UNIZIK JOURNAL OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

UJABE

Journal homepage: https://journals.unizik.edu.ng/ujabe/

February (2026), 1(1): 19-33

LINEARIZATION OF EVAPOTRANSPIRATION RATE IN NIGERIA USING AGRO-CLIMATIC DATA FOR COMPARING REFERENCE EVAPOTRANSPIRATION MODELS

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Received: 24th December 2025; **Accepted:** 15th February 2026; **Available Online:** 28th February 2026

ABSTRACT

The study presents Linearization of Evapotranspiration Rate in Nigeria using Agro-Climatic Data for Comparing Reference Evapotranspiration Models in order to prevent over or under irrigation by farmers, which could have a detrimental impact on crop yields. Agro-climatic data from 2013 to 2024 were gathered and examined for this study. Minimum and maximum temperatures (ºC), relative humidity (%), wind speed (km/day), sunlight (hr/day), and radiation (MJ/m^2/day) were the data collected. Using the mean monthly agro-climatic data for the six chosen agro-climatic weather stations in Nigeria [North-East (Yola), North-West (Sokoto), North-Central (Lokoja), South-East (Enugu), South-West (Lagos), and South-South (Port-Harcourt)], and FAO Penman-Monteith model was utilized as a universal standard model to calculate the mean monthly reference evapotranspiration (ET_o). The mean monthly reference evapotranspiration (ET_o) was calculated using five different evapotranspiration models (Priestley-Taylor model, Thornth-Waite model, Hargreaves model, ASCE-Penman Monteith model, and Blaney-Criddle model). The results were then compared with the standard FAO Penman-Monteith model. The FAO Penman-Monteith model's estimates and the reference ET_o estimates from the five models were compared using statistical regressions. According to the findings, the six agro-climatic weather stations' mean monthly average ETo estimates from the FAO Penman-Monteith model, Priestley-Taylor model, Thornth-Waite model, Hargreaves model, ASCE-Penman Monteith model, and Blaney-Criddle model were, respectively, 6.48, 7.66, 14.14, 11.16, 5.57, and 3.70 mm/day. The ASCE-Penman Monteith model, which has a strong correlation with the FAO Penman-Monteith model, was the strongest predictor; the Priestley-Taylor model was the second-best. The Blaney-Criddle model significantly overestimated the FAO Penman-Monteith model, whilst the Thornth-Waite and Hargreaves models yielded underestimated ET values. The models exhibit significant diversity and the relationship between them is location-dependent. The ASCE-Penman Monteith model and Priestley-Taylor model can be used in the absence of FAO 56 Penman-Monteith model. Both Blaney-Criddle model, Thornth-Waite and Hargreaves model are not suitable for use for regional water resource planning and accurate agricultural water management.

Keywords: Reference Evapotranspiration, Agro-Climatic Data, Evapotranspiration Models, Statistic Regression, Evapotranspiration

1.0 INTRODUCTION

Transpiration and evaporation are combined to form the word evapotranspiration. According to Suat and Dorota (2014), reference evapotranspiration (ET_o) is "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface of 70 sec/m, and an albedo of 0.23, closely resembling the evapotranspiration (ET) from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground. Reference evapotranspiration (ET_o) can be calculated using a variety of models in practice, but because each model has some empirical foundation, its performance varies depending on the environment (Pereira and Pruitt, 2004). For almost ten years, the FAO Penman-Monteith model has been regarded as a worldwide standard for estimating ET_o (Jensen *et al.*, 1990). A number of meteorological parameters, including net radiation, air temperature, vapour pressure deficit, relative humidity, sunshine, and wind speed, are necessary for this model to account for both aerodynamic and physiological parameters (Sentelhas *et al.*, 2010; Pankaj *et al.*, 2016). Based on their data requirements, the reference evapotranspiration estimation models can be categorized as temperature-based, radiation-based, or combination-based. The specific ET_o estimation model's implementation varies depending on the weather and the availability of meteorological data, and each model has different data requirements (Jensen *et al.*, 1990).

An even smaller subset of meteorological stations have accurate data for these criteria. This is particularly true in underdeveloped nations where it is difficult to obtain accurate data on radiation, humidity, and wind speed (Droogers and Allen, 2002). However, such climatic variables are frequently lacking or insufficient for many places, including Nigeria. The majority of meteorological stations in Nigeria do not have the necessary information available, or if they do, they have missing records. This could be due to poor maintenance of the meteorological stations, a lack of database management systems, or poor upkeep of climatic data records. As a consequence, the study tends to compare some selected reference evapotranspiration models by line arising evapotranspiration rate in Nigeria using agro-climatic data.

2.0 METHODOLOGY

2.1 Location of the Study Area

Nigeria, which has a total area of 923,768 km^2, is situated in the tropical region of West Africa on the African continent, between latitudes 4° N and 14° N and longitudes 2° 2' E and 14° 30' E. A map of Nigeria with a few weather stations in each of the six geopolitical zones is shown in Figure 1. The nation's maximum east-west length is around 1,150 km, while its north-south length is roughly 1,050 km. Thick mangrove forests make about 98.6% of the land area, with water covering about 13,000 km^2 (1.4%). Water covers about 13,000 km^2 of the area (1.4%), with the remaining 98.6% of the land cover ranging from near-desert to lush mangrove forests and rain forests in the south (Merem *et al*., 2017).

