ON THE ADEQUACY OF EVAPOTRANSPIRATION ESTIMATE USING PRIESTLY-TAYLOR'S APPROACH

T. A. Ewemoje and A. Y. Sangodoyin
Agricultural and Environmental Engineering Department
Faculty of Technology, University of Ibadan, Ibadan.

Abstract

The measurement of potential evapotranspiration ET_O using Priestly – Taylor (P-T) formula in humid tropical region was carried out at Shasha along Ojoo – Moniya road, Akinyele Local Government in the Ibadan Metropolitan Area of Oyo State, Nigeria. The difficulty and limitations of obtaining weather and vegetation input data in most of the evapotranspiration (ET) empirical formula are overcame in the P-T equation that is based more on physical parameters than being purely empirical. ET_O estimation of the study location was evaluated for two months using 1973 - 2002 daily climatological data obtained from a nearby weather station. The P-T method gave poor R^2 values of 0.056 and 0.167 for July and August 2004. However, an adjusted P-T model values gave R^2 values of 0.949 and 0.986 respectively. Validating the adjusted P-T model using year 2000 daily weather data of the study location for July and August gave R^2 values of 0.905 and 0.915. The P-T model efficiency in computing evapotranspiration was 62.3% for July and 49.2% for August. The findings indicate that the adjusted P-T model is a good method of ET_O estimation in the humid tropics where there is dearth of input data, and even when available, the data are usually expensive to obtain for research purposes.

Keywords

Evapotranspiration, Priestly-Taylor model, tropical condition.

1. Introduction

The major ways by which moisture is lost from the stream surface are evaporation, transpiration and evapotranspiration (Wilson, 1990). The only factors affecting ET_o are climatic parameters. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year. The International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organization of the United Nations (FAO) recommended the use of Penman-Monteith (P-M) method for determining ET_o from climatic data and as a standard to evaluate the reliability of other ET_O prediction methods (Allen, 1986; Di-Stefano and Ferro, 1997). Limitations to the use of the P-M equation were highlighted by Amatya et. al (1995) with the observation that the weather and vegetation input data for the P-M equation are often difficult and expensive to obtain for practical applications. A large number of methods for calculating ET_O by meteorological data have been developed and tested for different geographical and climatological conditions (Amatya et. al. 1995, Di-Stefano and Ferro, 1997). These methods vary from simple empirical relationships to more complex physically based methods (Verhoef and Feddes, 1991)

The Priestly-Taylor (P-T) method has been mentioned by some researchers because it closely approximates ET_o at the location evaluated, it is physically based and explicitly incorporates both physical and aerodynamic parameters (Laverty and Sterling, 2004). Moreover, procedures have been developed for estimating missing climatic parameters, which are a major limitation of the P-M method in the humid tropical regions.

Several formulas exist for calculating the potential evapotranspiration rate based on one or more combination of meteorological variables. Principally, the commonly used ones are those of Penman, Thornthwaite and Blaney and Criddle. The Penman formula was the first to combine both energy balance and aerodynamic theory to derive a relationship between evapotranspiration and meteorological variables (Brutsaeert, 1982). These methods of estimating potential evapotranspiration are empirical, complicated and requires the use of a monogram for solution. Also, a lot of complications are involved in estimating or recording the meteorological data which are inputs for accurate estimation of potential evapotranspiration in the formula mentioned. Furthermore, these methods have been developed and tested much in the temperate regions. Priestly – Taylor (P-T) formula detailed analysis show that it is based on more of physics than being purely empirical. This study attempts to; (i) estimate ET_O using P–T Method and to correlate the results with a nearby weather station data and (ii) validate the P-T method with previous years weather data to assess the model efficiency.

2. Materials and Methods

2.1 Theory

Priestly and Taylor found that in application of Penman equation to large areas, the second term of the equation being approximately 30% of the first term reduces to the form (Chavula, 2001).

$$ET = \frac{\alpha}{\lambda}\frac{\Delta}{\Delta+\gamma}(R_n - G) \qquad (1)$$

where $\alpha = 1.26$ in humid climates and $G = 0$ (assumed)

Since the equation refers to a well-watered surface, it provides an estimate of ET_O, and also the incoming short-wave radiation (net radiation) R_n is taken as an input variable. The equation is restricted to the wet season in tropics and to altitudes of less than 600m. R_n is evaluated from the following formula (Chavula, 2001).

