radiation and temperature based models and the Penman-Monteith model, although there were some discrepancies. The mean annual RET estimated by the Penman-Monteith model as the standard tool for Umuahia was found to be 1041.0mm. While the mean annual RET estimated by other five models were found to be 579.3mm, 1487.7mm, 513.7mm, 1543.3mm and 1367.7mm, respectively. Conversely, the weather parameters influencing this station were found to be high due to the flatness of the terrain. In addition, from the statistical regression analysis, Priestly Taylor (PT) had the highest T-scores and lowest Root Mean Square Error (RMSE), in the ranking the Thornthwaite, Blaney-Morin and Hargreaves-Samani predicted best among the five models in the station. Good correlation was found by the temperature based models when evaluated RET with data for Umuahia Station. The Penman-Monteith estimates was used to develop correction factors for the three models that predicted best in the station for their potential use in the areawithout sensitive error. This was done in order to achieve accurate and reliable evapotranspiration estimate.*

KEYWORDS: *Assessment, Evapotranspiration, Models*

I. INTRODUCTION

Evaporation is the process of water changing from its liquid phase to the vapour phase. Above the water surfaces are water molecules in the form of water vapour which are always found above liquid water. In addition are oxygen and nitrogen molecules, as well as air. From time to time one of the vapours on the surfaces gets knocked away or evaporates as they are always found moving around. Evaporation occurs when molecules of water attain high kinetic energy to eject themselves from the water surface into the atmosphere. The amount of energy used by a unit mass of water from the liquid state to the vapour state at constant temperature is known as the latent heat of evaporation, which is above 585 calories per gram. If no external source of energy is available, heat energy is extracted from water body and, consequently, it results in lowering of the water temperature (Anyanwu et al., 2016).

According to Flanagan and Johnson (2005), Vapour molecules continuously leave the water during evaporation. The motion of these molecules produces a pressure on the water surface, which is known as vapor

 Received-11-12-2024, Accepted- 30-12-2024

pressure. Thus the vapour pressure is due to vapour molecules present in air. If there is continuous supply of heat energy, more and more molecules accumulate, and finally a stage is reached when the air above the free surface becomes saturated with vapours and it cannot accommodate more vapours. The partial pressure exerted by the water vapours at that stage is called the saturation vapour pressure (e_s). The saturation pressure increases with an increase in temperature. If the vapour pressure in the air above the water surface remains less than that of the water surface, evaporation continues. As soon as the vapour pressure reaches the saturation vapour pressure, evaporation stops.

According to Dalton's law, the rate of evaporation depends on the difference between the saturation vapour pressure and the vapour pressure in the air above.

Thus,

$$E_a = C\,(e_s - e_a) \tag{1}$$

Where

E_a is the rate of evaporation (cm/day),

e_s is the saturation vapour pressure,

e_a is the vapour pressure in the air at about 2 m above the water surface and

C is a coefficient that depends on barometric pressure, wind velocity, etc.

For evaporation to continue, the following three conditions should be satisfied, there should be a constant supply of water, constant supply of heat, and a vapour deficit. Evaporation shall continue till $e_a = e_s$. On the other hand, if e_a is greater than e_s, condensation will take place. In that case, more molecules return to the water surface than those that leave it. (Arora, 2002).

Transpiration is a process through which water vapour passes into the atmosphere through the tissue of living plants. In areas where plants are grown, water vapour passes into the atmosphere by evaporation from the soil surfaces and by transpiration from plants. Plants obtain their water requirements from the soil through their roots. Because of the attraction of water by colloidal cell material of the plant, water is absorbed into the root hairs. This process of absorption of water is called imbibition. Water absorbed by the roots is utilized to meet water need of the plant body or transpired to the atmosphere as water vapour through the stomata of the leaves of the plants. Transpiration mainly occurs during daylight hours.

The rate at which a plant absorbs moisture from the soil depends on the capacity of the soil to provide water to the plant roots. Moreover, the plant roots can never remove the water completely from the soil. The water content of the soil when the plant ceases to extract water is called the wilting coefficient. Plants require a large quantity of water for their growth. The rate of transpiration depends upon the growth period of the plant. Transpiration ratio is the ratio of the total weight of water transpired during the entire growth period to the weight of dry matter produced by the plant. Thus,

$$\text{Transpiration Ratio} = \frac{\text{Weight of water transpired}}{\text{Weight of dry matter produced}} \tag{2}$$

The transpiration ratio for most crops varies from 300 to 800 (Arora,2002).