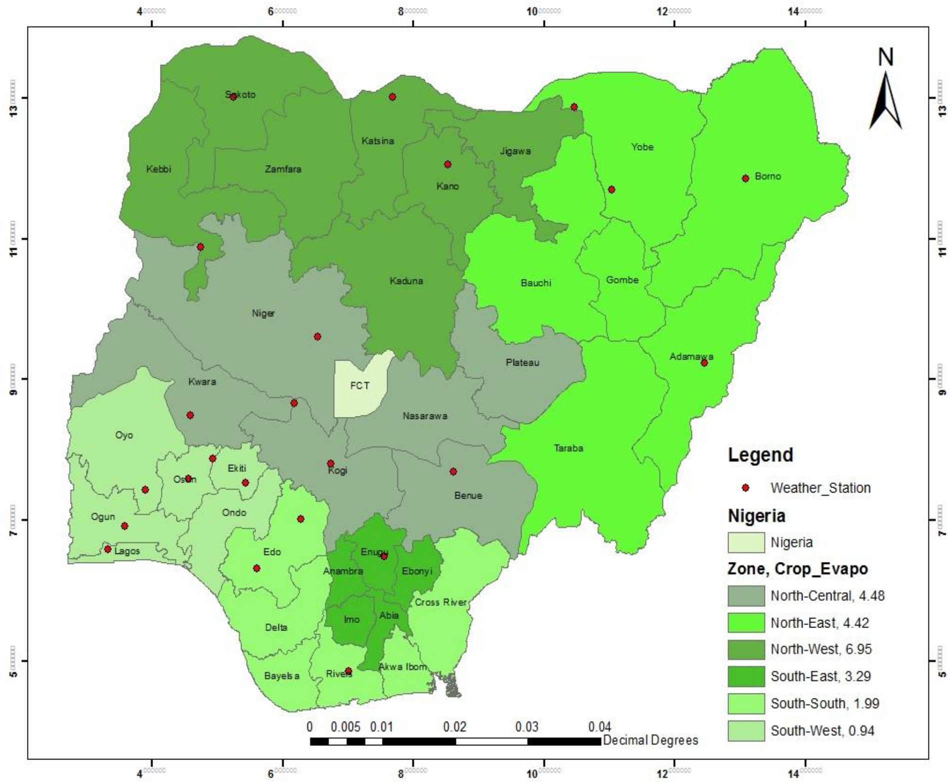

Figure 1: Map of Nigeria Showing Agro-Climatic Weather Stations in the Six Geopolitical Zones

2.2 Data Collection

This study has used the following data: radiation (MJ/m^2/day), wind speed (km/day), sunshine (hr/day), minimum and maximum temperature (^oC), and relative humidity (%). Weather data from 2013 to 2024 was obtained from Nigerian Meteorological Agency (NIMET) in Abuja, Nigeria, covering six agro-meteorological stations in Nigeria [North-East (Yola), North-West (Sokoto), North-Central (Lokoja), South-East (Enugu), South-West (Lagos), and South-South (Port-Harcourt)].

2.3 Data Analysis

2.3.1 Analysis of Agro-Climatic Data

The mean daily and monthly agro-climatic data values obtained from NIMET were calculated by adding together and averaging the values. The mean yearly values used to calculate reference evapotranspiration (ET_o) for Nigeria's six geopolitical zones were also calculated by averaging the mean monthly data for each station in the course of study.

2.3.2 Estimation of Reference Evapotranspiration using six ET models

Six different ET models; two combination-based models (FAO 56 Penman-Monteith and ASCE-Penman Monteith), two temperature-base models (Thornth-Waite and Blaney-Criddle) and two Radiation-based model (Priestley-Taylor and Hargreaves) were used to estimate mean monthly Reference evapotranspiration (ET_o) for six geopolitical zones of Nigeria (North-East, North-East, North-Central, South-West, South-East and South-South).

2.3.2.1 FAO 56 Penman-Monteith model:

The FAO 56 Penman-Monteith model with grass reference crop (as suggested by the Food and Agriculture Organisation of the United Nations (FAO, 1990) was used as the standard model for computing ET_o for each of the weather station representing the six geopolitical zones in the study area. An Excel computer program was developed to calculate ET_o for FAO 56 Penman-Monteith model on monthly basis, using the mean monthly weather data for the six stations. The FAO 56 PM model is based on the Penman-Monteith model is thus;

$$ET_o = \frac{0.408\,\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \ (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

ET_o = grass reference ET (mm/d);
R_n = net radiation at the crop surface (MJ/m^2/d);
G = soil heat flux density (MJ/m^2/d).
U_2 = wind speed at 2m height, ms^{-1}
e_s = saturation vapour pressure, Kp_a
e_a = actual vapour pressure, Kp_a
Δ = slope vapour pressure curve, $Kp_a{}^oC^{-1}$
γ = psychrometric constant, $Kp_a{}^oC^{-1}$

2.3.2.2 Estimation of ASCE-Penman Monteith model

ASCE-Penman Monteith model was used for computing ET_o for each of the weather station representing the six geopolitical zones in the study area. An Excel computer program was developed to calculate ET_o for ASCE-Penman Monteith model on monthly basis, using the mean monthly weather data for the six stations. The equation is given as:

$$ET_{sz} = \frac{0.408\,\Delta\left(R_n - G\right) + \gamma\ Cn \frac{(e_s - e_a)}{T_a + 273}\ u_2}{\Delta + \gamma\,(1 + C_d\ u_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where;

ET_o = reference evapotranspiration, mm day^{-1}
G = soil heat flux density, MJm^{-2} day^{-1}
R_n = net radiation in equivalent evaporation, MJm^{-2} day^{-1}
T = mean daily air temperature, ^oC
U_2 = wind speed at 2m height, ms^{-1}
e_s = saturation vapour pressure, Kp_a
e_a = actual vapour pressure, Kp_a
Δ = slope vapour pressure curve, $Kp_a{}^oC^{-1}$

Ɣ = psychrometric constant, $Kp_a{}^oC^{-1}$
C_n = numerator constant for reference type and calculation time step (900), and
C_d = denumerator constant for reference type and calculation time step (0.34).