$$R_n = (1-r)R_s + \sigma T^4(\varepsilon_{atm} - 1)\left[C_1 + C_2\left(\frac{n}{N}\right)\right] \qquad (2)$$

where; r = the Albedo (0.80), R_s= the Solar Radiation received at the earth's surface in MJ m^{-2} d^{-1}, σ= Stefan Boltzman constant (= 4.903×10^{-9} MJ m^{-2} d^{-1} K^{-4}), ε_{atm}= Effective emissivity of the atmosphere under clear skies, $\frac{n}{N}$ = Relative duration of bright sunshine. Where n is sunshine hours and N equals 12. C_1 and C_2 are empirical constants taken as 0.1 and 0.9 respectively. For ε_{atm} the well known Brunt Formula is applied.

$$\varepsilon_{atm} = C_3 + C_4\sqrt{e} \qquad (3)$$

where; e = vapour pressure (mbar); C_3 and C_4 are empirical constants. In the tropics, Brutsaert (1982) suggested $0.66 m/s^2$ and $0.044 m/s^2$ respectively for C_3 and C_4.

$$(\Delta) = \frac{4099\,e_s}{(T_a + 237.3)^2} \qquad (4)$$

Saturation vapour pressure:

$$(e_s) \text{ in kPa} = 0.6108 \exp\left\{\frac{17.27\ Ta}{Ta + 237.3}\right\} \qquad (5)$$

T_a = mean hourly air temperature (^{o}C),

Actual vapour pressure (ASAE EP505, 2004):

$$(e_a) \text{ in kPa} = e_s \times RH/100 \qquad (6)$$

RH = relative humidity (%)

Psychometric constant:

$$(\gamma) = 0.00163\ P / \lambda \qquad (7)$$

P = barometric pressure (kPa):

$$P = 101.3 \left[\frac{293 - 0.0065A}{293}\right]^{5.26} \qquad (8)$$

In which A = station elevation above mean sea level (t= 213.4m)

Latent heat of Vapourization in MJ/Kg (Temesgen and Eching, 2005):

$$(\lambda) = 2.501 - 0.002361\ T_a \qquad (9)$$

2.2 Methods

The study area is Ibadan, Latitude 07° 29′ 16N, Longitude 03° 54′ 44E. Ibadan is located at the edge of the rain forest vegetation region of Nigeria at an altitude of about 213.4m above sea level. It is characterized by moderate heavy rainfall occurring at times as convective thunderstorm with high intensity of relatively short duration. Annual rainfall of the city is between 1200 – 1500mm (Eze, 1997).

The data needed were obtained from the Geo – spatial laboratory of the International Institute of Tropical Agriculture (I.I.T.A.). The daily climatological data values collected are rainfall, evaporation, wind speed, solar radiation, minimum and maximum temperature, minimum and maximum relative humidity and sunshine hours for July and August, 2004. The evaluation was restricted to these two months because IITA monthly weather data (1973-2002) shows that for this geographical location, long-term average rainfall shows a remarkable break (or reduction); hence a good basis for wet and dry season comparison in the tropics. Average monthly values were imputed into Excel spreadsheet to determine parameter values of equations previously quoted.

The degree of agreement between the computed (x) and observed (y) was estimated using Coefficient of Determination (R^2). The computed P-T values were adjusted with the following relation (WMO,1983):

$$x^*_i = x_i(y_i - x_i) \times \sum_{i=1}^{n} x_i \div n \qquad (10)$$

where i = 1,2,……, n., and n = no of days of the month and x^*_i is the adjusted RT value.

Model parameters were determined by the minimization of the sum of squares as an objective function:

$$F = \sum_{i=1}^{n} \{ Et_{obs} - Et_{pre} \}^2 \qquad (11)$$

where i = 1,2,…………………,n and n is the number of days of the month.
Et_{obs} = Observed evapotranspiration, Et_{pre} = Predicted or modelled evapotranspiration

The model efficiency, which is related to the regression coefficient of determination, is defined as:

$$\text{Eff} = 100 \times \left[\frac{F_o - F}{F_o} \right] \qquad (12)$$

$$F_o = \sum_{i=1}^{n} \{ Et_{obsi} - \overline{Et} \}^2 \qquad (13)$$

In the case of error-free prediction, an efficiency of 100% is returned; a negative efficiency indicates that the sum of the squared model residuals exceeds the variance of the observed records (Nash and Sutcliffe, 1970)..

