Relationship between reference evapotranspiration and some climatic parameters, Umudike, Nigeria

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Abstract: Reference evapotranspiration, ET_o, is important as it is used to determine the evaporative demand of the atmosphere. There is a need for continued studies to determine the reference evapotranspiration of different locations as well as its relationship with various climatic parameters for the prediction of water demands for human and ecological reasons. A study undertaken to determine the relationship between ET_o, obtained using the Food and Agriculture Organization of United Nations, Penman-Monteith (FAO-56 PM) method, and some climatic data in Umudike, Nigerian environment were presented. The climatic parameters considered were solar radiation, sunshine hours and wind speed. The interactions of climatic parameters in the input variables of the ET_o model, were also investigated. Simple linear regression analyses of the ET_o and the climatic parameters of study area were conducted, and correlation coefficients between the ET_o and the climatic parameters were obtained to be +0.676 for solar radiation, +0.673 for sunshine hours, and –0.151 for wind speed. While the population regression coefficients were: +0.234 for solar radiation, +0.0274 for sunshine hours, and +0.0282 for wind speed. The R^2 was 0.976 and the significance F value was 0.000639. The results obtained were compared with results of study by other researchers, and they fitted well.

Keywords: reference evapotranspiration, climate, solar radiation, sunshine hours, wind speed

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1 Introduction

Reference evapotranspiration, ET_o, is a concept to measure the evaporative demand of the atmosphere, independent of the crop type, crop development and management practices (Isikwue et al., 2015). Reference evapotranspiration can be evaluated by direct and indirect methods. Direct methods include lysimeter, atmometers, etc. These methods are associated with high costs and are time consuming. Indirect methods involve using analytical or empirical models such as FAO-56 PM, Blaney-Morin-Nigeria (BMN), Hargreaves (HGRV), and Jensen and Haise (JHSE). In the indirect methods, climatic and meteorological data are used as inputs for evaluating ET_o which are utilized for planning purposes by agriculturists, engineers, hydrologists and environmentalists.

Many models are site and location specific, others reduce the input variables to make for adaptability, peculiarity or cost reduction of input gathering, and the largest number of climatic data are required by the FAO-56 PM model. For accuracy and operational computation of ET_o, and for agricultural and land use types, Pereira et al. (2015) advised the adaptation of FAO-56 PM model which has been successfully utilized globally.

Large investment in irrigation projects development need sound estimates of crop water demands against risk of crop failure due to drought. The Penman-Monteith

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combination equations are found to give the best agreement with measured crop water use in a series of lysimeter experiments across environments (Webber et al., 2016). The study of ET_o by FAO-56 PM method, gives the ultimate assessment for global acceptance.

Scientists have studied relationships of climatic parameters and evapotranspiration. The principal parameters affecting evapotranspiration are solar radiation, air temperature, relative humidity and wind speed (Isikwue et al., 2014). Some studies have reported that some climatic parameters have positive or negative correlation with evapotranspiration and can significantly affect ET_o, depending on their location. Isikwue et al. (2015), did statistical analyses of some climatic parameters and ET_o for three cities of Nigeria. Solar radiation, sunshine hours, air temperature, wind speed and clearness index had positive correlation with ET_o, while relative humidity and cloudiness were negatively correlated with ET_o.

Asaana et al. (2017) reported that potential evaporation showed strong positive correlation with temperature, solar radiation and wind speed, but was strongly negative with relative humidity in the Tono irrigation area in Upper East Region of Ghana. Ma et al. (2017) analyzed the role of ET_o in determining regional wet/dry conditions by regression analysis on the relationship of ET_o, precipitation, P, and the aridity index (AI). ET_o is one vital component of hydrological cycle and controls the energy and mass exchange between terrestrial ecosystems and atmosphere, and is influenced by air temperature and solar radiation. Malekinezhad (2012) found that one climatic parameter had a more pronounced role on the amount of evaporation than others, in Iran. Furthermore, in the coastal warm and humid regions of Iran, air temperature related climatic parameters were the main variables; wind speed was not an important variable on evaporation rate due to the high relative humidity.

