Evaluation of the Performance of some Evapotranspiration Models at a Tropical Location in Ile – Ife, Nigeria

Adekunle B. Toyeje[1], Lukman A. Sunmonu[1], Ayodele P. Olufemi[2*], Oladimeji A. Babatunde[1], Olawale E. Abiye[3], Olanrewaju O. Soneye-Arogundade[1], Muritala A. Ayoola[1], Opeyemi R. Omokungbe[1], Omodara E. Obisesan[1]

[1]Department of Physics and Engineering Physics, Obafemi Awolowo University
Ile–Ife, Nigeria

[2]Department of Physics, University of Medical Sciences
Ondo, Ondo State, Nigeria

[3]Centre for Energy Research and Development (CERD), Obafemi Awolowo University
Ile–Ife, Nigeria

[*]*Corresponding author e-mail: aolufemi [AT] unimed.edu.ng*

ABSTRACT---- ***This study evaluates the performance of some evapotranspiration models at Ile – Ife (7º 33' N, 4º 33' E) Nigeria. This was to identify suitable evapotranspiration (ET) models at the study site and to provide useful information for standardizing evapotranspiration estimations at a tropical location. Meteorological parameters (wind speed, relative humidity, temperature, solar radiation, soil heat flux, and net radiation) were routinely measured at the Obafemi Awolowo University (OAU) Meteorological Station located within the Teaching and Research Farm of the campus for a period of a month (1st – 29th July 2014). Nine standardized models for the estimation of ET; Penman-Monteith (FAO-56 PM), Priestly-Taylor (PT), Makkink (MAKK), Jensen-Haise (JH), Hargreaves-Samani (HS), Ivanov (IVA), Modified Romanenko (MROM), FAO-24 Radiation (FAO-24 RAD) and Turc (TURC) models were employed. The ET values obtained from these models were then compared to the estimated values obtained from the FAO-56 PM equation recommended as the international standard method for determining reference ET. The estimation of the ET obtained from FAO – 56 PM model ranged between 0.426 – 2.239 mm/day, MAKK, JH, and HS gave estimation closest to this, ranging from 0.544 – 2.272 mm/day. The estimation of ET from other models revealed that PT has the highest value ranging between 1.323 – 6.936 mm/day, followed closely was FAO – 24 RAD with values ranging between 1.197 – 6.500 mm/day, values of IVA model ranged from 0.620 – 1.829 mm/day, MROM value ranged from 1.240 – 3.659 mm/day, TURC has the least value ranging from 0.190 – 0.584 mm/day. Using the result of the mean biased error and regression analysis, JH model compared best with the FAO – 56 PM with coefficient of determination (R2) = 0.927; slope (b) = 0.957; mean biased error (MBE) = 0.133, this was followed closely by HS with value R2 = 0.929; b = 1.199; MBE = - 0.075 and MAKK with the value R2 = 0.931; b = 1.198; MBE = - 0.052. However, the other models showed significant over or underestimation of the ET benchmark values. The performance of the other models showed no improvement after they were recalibrated by adjusting their original coefficients. Thus, six out of the ET models employed in this study [the Priestly-Taylor (PT), Makkink (MAKK), Jensen-Haise (JH), Hargreaves-Samani (HS), FAO-24 Radiation (FAO-24 RAD) and Turc (TURC)] were found suitable for the climatic region of Ile – Ife after the adjustment of their coefficients.***

Keywords---- Evapotranspiration, Peaman-Monteith, Hagreaves-Samani, Makkink, Turc, FAO-24 Radiation

---

1. INTRODUCTION

Evapotranspiration (ET) is a crucial parameter for monitoring the transfer of mass, momentum, and energy between the soil-vegetation-atmosphere interface. The quantification of the Evapotranspiration parameters is important for climatological and agro-meteorological purposes (Hasen *et al.*, 1980; Abdelkrim *et al.*, 2014). The direct measurement techniques of ET are reportedly costly and tedious for long-term deployment (Fontenot, 2004; Smith *et al.*, 1991; Allen *et al.*, 1998; Ogolo, 2014). Researchers have resorted to estimating this parameter from empirical relationships that depend on routinely measured surface layer weather parameters. Hill *et al.* (1983) reported more than fifty methods or variations available for estimation of Evapotranspiration. These methods can be broadly classified as (a) temperature-based, (b) radiation based, and (c) combined method comprising of both temperature and radiation parameter in its mathematical expression (Jensen *et al.*, 1990; Dingman, 1994; Watson and Burnett 1995; Drexler *et al.*, 2004). The combined method accommodates vapourization dynamics, aerodynamic characteristics, and other surface layer flow properties in its formulation. This allows for robust and accurate ET estimates irrespective of the climatic regime. Therefore, as a generally