Evaporation *(E_a)* and transpiration *(T_p)* are the two most important processes governing removal of water from the land into the atmosphere. These processes occur simultaneously, and are hard to distinguish from each other (Allen et al., 1998).

According to Allen et al., (2007), considerable interaction exists between the two processes, evaporation and transpiration. The term evapotranspiration *(ET)* was coined to define the total loss of water from an area. While occurring simultaneously, *Ea* is governed by the availability of water in the topsoil and the fraction of solar radiations reaching soil surface. The amount of solar radiation reaching soil surface varies with the degree of crop shading. Transpiration *(Tp)* on the other hand is a function of crop canopy and soil water status. *Ea* has been

found to dominate the *ET* by as much as 100% during early stages of crop growth while *Tp* contributes to nearly 90% of the ET for a fully matured crop (Allen et al., 1998).
According to Liu et al. (2000) reported that soil *Ea* constitutes nearly 30% of the total *ETc* for winter wheat. A similar study by Kang et al. (2003) found that *Tp* accounted for 67% and 74% of seasonal *ETc* for wheat and maize respectively, grown under semi humid conditions. *ET* can be classified into: reference evapotranspiration *(ETo)* and crop evapotranspiration *(ETc)* (Allen et al, 1998). The evapotranspiration rate is normally expressed in millimetres (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year. As one hectare has a surface of 10 000 m^2 and 1 mm is equal to 0.001 m, a loss of 1 mm of water corresponds to a loss of 10 m^3 of water per hectare.

1.1 TYPES OF EVAPOTRANSPIRATION

1.1.1 Reference Evapotranspiration (ET_O)

ET_o is a representation of the Ea demand of atmosphere, independent of crop growth and management factors (Allen et al., 1998). It can be estimated from the weather data (Allen et al., 1998).
Allen et al., (2007), define ET_o as "the rate of ET from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground". ET_o determines the loss of water from a standardized vegetated surface, which helps in fixing the base value of ET specific to a site.
ET_o can be estimated by measuring the open water surface evaporation from an evaporation pan. Open water Ea incorporates the effects of temperature, humidity, wind speed and solar radiation. Pan evaporation coupled with the use of a calibrated pan coefficient *(Kp)* to relate *Ea* with the standard vegetative surface, can provide good estimates of *ETo*, provided that soil water is readily available to the crop (James, 2008). Some of the commonly used pans are: Class-A Evaporation pan and Sunken Colorado pan. However, pan evaporation method requires regular maintenance of the evaporation pan and the vegetation around it. Also, unavailability of regional pan coefficient can limit the accuracy of *ETo* estimates. Alternatively *ETo* can be estimated from meteorological data using empirical and semi-empirical equations. Numerous empirical methods have been developed to estimate evapotranspiration from different climatic variables. Examples of such methods include Penman-MonteithMethod and Blaney-Criddle Method. One of the most important factors governing the selection of a method is the data availability. For instance, Blaney-Criddle only requires the temperature data while the Penman-Monteith requires additional parameters such as wind speed, humidity, solar radiation. In addition, since the Blaney-Criddle method is used to calculate monthly *Kc* values as compared to daily, less data is needed for this method. Several studies have been conducted over the years to evaluate the accuracy of different *ETo* methods. Most of these studies have concluded that Penman-Montieth equation in its different forms provides the best *ETo* estimates under most conditions. Therefore, the Food and Agricultural Organization *(FAO)* recommended FAO-Penman Monteith *(FAO-PM)* method as the sole standard method for computation of *ETo* (Allen et al., 1998).

1.2 CROP EVAPOTRANSPIRATION

The actual crop water use depends on climatic factors, crop type and crop growth stage. While *ETo* provides the climatic influence on crop water use, the effect of crop type and management is addressed by *ETc.* Factors affecting *ETc* such as ground cover, canopy properties and aerodynamic resistance for a crop are different from the factors affecting reference crop (grass or alfalfa); therefore, *ETc* differs from *ETo*. The characteristics that distinguish field crops from the reference crop are integrated into a crop factor or crop coefficient *(Kc). Kc* is used to determine the actual water use for any crop in conjunction with *ETo*. (Allen et al., 1998)
The main purpose of the research reported in this paper is to compare and evaluate the reliability of the five approximate RET prediction models as compared to the standard Penman-Monteith (PM) model using data collected for Umuahia in South-Eastern Nigeria. The mean monthly and annual RET values estimated by the five

methods were compared with estimates by the standard PM method. The objective for such comparison is to examine the relationships and to determine the method that best predicted RET as compared to the PM method. The second objective was to evaluate the reliability of the methods when data from nearby stations are used for estimating RET. Thirdly, monthly correction factors for adjusting the models that predicted best were developed for their potential use at the study site.