Shrivastava et el. (2000) observed that the multiple linear regression equation which includes maximum air temperature, maximum relative humidity, sunshine hours and wind speed gave better estimation of the rate of pan evaporation for Sunderbans, India. Karume et al. (2007) found that relative humidity and maximum air temperature were enough to capture the variability of sunshine hours in Uganda. A multiple analytical model involving the three parameters will give a better interpretation if inter action is indicated.

Mahida and Patel (2015) used a multiple linear regression model and compared the prediction of ET_o of various climatic parameters ET_o combinations in Vadodara district of Gujarat state, India. The combination of maximum air temperature, relative humidity, sunshine hours and wind speed gave the best correlation of predicted ET_o with observed. Purohit et al. (2016) tested the influence of different meteorological variable on evapotranspiration under humid climatic conditions in India. They found that sunshine hours, air temperature, and wind speed had strong and positive correlation with ET_o, but relative humidity was negatively correlated with ET_o. Maximum relative humidity contributes more in ET_o estimation and more emphasis should be given to it, during estimation in humid regions.

Abarikwu et al. (2017) reported the findings on air temperature, relative humidity and rainfall in the Umudike area, Nigeria. This paper reported on the relationships of ET_o with solar radiation, sunshine hours, and wind speed at Umudike, Nigeria. The study investigated the relationship of these climatic parameters with ET_o using linear regression analysis, inter action of these climatic variables in the FAO-56 PM method and the appropriateness of utilizing linear regression analysis in a statistical prediction model for ET_o.

2 Materials and methods

2.1 Location of the study area

Umudike is a town in Ikwuano Local Government Area of Abia State, Nigeria. The town plays host to two federal institutions namely National Root Crops Research Institute and Michael Okpara University of Agriculture. A number of parastatals also have their substation in the town. Some of these parastatals are, National Seed Council, the National Veterinary Research Institute, the Agricultural Extension Research and Liaison Services, etc. Umudike is approximately at an altitude of 122 m above the sea level on latitude 05°29′N and longitude location at 07°33′E, 8 km on Umuahia - Ikot-Ekpene road.

It is 140 km north of Port-Harcourt International airport and 80 km east of Owerri airport. The National Root Crops Research Institute (NRCRI) has very well equipped and reliable Agricultural and Meteorological (Agro Met) Unit. The Agro Met Unit collects and records all the climatic data of maximum and minimum air temperature, maximum and minimum relative humidity, solar radiation, daily sunshine hours, wind speed at 2 ms^{-2} and 5 m s^{-2} heights, and rainfall.

2.2 Data collection

The climatic data used for this study were sourced from NRCRI Agro Met Unit and were inputs in the evaluation of ET_o for Umudike using the FAO-56 PM method and were shown in Table 1.

Table 1 Monthly means of daily climatic data, Umudike and *ETo* by FAO-56 PM

(1) Month	(2) Mean Temp (°C)	(3) Mean rel humidity (%)	(4) Radiation (MJ m^{-2} day^{-1})	(5) Sunshine (hour)	(6) Wind speed ($ms^{-1}day^{-1}$)	(7) Rainfall (mm)	(8) ET_o (mm $^{day-1)}$
Jan.	27.0	47.5	3.8	4.8	27.9	9.1	13.0
Feb.	28.6	50.0	5.4	4.7	26.8	44.5	13.1
Mar.	28.7	61.5	4.9	4.2	30.7	86.6	10.7
Apr.	28.2	68.5	4.7	4.6	30.7	192.4	7.8
May	27.7	77.0	4.4	5.0	26.6	248.3	7.2
Jun.	26.7	75.5	3.3	4.0	27.9	325.4	6.1
Jul.	26.8	78.0	2.2	2.6	28.6	306.7	5.3
Aug.	25.6	79.5	2.1	2.6	35.4	346.7	5.0
Sep.	25.8	78.0	3.2	2.7	28.7	322.3	5.9
Oct.	26.6	74.5	3.2	3.7	23.6	273.3	6.1
Nov.	27.0	69.0	5.0	4.5	23.5	54.8	7.3
Dec.	26.8	59.0	4.3	5.3	26.1	4.3	9.8

Note: Source from Abarikwu and Ekpo (2017).