2.3.2.3 Estimation of Thornth-Waite Model

Thornth-Waite model was used for computing ET_o for each of the weather station representing the six geopolitical zones in the study area. An Excel computer program was developed to calculate ET_o for Thornth-Waite model on monthly basis, using the mean monthly weather data for the six stations. The equation is given as:

$$\text{PET} = 16\ x\ \frac{(10\,\text{T}_a)^a}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

PET = potential evapotranspiration rate, in mm per month;
T_a = mean monthly air temperature, in degrees Celsius (ºC);
I = summation of the 12 monthly heat index i, where i = $(T_a / 5)^{1.514}$;
α = an empirical coefficient, which is calculated using the following equation:

$$a = 0.675*10^{-6} I^{3} - 77.1*10^{-6} I^{2} + 0.01792I + 0.49239 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2.3.2.4 Estimation of Blaney-Criddle model

The Blaney-Criddle model is an empirical equation and was developed as a simple mathematical model. An Excel computer program was developed to calculate ET_o for Thornth-Waite model on monthly basis, using the mean monthly weather data for the six stations, thus:

$$u = KP\ [\frac{\left(45.7\,T_a + 813\right)}{100}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where;

u = monthly consumptive use, in inches;
p = monthly percentage of daytime hours of the year;
k = empirical consumptive use crop coefficient for monthly period;
K = empirical consumptive use crop coefficient for irrigation season or growing period.
T_a = mean monthly temperature, in degrees Centigrade/Celsius (ºC).

2.3.2.5 Estimation of Priestley-Taylor model

Priestley-Taylor model was used to compute reference evapotranspiration using the climatological data. An Excel computer program was developed to calculate ET_o for Priestley-Taylor model on monthly basis, using the mean monthly weather data for the six stations, Thus:

$$E_{tp} = \alpha\ \frac{\Delta}{\Delta+\gamma}\frac{\left(R_n - G\right)}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where,

α = constant which varies from 1.08 to 1.45

G = soil heat flux density, $MJm^{-2}\ day^{-1}$
R_n = net radiation in equivalent evaporation, $MJm^{-2}\ day^{-1}$
Δ = slope vapour pressure curve, $Kp_a{}^oC^{-1}$
Ɣ = psychrometric constant, $Kp_a{}^oC^{-1}$
λ = latent heat of vaporization, 2.45 ($MJ\ kg^{-1}$),

2.3.2.6 Estimation of Hargreaves model

Hargreaves model was used to compute reference evapotranspiration using the climatological data. An Excel computer program was developed to calculate ET_o for Hargreaves model on monthly basis, using the mean monthly weather data for the six stations, thus:

$$ET_o = 0.0075\, R_s\, T_F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

Where,

ET_0 = potential ET for a grass reference surface in the same units as R_s;
R_s = global solar radiation at the surface in equivalent water evaporation, usually mm of evaporation;
T_F = mean air temperature in degrees Fahrenheit (°F).

2.3.3 Comparison of ET_o values of the five models with FAO 56 Penman-Monteith model

The mean monthly and annual reference evapotranspiration (ET_o) for six geopolitical zones of Nigeria [North-East (Yola), North-West (Sokoto), North-Central (Lokoja), South-East (Enugu), South-West (Lagos), and South-South (Port-Harcourt)] was estimated using six different ET models: two combination-based models (FAO 56 Penman-Monteith and ASCE-Penman Monteith), two temperature-based models (Thornth-Waite and Blaney-Criddle), and two radiation-based models (Priestley-Taylor and Hargreaves).The link between the reference ET_o estimates from the five ET models and the estimates from the standard FAO Penman-Monteith model for Nigeria's six geopolitical zones was investigated using statistical regressions. However, the regression model is given in Equation 8:

$$Y = MX + C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

Where,

Y = FAO Penman-Monteith monthly reference ET_o
X = Mean monthly reference ET_o estimated from each of the other two models, and
M and C = Slope and intercept, respectively.

The mean monthly estimations from the standard FAO Penmen-Monteith model were plotted against the values calculated from the mean monthly ET_o for each of the five models. The graph's discrepancies with regard to FAO Penman-Monteith were corrected. In 1974, Parmele and McGuiness suggested that the model with the lowest absolute deviation, C value closest to zero, M value closest to 1.0, shortest RMSE, and maximum R^2 would be the best. The ratio of the monthly total FAO Penman-Monteith reference ET_o to the monthly total for each model averaged over the record period was also used to calculate the mean monthly correction factors for the possible usage of selected models in the study region.

The Root Mean Squared Error (RMSE) formula calculates the average magnitude of prediction errors by taking the square root of the average squared differences between predicted ($\hat{yi}$) and actual (yi) values, by calculating the residuals ($yi-\hat{yi}$), square them, find the mean (Mean Squared Error), and take the square root.. The RMSE formula is expressed in the Equation 9:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \bar{y}_i\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where;

yi = Observed/actual value.

$\hat{yi}$ = Predicted value.

n = Total number of observations.

Similarly, Absolute Deviation of Data (ADD) point (xi) from a central value (usually the mean (μ) or median) is calculated as the absolute difference by estimating the mean value, subtract mean from each data point, take absolute value and average the results. The ADD formula is expressed as given in Equation 10.

$$\text{ADD} = (\text{xi}-\mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where;

n = Total number of data points.