II. MATERIALS AND METHODS

In determining the reliability studies of six evapotranspiration models for Umuahia in South-Eastern Nigeria, six different models (one combination: Penman-Monteith; two radiation based: Priestly Tylor and Jensen Haise and three temperature based: Hargreaves- Samani, Thornthwaite (TH) and Blaney- Morin Nigeria were used to estimate RET in Umuahia. Meteorological data were assembled and collected from meteorological stations distributed all over the study area from 1997-2017 with the assistance of staff in the computer units of Nigerian Meteorological Agency (NIMET) Lagos state. The parameters to be collected are mean monthly values of air temperature including maximum and minimum temperatures, sunshine hours, wind speed, vapour pressure, relative humidity and rainfall. The short- wave radiation(Rn), Stefan- Boltzman constant ($\delta T a 4$), black body radiation(δ TK4), rate of change of temperature with saturation vapour pressure (ea), Extra- terrestrial radiation (Ra), mean daily maximum duration of bright sunshine hours (N) and Psychometric coefficient (ᵞ) were obtained from meteorological monograph. The mean monthly RET were computed for each month using weather data for the month in the RET equation. Regression and correlation analysis were performed to examine the relationships of the mean monthly RET estimates from the five methods and the mean monthly estimates by the standard Penman-Monteith method.

The Root Mean Square Error (RMSE) parameter was used to indicate the goodness of fit of RET estimates as compared to the standard of PM method without any adjustment. The conclusion was further verified by calculating a t-statistics for each of these models as suggested by Jacovides and Kontaytinanis(1995). These authors suggested that the t-statistics should be used in conjunction with the RMSE to better evaluate a model's performance.

III. RESULTS AND DISCUSSION

Table 1: Long Term (1997-2017) Mean Monthly Weather Parameters for Umuahia Station.

Month	J	F	M	A	M	J	JL	A	S	O	N	D
TMAX	26.3	33.7	30.0	30.2	28.2	26.6	29.6	26.4	27.3	30.7	29.6	31.3
TMIN	17.3	22.0	20.0	22.0	21.7	21.2	21.9	18.6	19.7	21.0	21.4	19.7
AVET	21.8	27.9	25.0	26.1	25.0	23.9	25.8	22.5	23.5	25.9	25.5	25.5
RAIN.F (mm)	23.5	37.2	90.0	168.7	245.0	300.2	374.1	316.9	356.7	249.0	53.0	6.9
SUNHRS (W/m^2)	1.9	2.3	1.7	1.8	2.2	1.1	0.9	0.7	1.0	1.3	2.1	2.0
RH (	53.3	59.4	66.3	72.9	75.6	71.4	79.0	83.5	82.2	79.4	71.1	61.3
VAP (mb)	21.5	25.6	27.7	29.4	29.3	26.5	26.8	28.2	29.2	29.4	28.8	25.5
WID Speec (mph)	90.2	99.2	122.5	112.7	131.1	105.3	117.3	151.1	124.1	122.1	110.8	112.0
Ra	14.6	15.2	15.6	15.6	15.1	14.6	14.8	15.2	15.3	15.2	14.7	14.4
Rs	3.0	3.4	3.1	3.1	3.2	2.5	2.4	2.3	2.5	2.7	3.1	3.0
Rs/A	0.08746	0.09912	0.09037	0.09379	0.09329	0.07288	0.06997	0.06705	0.07288	0.07871	0.09037	0.08746

Table 2: Mean monthly and Annual RET estimated by different methods for Umuahia Station

Mont	BMN	HS	JH	PM	PT	TH
J	165.5	124.1	40.3	80.9	41.7	82.6
F	170.6	135.3	55.9	82.0	51.8	130.8
M	152.7	152.1	54.6	101.2	54.6	131.1
A	130.9	135.3	48.7	89.9	54.7	131.5
M	129.8	129.1	48.4	102.5	56.8	124.3
J	102.0	95.6	27.2	92.5	41.0	98.8
JL	91.0	127.5	37.4	92.5	45.8	131.8
A	72.8	115.3	28.4	84.5	40.9	90.1
S	80.2	120.2	32.6	73.1	43.0	92.8
O	101.2	137.8	43.1	82.3	49.8	119.9
N	133.8	125.8	46.1	74.9	51.7	118.2
D	157.2	145.4	51.2	84.9	47.5	115.5
Annual	1487.7	1543.3	513.7	1041.0	579.3	1367.7

Table 3: Results of the regression analysis of mean monthly RET estimated by five methods against that estimated by Penman Modified RET methods for Umuahia station.