2.3 Models used and method of analysis

In this study, simple linear regression analyses of ET_o and each climatic parameter were made as indicated in Equation (1) (Devore and Peck, 2001).

$$y = \alpha + \beta x + e \quad (1)$$

where, y = response variable; x = predictor variable; α = constant term; β = regression coefficient; e = random deviation.

In the context of regression analysis, ET_o is the response variable, while the climatic parameters are the predictor variables. The coefficient of determination, r^2, is a measure of the utility of regression equation while, the linear correlation r, gives a descriptive measure of the strength of the linear relationship of the variables (Weiss, 2008). *P*-value is the probability of observing a value of the statistic as inconsistent with the value of the test statistic observed. The smaller *P*-value, shows the stronger the evidence against the null hypothesis. Values of r^2 close to 0, suggest that the regression equation is not useful for making prediction, while r^2 near 1 suggest it is quite useful. A value of r, close to +1 or –1, indicates strong linear relationship positive or negatively of the variables, while a r value closes to 0, indicates a weak linear relationship and poor predictor to response variable.

However, the FAO-56 PM combination equations model for ET_o, has wind speed and solar radiation terms with other climatic parameters as analyzed in the study. A multiple regression analysis is one which includes more than one predictor variable x_1, x_2, x_3, x_k, against a dependent variable, y. The statistical model to predict ET_o may not be linear but a polynomial model. Devore and Peck (2001), gave the model for two independent variables x_1 and x_2, and y dependent variable of a polynomial model, in Equation (2), as:

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + e \quad (2)$$

where, y = dependent variable/population regression function; x_1, x_2, x_3 = predictor variables; β_1, β_2, and β_3 = population regression coefficients; e = random deviation; α = estimate of constant term.

If x_1 and x_2 are interaction variables, i.e. where one is a function of the other, then $x_3 = x_1x_2$.

When x_1 and x_2 do interact, this model will give a much better fit to resulting sample data –and thus explain more variation in y - than would the no-reaction model. Failure to consider a model with interaction, often leads an investigator to conclude incorrectly that there is no strong relationship between y and the set of independent variables (Devore and Peck, 2001).

3 Results and discussions

The summary of the linear regression analysis of each climatic parameter and the ET_o is shown in Table 2. From the Table 2, ET_o is inversely proportional to wind speed and proportional to sunshine hours and solar radiation, implying that increase of wind speed reduces ET_o, while ET_o increases with increase in solar radiation and sunshine hours in Umudike environment. The graphical results and discussions for each climatic variable are in Figures 1 to Figure 3, and section 3.1 to section 3.3 below.

Table 2 Summary linear regression analysis results of ET_o and each climatic parameter

Parameter	r	Regression equation	R^2
Solar radiation	0.676	$y = 1.7872x+1.1829$	0.4583
Sunshine hours	0.673	$y = 2.0124x-0.0587$	0.4533
Wind speed	–0.151	$y = 0.1354x+11.9047$	0.0237

3.1 Relationship between ET_o and solar radiation for Umudike

Figure 1 is the plot of reference evapotranspiration with solar radiation, giving the relationship between ET_o and solar radiation for Umudike. From Figure 1, the ET_o and solar radiation are strongly and positively related. The coefficient of determination is found to be 0.4583 which is an indication that the parameter is important in predicting ET_o value using the model. This result is in agreement with the study by Isikwue et al. (2015), which showed that solar radiation was positive in the three cities of Ibadan, Sokoto and Kano with correlation coefficients of 0.538, 0.340 and 0.678 respectively. Also, Asaana et al. (2017), showed that solar radiation was positively related to potential evapotranspiration in the Toro Irrigation Area, Upper East Region of Ghana. These findings collaborated with Bashir (1991), that in the tropical environment of our study, solar radiation predominated, contributing 50% to 97% of the potential evapotranspiration.