3. Results and Discussion

The computed P-T potential evapotranspiration (x) and observed potential evapotranspiration data values (y) obtained from IITA Weather station are presented in Table 1 with the adjusted P-T values (x^*). When computed P-T values were plotted against observed values, the Coefficient of Determination (R^2) was 0.056 and 0.167 for July and August respectively (Figs 1 and 2). Adjusting the P-T values using equation 10 gave R^2 values of 0.949 and 0.986 for the months of July and August 2004 (Figs 1 and 2). The derived linear trend line equations were given as;

$y = 0.8601x + 1.0847$ for July;

$y = 1.0127x + 0.9057$ for August.

The high value of the Correlation Coefficient implies that the Adjusted P-T values and the observed evaporation values are strongly and positively related. This implies that in the absence of observed data, the P-T model can be relied on without loss of accuracy. Furthermore, the high Coefficient of Determination (R^2) means that 94.9% and 98.6% of variation in Adjusted P-T values was due to observed evaporation values, while 5.1% and 1.4% of the variation in Adjusted P-T values for July and August was due to other factors which may be due to stochastic or randomness of weather data, other than observed evaporation.

The adjusted P-T values were validated using year 2000 daily-recorded data for the months of July and August respectively. When P-T values were plotted against Observed values, the Coefficient of Determination (R^2) were 0.905 and 0.915 for July and August respectively (Figure 3). The model Efficiency was determined by substituting the year 2000 daily recorded and predicted values into equations 11 – 13. Model efficiency were 62.3% and 49.2% for the months of July and August respectively. The low model efficiency in the month of August may be attributed to the August break (reduction in rainfall) because the P-T equation is restricted to the wet season in the tropics.

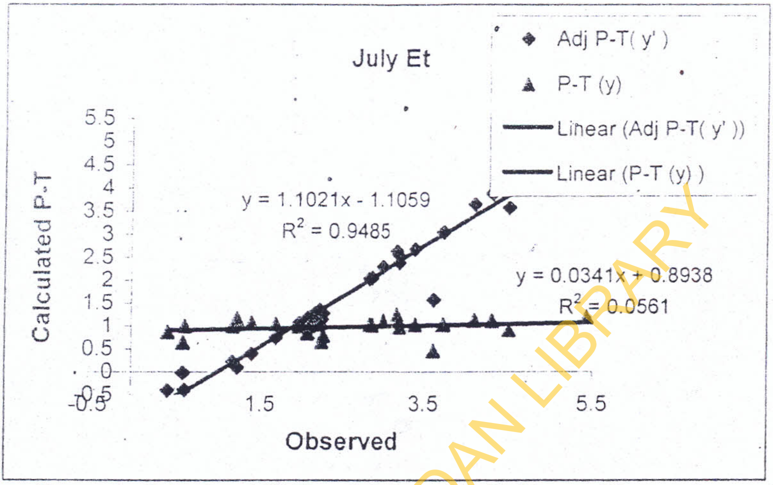

Figure 1: Calculated (P-T and Adjusted P-T) Versus Observed Et Values for July.

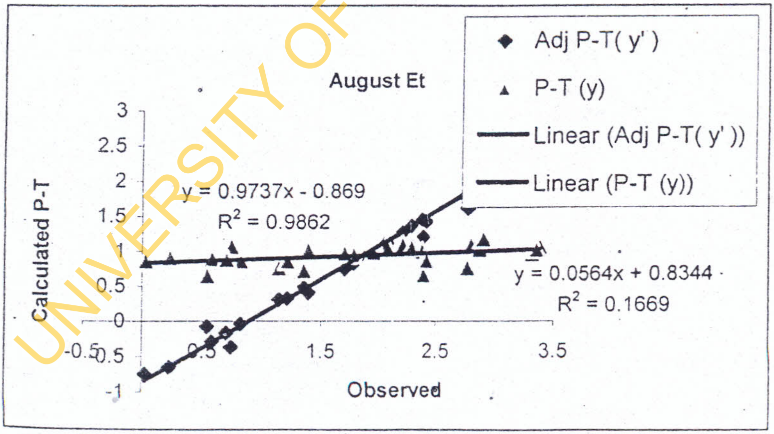

Figure 2: Calculated (P-T and Adjusted P-T) Versus Observed Et values for August.