Estimation Method	Regression Equation	R	RMSE	T-Value	P
BMN	PM = 1.13 + 0.696 BMN	0.996	24.56	19.5	0.000
HS	PM= 0.18 + 0.674 HS	0.999	12.33	52.5	0.000
JH	PM = 0.74 + 2.01 JH	0.997	20.22	51.0	0.000
PT	PM = 0.14 + 1.81 PT	0.999	10.77	68.3	0.000
TH	PM = 0.27 + 0.761 TH	0.999	12.92	30.1	0.000

Table 4: Results of Comparative Statistics of Penman Modified RET Prediction by five methods for the period 1997-2017 for Umuahia station using Actual Data

	BMN	HS	JH	PT	TH
Total Annual RET (mm)	1487.7	1543.3	513.7	579.3	1367.7
Intercept	1.13	0.18	0.74	0.14	0.27
Slope	0.70	0.67	2.01	1.81	0.76
T-Value	19.5	52.5	51.0	68.3	30.1
P-Value	0.00	0.00	0.00	0.00	0.00
R	0.996	0.999	0.997	0.999	0.999
R-Sq. (%)	99.20	99.80	99.50	99.80	99.80
RMSE	24.56	12.33	20.22	10.77	12.92
F-Value	1396.4	5569.67	2062.24	7308.52	5062.99

3.1 DISCUSSION

The mean monthly and mean annual RET obtained by averaging the monthly and annual values across the period of record for the station is summarized in Table 2.The mean annual RET estimated by the Penman modified model as the standard tool for Umuahia was found to be 1041.0mm. While the mean annual RET estimated by other five models were found to be 579.3mm, 1487.7mm, 513.7mm, 1543.3mm and 1367.7mm respectively. Blaney Morin Nigeria (BMN), Hargreaves-Samani (HS) and Thornthwaites (TH) overestimated the Penman-Monteith (PM) RET which was used as a standard by 43%, 48% and 31% respectively while Jensen- Haise(JH) and

Priestly Taylor (PT) under-estimated the Penman modified (PM) RET by 51% and 45% respectively. It was suspected to be partly due to high climatic parameters and flatness of the region.

The summary of statistics for regression of mean monthly RET estimated by each of the five methods against that estimated by the standard Penman-Monteith method is presented in Table 3. The best method for estimating RET (as stated in the methodology) compared to Penman-Monteith method is the one with intercept value closest to zero, regression slope value closest to 1.0, the smallest RMSE and t-statistics values and the highest co-efficient of simple determination with greater emphasis on the RMSE and t-statistics values. Based on these results, Thornthwaite model, Blaney-Morin Nigeria model and Hargreaves-Samani model ranked first , second and third respectively with the lowest RMSE and t- score for RET predictions in Umuahia Station.

The degree of fit of the regression on a monthly basis improved considerably from that achieved with the measured weather data for same period. The Thorn Thwaite model again performed better as there was significant improvement in all most all of its statistical parameters compared to other models since it ranked first in the station, most especially to that of radiation based. Hence, it is important to note that the positive results achieved highlighted above was probably due to a strong correlation of temperature obtained by using empirical relationships with data from the stations.

A graphical representation was equally considered for the station to best showcase or ascertains the relationships among the models. Also, it was clearly showed that the temperature based models predicted and performed better than that of radiation based models.