3.2 Relationship between ET_o and sunshine hours for Umudike

Figure 2 gives the relattionship between reference evapotranspiration and sunshine hours for Umudike. As shown in Figure 2, there is a strong positve correlation of reference evapotranspiration with sunshine hours with the correlation of 0.673. The coefficient of determination is found to be 0.4533 indicating the usefulness of this parameters in predicting ET_o value in the model.

Isikwue et al. (2015) studied cleareness index which could be linked with sunshine hours. Cleareness index had positive correlation coefficients of 0.591, 0.700 and 0.818 in Ibadan, Sokoto and Kano respectively. These findings agree with the results of this study.

3.3 Relationship between ET_o and wind speed for Umudike

The relationship between reference evapotranspiration and wind speed in Umudike environment is shown in Figure 3. From Figure 3, the correlation coeffieient is found to be –0.151 which shows that the climatic parameter, wind speed, is negatively correlated to the ET_o values in Umudike. Isikwue et al. (2015), had very weak positive correlation in Sokoto and Kano of 0.164 and 0.031 respectively, while the correlation of 0.608 at Ibadan was strong. The coefficient of determination, in our study, was 0.0237. They were 0.0269 and 0.0096 in Sokoto and Kano but 0.3696 in Ibadan (Isikwue et al., 2015). These values are close to 0, indicating that wind speed is not very useful for prediction of ET_o in Umudike environment, and in Sokoto, Kano.