3.0 RESULTS AND DISCUSSION

3.1 Results of the Mean Monthly Reference Evapotranspiration (mm/day)

The mean monthly ETo for the six ET models was calculated using a Microsoft Excel 2021 and the results are displayed in Tables 1, 2, 3, 4, 5, 6, and 7, respectively. Table 1 shown that the six meteorological stations in the study area had FAO Penman-Monteith mean monthly ET_o estimations that varied from 1.56 mm/day for the South-West to 11.58 mm/day for the North-West. North-East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ET_o estimates of 9.45 mm/day, 11.58 mm/day, 7.47 mm/day, 5.49 mm/day, 1.56 mm/day, and 3.31 mm/day, respectively.

Table 1: Reference Evapotranspiration (ET_o mm/day) using FAO Penman-Monteith Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	11.45	11.22	7.18	6.98	2.69	4.19
2014	15.67	13.61	8.87	9.02	3.08	4.54
2015	20.73	20.45	9.78	10.84	2.52	4.52
2016	15.94	23.62	9.76	6.32	1.87	4.29
2017	9.66	16.07	7.30	4.49	1.17	3.34
2018	4.22	10.15	5.52	3.67	0.01	2.79
2019	4.19	4.93	13.42	3.28	0.17	2.13
2020	3.35	2.53	4.43	3.45	1.22	2.30
2021	3.56	3.13	4.31	3.46	1.05	2.31
2022	5.56	9.28	4.94	3.69	0.98	2.73

2023	8.90	13.26	7.50	4.84	1.38	3.17
2024	10.22	10.75	6.64	5.85	2.63	3.44
Mean	9.45	11.58	7.47	5.49	1.56	3.31

In Table 2, the study area's six meteorological stations' Priestley-Taylor mean monthly ET_o estimations varied from 6.56 mm/day for the South-South to 8.82 mm/day for the North-West. North-East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ET_o estimates of 7.98 mm/day, 8.82 mm/day, 7.97 mm/day, 7.52 mm/day, 7.13 mm/day, and 6.56 mm/day, respectively.

Table 2: Reference Evapotranspiration (ET_o mm/day) using Priestley-Taylor Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	8.10	7.90	8.09	7.58	7.12	6.93
2014	8.89	9.01	8.88	8.45	8.14	7.84
2015	8.94	9.48	8.93	8.15	8.28	7.26
2016	8.46	9.37	8.45	8.28	8.26	7.30
2017	8.33	9.56	8.32	8.02	7.49	7.04
2018	7.56	9.61	7.55	7.10	6.35	5.90
2019	7.00	8.36	6.99	6.42	5.75	5.46
2020	6.72	7.79	6.71	6.22	5.99	5.63
2021	7.32	8.78	7.31	6.66	6.19	5.53
2022	7.96	9.41	7.95	7.54	7.09	6.29
2023	8.43	8.68	8.42	7.96	7.59	6.63
2024	8.07	7.96	8.06	7.80	7.34	6.91
Mean	7.98	8.82	7.97	7.52	7.13	6.56

Table 3 revealed that the six meteorological stations in the study area had mean monthly ET_o estimations from Thornth-Waite that varied from 13.89 mm/day for South-South to 14.47 mm/day for North-West. North-East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ET_o estimates of 14.38 mm/day, 14.47 mm/day, 14.11 mm/day, 14.07 mm/day, 13.92 mm/day, and 13.89 mm/day, respectively.

Table 3: Reference Evapotranspiration (ET_o mm/day) using Thornth-Waite Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	13.51	13.26	13.71	13.94	14.07	13.91
2014	14.37	13.82	14.48	14.56	14.43	14.29
2015	15.58	15.13	14.93	14.71	14.45	14.27
2016	16.26	16.26	14.66	14.93	14.27	14.19
2017	15.11	15.87	14.38	14.14	13.99	14.02
2018	14.41	14.95	13.96	13.84	13.56	13.76
2019	14.02	14.29	13.78	13.65	13.46	13.53
2020	13.81	13.82	13.78	13.66	13.41	13.55
2021	13.87	14.13	13.78	13.72	13.53	13.62
2022	14.21	14.78	13.96	13.90	13.78	13.75
2023	13.91	14.13	14.17	14.00	14.04	13.90
2024	13.48	13.26	13.71	13.81	14.02	13.84
Mean	14.38	14.47	14.11	14.07	13.92	13.89

In Table 4, the study area's six meteorological stations had Hargreaves' mean monthly ET_o estimations ranging from 8.00 mm/day for South-South to 14.77 mm/day for North-West. North-

East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ETo estimates of 12.67 mm/day, 12.70 mm/day, 11.34 mm/day, 10.73 mm/day, 10.14 mm/day, and 9.39 mm/day, respectively.

Table 4: Reference Evapotranspiration (ET_o mm/day) using Hargreaves Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	11.61	10.51	11.35	10.70	10.21	9.87
2014	13.73	12.38	12.81	12.30	11.80	11.30
2015	14.72	14.10	13.23	12.02	12.00	10.54
2016	14.54	14.77	12.38	12.35	11.83	10.53
2017	14.11	14.77	11.10	11.42	10.63	10.07
2018	12.60	14.14	10.69	10.02	8.90	8.47
2019	11.27	11.95	9.85	9.03	8.09	7.78
2020	10.49	10.86	9.50	8.80	8.35	8.00
2021	11.34	12.35	10.25	9.38	8.68	7.92
2022	13.04	13.73	11.20	10.62	9.97	8.95
2023	12.87	12.23	11.96	11.23	10.80	9.48
2024	11.75	10.58	11.12	10.87	10.46	9.79
Mean	12.67	12.70	11.34	10.73	10.14	9.39

Table 5 shown that the six meteorological stations in the study area had Blaney-Criddle mean monthly ET_o estimations that varied from 5.20 mm/day for North-West to 6.32 mm/day for North-East and North-West. North-East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ET_o estimates of 5.66 mm/day, 5.69 mm/day, 5.56 mm/day, 5.55 mm/day, 5.49 mm/day, and 5.48 mm/day, respectively.