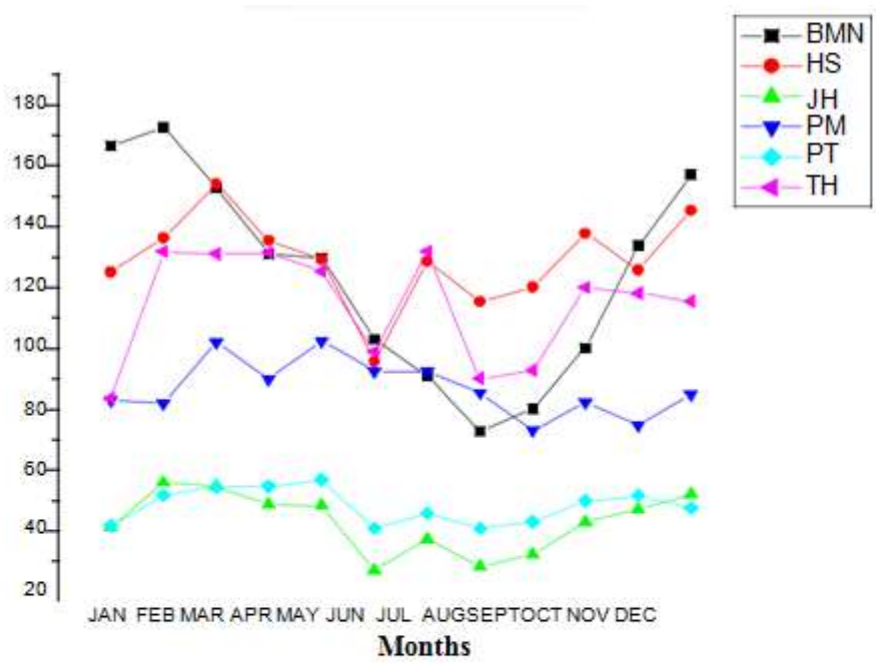

Fig. 1: Graph of mean monthly annual reference evapotranspiration estimated by different methods for Umuahia station.

IV. CONCLUSION

Based on the mean monthly RET estimates, statistical regression analysis and comparative analysis of the results for the station, the estimates of the five different methods (two radiations based: Priestly Taylor and Jensen Haise and three temperatures based: Hargreaves. Samani, Thornthwaite and Blaney-Morin Nigeria) when compared with the one combination; Penman-Monteith (PM) RET which was used as a standard, the following conclusions were drawn from the results of the research.

The mean annual RET estimated by the Penman-Monteith method as the standard for Umuahia was found to be 1041.0 mm. The mean annual RET estimated by the other methods namely Blaney-Morin, Hargreaves-samnai, Jensen-Haise, Priestly-Taylor and Thornthwaites were found to be 1487.7mm, 1543.3mm, 513.7mm, 579.3mm and 1367.7mm for Umuahia, respectively.

From the study, best RET estimate for Umuahia station was given by Thornthwaite model. The temperature based models from the RET estimate obtained was highly reliable since it predicted best and also ranked first in all the analysis for the station. Monthly correction factors were developed for Thornthwiate, Blaney-Morin Nigeria and Hargreaves-Samani since they ranked first, second and third in the station. The reason is to get an accurate and reliable ET without sensitive error. The comparison of methods for estimating RET in different stations is very paramount since the accurate estimation of ET, hence, crop water requirement is highly essential for efficient planning, operation and management of irrigation systems.

From T- tabulated, 22 degrees at freedom and 0.005 significant level was found to be 2.819 which means that the models that predicted best were significant since T-tabulated is less than T-calculated.

V. REFERENCES

1. Allen, R. G. (2000). Using the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration intercomparison study. *Journal of Hydrology. 229, 27–41*.
2. Allen, R.G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy, 300.
3. Allen, R.G., Tasumi, M. and Trezza, R. (2007). Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)-model. *Journal Irrigation Drainage,133, 380-394.*
4. Anyanwu, V., Egwuonwu, C. and Oguoma, O. (2016). Comparative study of evapotranspiration models for owerri. *International Journal of Agricultural and Biosciences.*
5. Arora K.R. (2002). Irrigation water power and water resources engineering. Standard publishers distributors New Delhi 4th edition Reprinted in 2009.
6. Flanagan, L.B. and Johnson, B.G., (2005). Interacting effects of temperature, soil moisture and crop biomass production on ecosystem respiration in a northern temperate grassland. Agricultural and Forest Meteorology 130: 237-253.
7. Food and Agriculture Organization, (2002). *Nigeria country report*. Gateway to Land and Water Information. http://www.fao.org/ag/aGL/swlwpnr/reports/y_sf/z_ng/ng.htm.
8. Jacovides, C. P. and Kontoyiannis, H., (1995). Statistical procedures for the evaluation of evapotranspiration computing models. Agric. Water Manage. 27, 365–371.
9. James, L. G. (2008). Principles of farm irrigation system and design. ED. 1993. New York, NY: John Wiley and Sons.
10. Kang, S., B. Gu, T. Du, and J. Zhang. (2003). Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi humid region. *Agricultural water management 59 (1): 239-254.*
11. Liu, C., Xiying Z., Maozheng, Y. (2000). Determination of daily evaporation and evapotranspiration of winter wheat field by large-scale weighing lysimeter and micro lysimeter. *Journal of Hydraulic Engineering 10*.