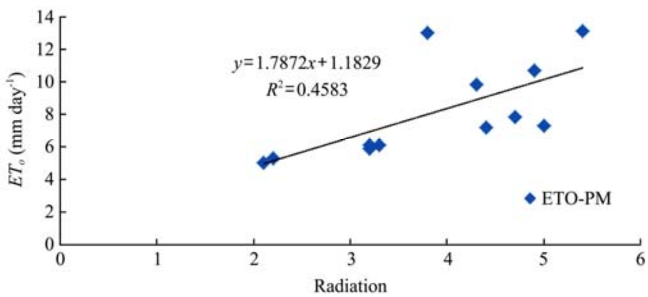

Figure 1 Correlation of solar radiation with ET_o at Umudike

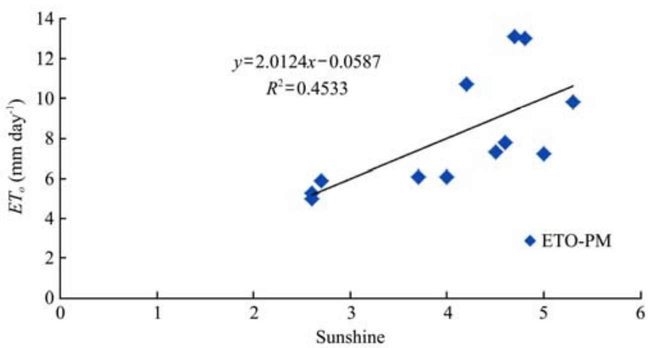

Figure 2 Correlation of sunshine hours with ET_o at Umudike

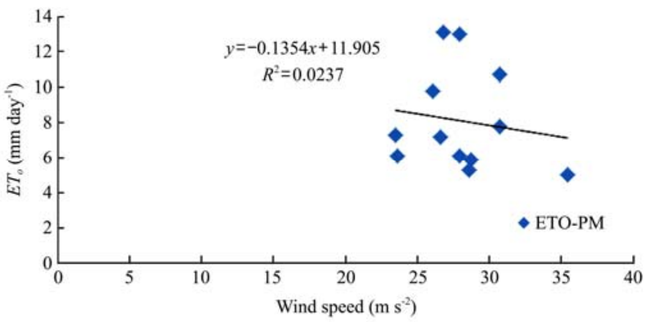

Figure 3 Correlation of wind speed with ET_o at Umudike

3.4 Regression results of ET_o with the population of the climatic parameter acting together

The summary of the ET_o with the population of the climatic parameter acting together are shown in Table 3. When all the climatic parameters were regressed with ET_o values derived using FAO-56 PM model, ET_o is found to be proportional to solar radiation; very weak to sunshine hours and poorly related to wind speed. The population regression coefficients are 0.234, 0.0274 and 0.0282 for solar radiation, sunshine hours and wind speed respectively, and for each unit increase of solar radiation, sunshine hours and wind speed, ET_o will increase by 0.234, 0.0274 and 0.0282 respectively. The significance F is 0.000639 but the P values are high, for these climatic parameters.

Table 3 Results of ET_o regressed with all the climatic parameters in a population regression analysis

Regression statistics		Parameter regression coefficients		P-value
Significance	F 0.000639	Temperature	0.300	0.4572
Multiple	R 0.988	Rel. humidity	–0.256	0.0021
R square	0.976	Radiation	0.234	0.6381
Adjusted R square	0.948	Sunshine	0.0274	0.9470
Standard error	0.651	Wind speed	0.0282	0.7154
Observation	12	Rainfall	0.00326	0.4950

3.5 The interaction of climatic parameters in the regression model

The summary of the investigation into the relationship and interaction of the input climatic variables of the FAO-56 model is presented in Table 4 below. There is a strong relationship of solar radiation with temperature and sunshine hours, the correlation coefficients being 0.8 and 0.806 respectively; their relationships are directly proportional. The relationship of solar radiation with relative humidity is inversely proportional and strong, while windspeeed and relative humidity has a weak direct propotionality. The coefficient of determination of solar radiation versus temperature and that of solar radiation versus sunshine hours of 0.64 and 0.651 respectively, are good indicators of inter action in the model.

Table 4 Summary of relationship and inter action of input climatic parameters in the model

Compared climatic parameters	r, correlation coefficient	Regression equation	r^2
Radiation versus R. humidity	–0.622	y=–0.060x+7.976	0.387
Radiation versus Temperature	0.8	y=–0.872x–19.78	0.64
Radiation versus Sunshine hours	0.806	y=0.913x+0.165	0.651
Temperature versus Sunshine hours	0.613	y=0.637x+24.54	0.376
Temperature versus R. humidity	0.539	y=–0.047x+30.38	0.291
Wind speed versus R. humidity	0.187	y=0.055x+24.29	0.035

4 Conclusions

The following inferences were made from this study:

1. The relationship between reference evapotranspiration ET_o, calcutated using FAO-56 PM method and solar radiation, sunshine hours and wind speed has been established in Umudike area;

2. The reference evapotranspiration, ET_o has strong, direct, proportionality to solar radiation and sunshine hours, while it is inversely proportional and weak with wind speed;

3. The regression coefficient for solar radiation, sunshine hours and wind speed in a population regression analysis are 0.234, 0.0274 and 0.0282 respectively. An increase of one unit in these parameters in the model, will cause an increase of 0.234, 0.0274 and 0.0282 unit in ET_o;

4. The relationship between reference evapotranspiration, ET_o and wind speed is very weak positively in Umudike area; generally it differs from location to location;

5. The relationship between individual climatic parameters shows that solar radiation has strong, direct, propotional relationship to air temparature and sunshine hours, but inversely propotional to relative humidity. A polynomial regression analysis may be adopted for a better fit in a prediction model using these parameter.

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