Table 5: Reference Evapotranspiration (ET_o mm/day) using Blaney-Criddle Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	5.32	5.20	5.40	5.50	5.55	5.49
2014	5.67	5.45	5.71	5.74	5.69	5.64
2015	6.10	5.96	5.88	5.80	5.70	5.63
2016	6.32	6.32	5.78	5.88	5.63	5.60
2017	5.94	6.20	5.68	5.58	5.52	5.53
2018	5.69	5.89	5.51	5.46	5.34	5.43
2019	5.53	5.64	5.43	5.38	5.30	5.33
2020	5.45	5.45	5.43	5.38	5.27	5.33
2021	5.47	5.58	5.43	5.41	5.33	5.36
2022	5.61	5.82	5.51	5.48	5.43	5.42
2023	5.49	5.58	5.59	5.53	5.54	5.48
2024	5.30	5.20	5.40	5.45	5.53	5.46
Mean	5.66	5.69	5.56	5.55	5.49	5.48

Table 6 revealed that the six meteorological stations in the study area had ASCE-Penman Monteith mean monthly ET_o estimations that varied from 0.08 mm/day for the South-West to 11.94 mm/day for the North-East. North-East, North-West, North-Central, South-East, South-West, and South-South had mean monthly ETo estimates of 5.41 mm/day, 6.74 mm/day, 4.18 mm/day, 3.12 mm/day, 0.90 mm/day, and 1.85 mm/day, respectively.

Table 6: Reference Evapotranspiration (ET_o mm/day) using ASCE-Penman Monteith Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	6.50	6.45	4.01	3.96	1.50	2.34
2014	8.97	7.86	4.97	5.15	1.73	2.55
2015	11.97	11.94	5.51	6.20	1.41	2.53
2016	9.24	13.89	5.49	3.62	1.04	2.41
2017	5.55	9.43	4.09	2.55	0.65	1.87
2018	2.40	5.91	3.07	2.08	0.36	1.55
2019	2.38	2.85	7.52	1.85	0.08	1.18
2020	1.90	1.45	2.46	1.95	0.67	1.28
2021	2.01	1.80	2.39	1.96	0.58	1.28
2022	3.16	5.40	2.74	2.09	0.54	1.52
2023	5.06	7.68	4.19	2.74	0.76	1.77
2024	5.80	6.18	3.70	2.31	1.47	1.91
Mean	5.41	6.74	4.38	3.12	0.90	1.85

Table 7 displays the calculated mean monthly ET_o for each of the six ET models throughout the six geopolitical zones. The six weather stations have mean monthly average ET_o estimates of 6.48, 14.14, 7.66, 11.16, 5.57, and 3.70 for FAO Penman-Monteith model, Thornth-Waite model, Priestley-Taylor model, Hargreaves model, Blaney-Criddle model, and ASCE-Penman Monteith model, respectively.

Table 7: Mean monthly ET_o (mm/day) for the six ET models across the six geopolitical zones

Agro-Climatic Zone of Nigeria	FAO Penman-Monteith	Thornth-Waite	Priestley-Taylor	Hargreaves	Blaney-Criddle	ASCE-Penman Monteith
North-East	9.45	14.38	7.98	12.67	5.66	5.41
North-West	11.58	14.47	8.82	12.70	5.69	6.74
North-Central	7.47	14.11	7.97	11.34	5.56	4.18
South-East	5.49	14.07	7.52	10.73	5.55	3.12
South-West	1.56	13.92	7.13	10.14	5.49	0.90
South-South	3.31	13.89	6.56	9.39	5.48	1.85
MESN	6.48	14.14	7.66	11.16	5.57	3.70

3.2 Results of Statistical Regression of six Evapotranspiration Models

Plotting was done between the mean yearly ET_o calculated by the FAO 56 Penman-Monteith model and the mean monthly ETo values for each year average over specified years of record as estimated by various ET models. Figures 2, 3, 4, 5, and 6 illustrate the link (regression equation) between the mean monthly ET_o estimations for each model against the FAO 56 Penman Monteith ET_o and the coefficient of determination (R^2) using the linear regression form.