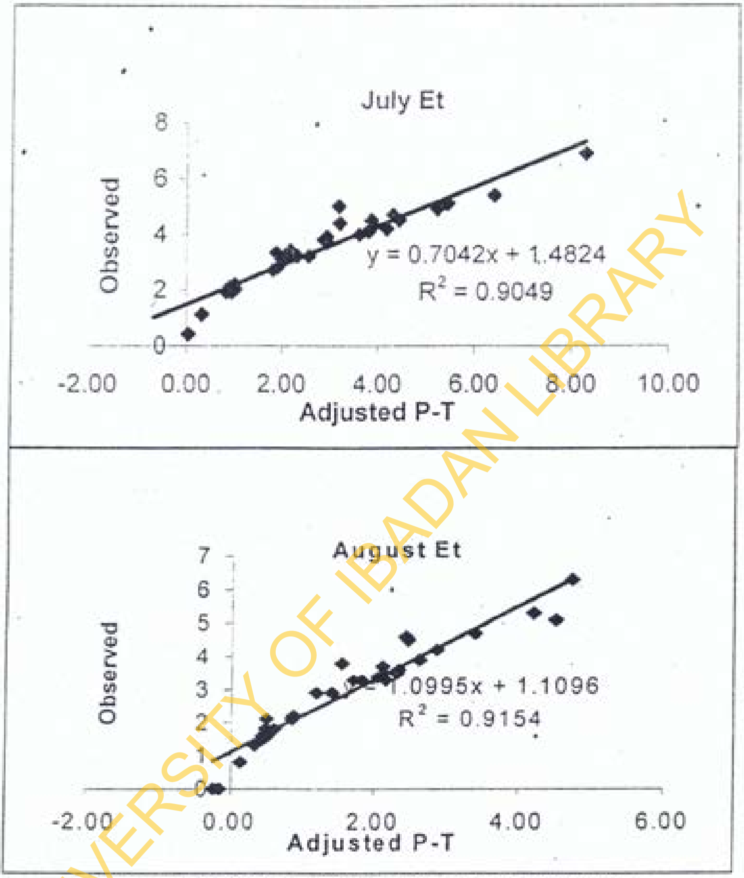

Figure 3: P-T Model Versus Observed Validation.

For application in data-short situations, the P-T model results were in agreement with Laverty and Sterling (2004), who had earlier observed that radiation methods show good results in humid climates where the aerodynamic term is relatively small and when applied to very large areas. Also from Table 1, the P-T(y) model result underestimate evapotranspiration before the model adjustment.

Table 1. Computed and adjusted P-T values

Days	July 2004			August 2004		
	Obs (x)	Adj P-T(y')	P-T (y)	Obs (x)	Adj P-T (y')	P-T (y)
1	3.17	2.63	1.25	2.81	1.97	1.09
2	3.73	3.04	1.03	2.20	1.27	1.09
3		-1.07	0.99	3.32	2.38	0.96
4	3.40	2.67	1.03	0.58	-0.29	0.89
5	2.17	1.28	1.03	2.38	1.45	1.00
6	3.62	1.56	0.45	1.14	0.30	0.76
7	4.30	3.87	1.11	1.92	0.97	0.99
8	2.82	2.02	1.03	2.78	1.61	0.76
9	3.20	2.38	0.98	0.54	-0.08	0.65
10	2.26	1.27	0.79	1.21	0.32	0.86
11	3.20	2.37	0.97	0.03	-0.75	0.86
12	1.23	0.09	1.16	2.41	1.43	0.91
13	2.22	1.35	1.14	1.78	0.83	0.95
14	3.19	2.54	1.12	0.82	-0.04	0.86
15	4.09	3.64	1.12	2.39	1.20	0.66
16	2.08	1.18	1.00	0.23	-0.65	0.91
17	2.99	2.28	1.11	1.91	0.96	0.96
18	1.97	1.06	0.99	2.06	1.11	1.08
19	2.24	1.13	0.65	1.96	1.01	1.04
20	0.62	-0.40	0.99	2.28	1.36	1.05
21	4.50	3.57	0.91	1.35	0.48	0.72
22	2.07	1.14	0.86	2.42	1.42	0.87
23	0.60	-0.03	0.64	3.39	2.59	1.06
24	2.85	2.04	1.02	0.74	-0.37	1.07
25	5.43	5.52	1.19	1.70	0.74	0.97
26	2.07	1.13	0.84	1.39	0.40	1.02
27	2.22	1.35	1.07	1.95	1.00	0.98
28	1.40	0.39	1.07	2.88	1.99	1.02
29	1.18	0.21	0.99	3.36	2.51	1.02
30	1.69	0.74	1.04	0.70	-0.17	0.88
31	0.42	-0.41	0.86	2.91	2.14	1.17

4. Conclusion

From the observed and computed values, the adjusted P-T model is a good method of estimating evapotranspiration in the study area. There are advantages to be derived in that it incorporates climatological data and leaves out the need for the requirement of local calibration of the wind function and over dependence on temperature methods, which remain empirical.

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