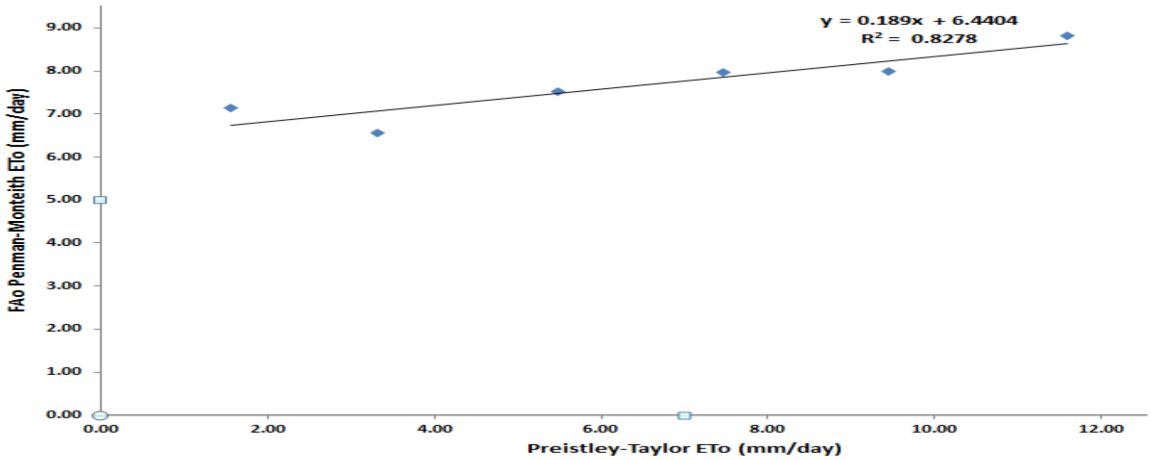

Figure 2: Mean monthly FAO Penman-Monteith ET_o against Priestley-Taylor's ET_o

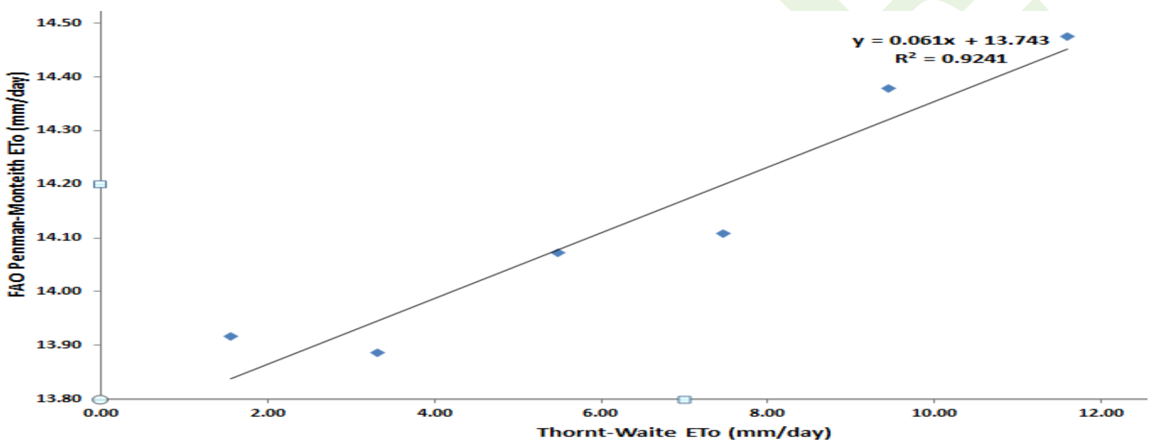

Figure 3: Mean monthly FAO Penman-Monteith ET_o against Thornth-Waite ET_o

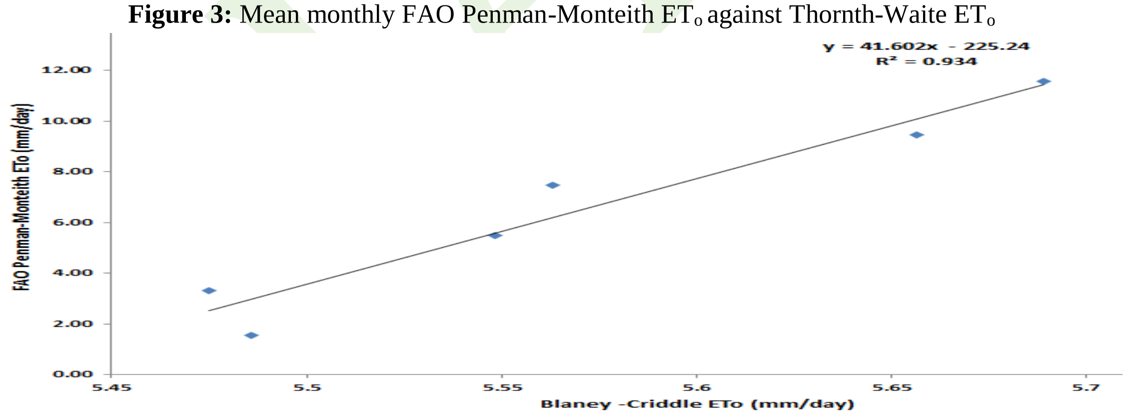

Figure 4: Mean monthly FAO Penman-Monteith ET_o against Blaney-Criddle ET_o

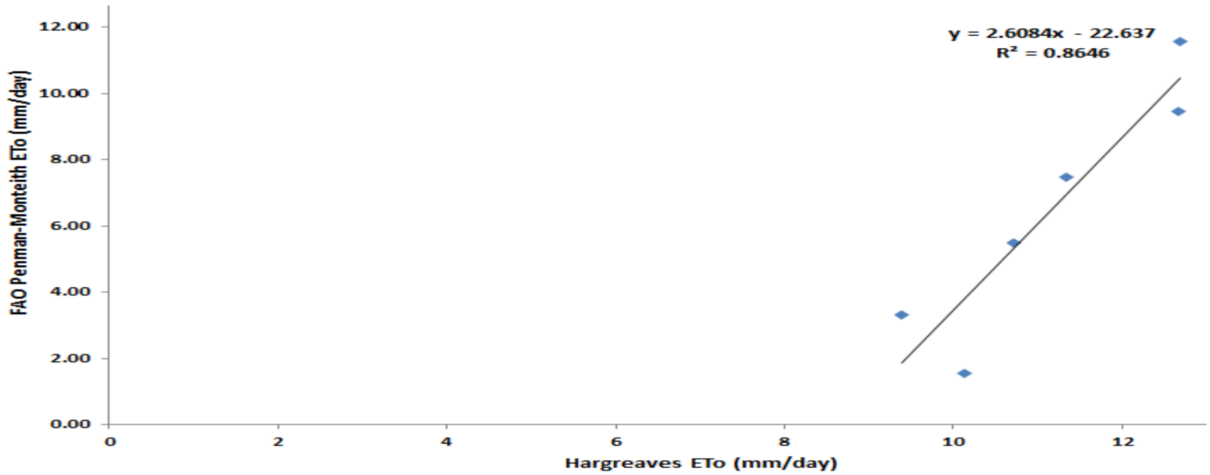

Figure 5: Mean monthly FAO Penman-Monteith ET_o against Hargreaves ET_o

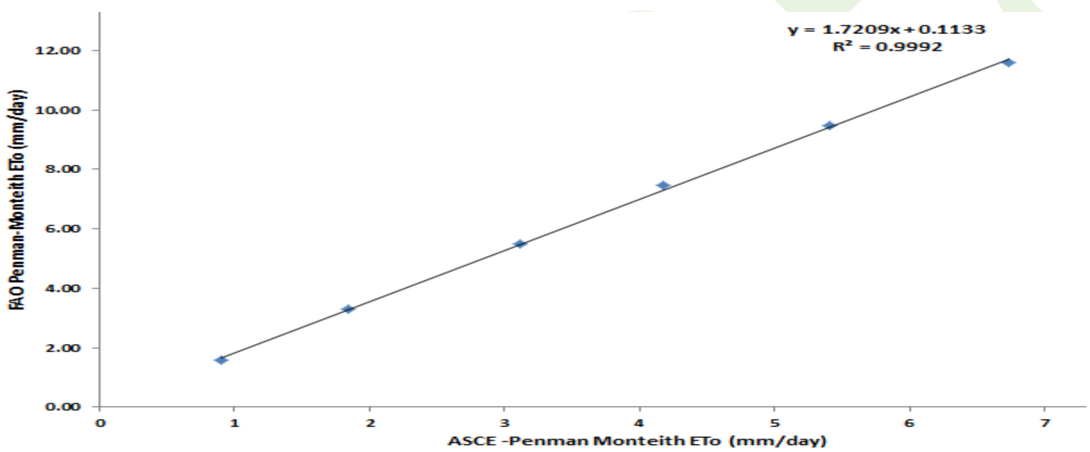

Figure 6: Mean monthly FAO Penman-Monteith ET_o against ASCE-Penman Monteith ET_o

3.3 Discussion of Statistics for Regression of mean annual ET_o

In order to compare the measured and estimated values, each regression line's intercept and slope are also displayed. Table 8 shows summary statistics for the regression of monthly ET_o calculated by each of the five ET models against that estimated by the standard FAO Penman-Monteith model for the whole observation period across twelve years of weather data. The best fit between the estimated ET_o and the FAO 56 Penman-Monteith model estimates is represented by a correlation coefficient (R^2). For each of the five models, the RMSE and ADD values varied from -5.43 to 0.92 mm/day and 0.025 to 1.740 mm/day, respectively. In a more thorough way, the departure of estimated ET_o from the FAO 56 Penman-Monteith model estimates is also shown by root mean square error (RMSE) and absolute average deviation (ADD) (Kobayashi and Salam, 2000).

Table 8: Summary Statistics for Regression of mean annual ET_o estimated by five ET models against that estimated by FAO Penman-Monteith model (N = 4380 days)

S/N	ET Models	Statistics Regression	R^2	RMSE	ADD
1	Priestley-Taylor	$Y = 0.1890\ X + 6.4404$	0.8278	-2.87	0.053
2	Thornth-Waite	$Y = 0.0612\ X + 13.743$	0.9241	-5.27	0.040

3	Hargreaves	$Y = 2.6084\,X - 22.637$	0.8646	0.81	0.126
4	ASCE-Penman Monteith	$Y = 1.7209\,X + 0.1133$	0.9992	-5.43	0.025
5	Blaney-Criddle	$Y = 41.602\,X - 225.24$	0.9340	0.92	1.740

Given the best anticipated values, the ASCE-Penman Monteith model produced regression equations with a slope (M) somewhat greater than unity (1.7209) and an intercept (C) near zero (0.1133). The ASCE-Penman Monteith model (R^2 = 0.9992%) was found to be the best suitable model for calculating ET_o. This model requires a number of parameters, including monthly radiation, mean temperature, wind speed, and vapour pressure data. With the lowest RMSE value of -5.43 mm/day, the ASCE-Penman Monteith model outperformed the other models examined. The Priestley-Taylor model produced the second-best values (M = 0.1890 and C = 6.4404). However, to better understand the effects of seasonal climate variability, Gelcer *et al.* (2010) carried out a study on the evaluation of methodologies to estimate reference evapotranspiration in Florida. The use of the FAO Penman-Monteith model with and other models were compared. The Priestley-Taylor model was found to be the best model to use. The Hargreaves model generated the least underestimated values (7%), while the Thornth-Waite model gave the most underestimates (up to 16%). Conversely, Koffi *et al.* (2015), evaluated the performance of sixteen ET_o models against the ASCE Penman-Monteith model under the Sahelian conditions at Ndiaye and Fanaye (Senegal) for alternate model for ET_o estimation with less climatic parameters. The results showed that the Hargreaves model systematically overestimated ET_o with the highest percent error of estimate (PE). In a study conducted by Swati *et al.*, 2014 on a statistical comparison of ET_o models from Jharkhand state of India, the comparative analysis indicated the suitability of Hargreaves model (98.8%) over Christiansen model and Pan Evaporation method.

In contrast, the Blaney-Criddle model had the worst estimates of all the models that were tested, overestimating by up to 24%. In a similar vein, the Blaney-Criddle model was the least successful model with an ADD value of 1.740 mm/day and RMSE of 0.92 mm/day, as against the study conducted by Mohammad *et al.* (2013), with different models compared with FAO Penman-Monteith model. Results show that Blaney-Criddle model was the best in light of mean biased error (MBE), root mean square error (RMSE) and maximum absolute error (MAXE). The values of MBE, RMSE and MAXE computed as -0.554, 0.690 and 1.429 mm/day for Blaney-Criddle, respectively. Similarly, Csaba *et al.* (2013) carried out analyses to explore the output range and sensitivity of models of different physical approaches under local conditions. As regards the systematic error, Blaney-Criddle was found to be the closest to the FAO Penman-Monteith model as a reference value. Table 9 displays the mean monthly correction factors that can be used to modify the Blaney-Criddle, Hargreaves, and Thornth-Waite models for possible application at each geopolitical zone.

Table 9: Mean monthly correction factors for Blaney-Criddle, Hargreaves and Thornth-Waite model

Agro-Climatic Zones	**Blaney-Criddle**	**Hargreaves**	**Thornth-Waite**
North-East	0.126	0.267	0.068
North-West	1.153	0.341	0.210

North-Central	0.151	0.334	1.146
South-East	0.117	1.026	0.164
South-West	0.225	0.191	1.420
South-South	0.142	0.273	0.260

4.0 CONCLUSION and RECOMMENDATIONS

4.1 Conclusions

The most reliable and precise approach for estimating ET_o is the FAO 56 Penman-Monteith model. The six agro-climatic weather stations have mean monthly average ET_o estimations of 6.48, 14.14, 7.66, 11.16, 5.57, and 3.70 for FAO 56 Penman-Monteith, Priestley-Taylor, Thornth-Waite, Hargreaves, ASCE-Penman Monteith, and Blaney-Criddle models, respectively. The models exhibit significant diversity, and the relationship between them is location-dependent, according to the results of the study. The ASCE-Penman Monteith model, which has a strong correlation with the FAO 56 Penman-Monteith model, is the strongest predictor; the Priestley-Taylor model is still the second-best. The Blaney-Criddle model significantly overstated the FAO 56 Penman-Monteith model, but the Thornth-Waite and Hargreaves model generated the underestimated numbers.

4.2 Recommendations

This study led to the following recommendations:

(i) The Priestley-Taylor, Hargreaves, and Blaney-Criddle model with the created correction factors in this study can be utilized to estimate agricultural water requirements in Nigeria in the lack of radiation, vapour pressure, and sunshine data that may prevent the use of the FAO 56 Penman-Monteith model

(ii) To estimate ET_o more accurately, it is advised to use weather data spanning ten to thirty years.

REFERENCES

Csaba, R., Janos, N., and Attila, C. D. (2013): Comparison of Several Methods for Calculation of Reference Evapotranspiration. Institute for Land Utilization, Regional Development and Technology, Centre for Agricultural and Applied Economic Sciences, University of Debrecen, Debrecen, Hungary.

Droogers, P. and Allen, R. G. (2002): Estimating reference evapotranspiration under inaccurate data conditions. Irrigation Systems. 16, 33-45.

FAO (1990): Report on the Expert consultation on revision of FAO methodologies for crop water requirements. Annex V, Rome, Italy. 26 Pp.

Gelcer, E M., Fraisse, C. W., and Sentelhas, P. C. (2010): Evaluation of Methodologies to Estimate Reference Evapotranspiration in Florida. Proceeding of Florida state Horticulture Society. 123: 189-195.

Jensen, M. E., Burman, R. D. and Allen, R. G. (Eds.) (1990): Evapotranspiration and Irrigation Water Requirements. Committee on Irrigation Water Requirements, Irrigation and Drainage Division of ASCE, Manual No. 70.Amer. Soc, of Civil Engr., New York, 332 p.

Kobayashi, K. and Salam, M. U. (2000): Comparing simulated and measured values using mean squared deviation and its component. Journal of Agronomy, 92: 345-352.

Koffi, D., Alpha, B. B., Abdoulaye, S., Bertrand, M., Suat, I., Mamadou, K., N., Baboucarr, M., Yonnelle, D. M., Koichi, F., and Kazuki, S. (2015): Evaluation of Sixteen Reference Evapotranspiration Methods under Sahelian Conditions in the Senegal River Valley. Journal of Hydrology: Regional Studies. Vol. 3: 139-159.

Merem, E. C., Twumasi, Y., Wesley, J., Isokpehi, P., Shenge, M., Fageir, S., Crisler, M., Romorno, C., Hines, A., Ochai, S., Leggetti, S. and Nwagboso, E. (2017): Hydrological Study of Nigeria. Department of Urban and Regional Planning, Jackson State University, Jackson, MS, USA.

Mohammad, M. H., Reza, N. N., Mohammad, V., Ali, A., and Morteza, H. (2013: Comparison of Evapotranspiration Models for Estimating Reference Evapotranspiration in Arid Environment. Middle-East Journal of Scientific Research. Vol. 15 (9). 1331-1337. ISSN: 1990-9233.

Pankaj, K. P., Parmendra, P. D. and Vanita, P. (2016): Evaluation of reference evapotranspiration methods for the north eastern region of India. Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Itanagar, Arunachal Pradesh, India.

Pereira, A. R. and Pruitt, W. O. (2004): Adaptation of the Thornth-Waite scheme for estimating daily reference evapotranspiration. Agricultural Water Management. 66:251-257.

Sentelhas, P. C., Gillespie, T. J. and Santos, E. A. (2010): Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. Agr. Water Mgt. 97: 635-644.

Suat, I. and Dorota, Z. H. (2014): Evapotranspiration: Potential or Reference. UF IFAS Extension University of Florida, USA.

Swati, P., Manoj, K., Soublhik, C., and Mahanti, N. C. (2014): A Statistical Comparison of Reference Evapotranspiration: A CaseStudy from Jharkhand State of India. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 3, Issue 1. 8765-8777. ISSN: 2319-8753.

To cite this article:

Olayaki-Luqman, M., Dauda, K. A. and Kawata, M. A, 2026. Linearization of Evapotranspiration Rate in Nigeria Using Agro-Climatic Data for Comparing Reference Evapotranspiration Models. 1(1): 19-33. https://journals.unizik.edu.ng/ujabe/