accepted variant of the combined method, the *FAO-56* Penman-Monteith equation is recommended as the international standard method for determining reference ET (Jensen *et al.*, 1990; Allen *et al.*, 1998; Allen *et al.*, 2011; Irmak *et al.*, 2008; Hargreaves and Allen, 2003). Based on the foregoing, studies have established that ET estimates obtained from the Penman-Monteith equation have strong correlations with directly measured ET values under different climatic conditions (Xu and Singh, 2002; Oudin *et al.*, 2005; Egwuonwu *et al.*, 2011). However, because of the expansive framework of the FAO-56 PM equation requiring numerous input data, there is the need to evaluate the performances of other ET estimation methods that require fewer input parameters for regions like Nigeria with data paucity.
In a recent study carried out in Ile-Ife, the FAO-56 PM method compared favorably with the direct measurement of ET obtained from the Eddy Covariance technique (Babatunde *et al.*, 2017). Although the study demonstrated the veracity of the FAO-56 PM method as an accurate ET determining technique in the absence of direct measurements, it is limited in terms of the number of models requiring fewer input parameters evaluated. In this present study, eight ET models requiring fewer input parameters will be evaluated based on the estimates obtained from FAO-56 PM.

2. METHODOLOGY

Site Description and Instrumentation
Figure 1 shows the location of Ile-Ife (7.52º N, 4.52º E) Nigeria, at the "tropical wet and dry" zone of West Africa according to Köppen's classification (Griffiths, 1974). Average annual precipitation ranges from 1000 to 1500 mm, and the surface wind is typically weak, $u < 1.5$ ms^{-1} (Hayward and Oguntoyinbo, 1987; Jegede, 1998; Jegede, *et al.*, 2006). Due to its proximity to the equator, the intensity of solar radiation received at Ile-Ife's surface is high all year round. From the hourly global radiation data at Ile-Ife, maxima are found at about 13:00 LT, with values of 1100 and 800 Wm^{-2} for March and August, respectively (Balogun *et al.*, 2003).

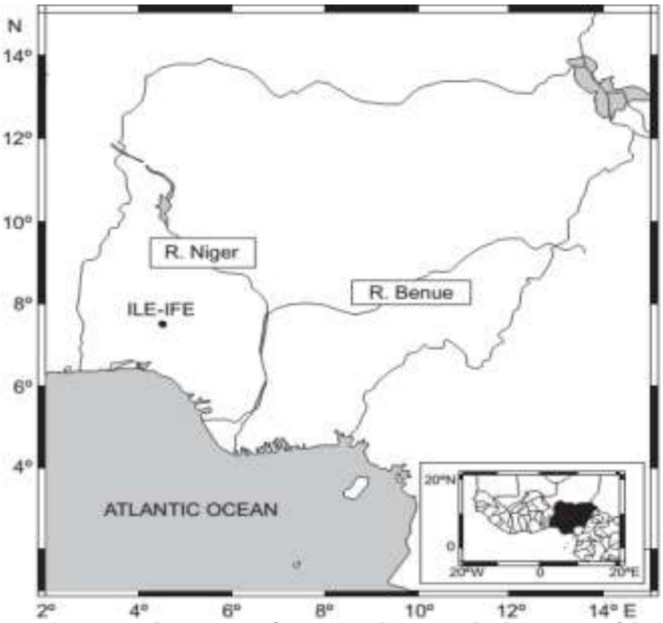

***Fig. 1.** Outline map of Nigeria showing the location of Ile-Ife (7.52º N, 4.52º E), where the routine measurement parameter was recorded. Insert is the sub-continent of West Africa.*

***Fig 2:** OAU Meteorological Station located within Teaching and Research Farm, OAU Campus, Ile – Ife.*

A time series of the basic meteorological parameters such as net radiation, ground heat flux, air temperature, humidity, soil heat flux, vapor pressure, atmospheric pressure, among others were sampled every 10 s and stored at every minute. The measurement site had dimensions approximating 50 m by 60 m and its surface was covered by short grass which was mowed regularly throughout the measurement period to maintain its evenness. In the middle of the measurement enclosure, a 6 m mast with booms hanging meteorological sensors such as cup anemometer, temperature, and humidity sensor was positioned at two levels (0.3 m and 2 m) for gradient measurement of wind speed, air temperature, and relative humidity. Also, on another 1.7 m high radiation stand, a REBS net radiometer (*NR-LITE*) was positioned (Fig. 2). Heat flux plates were buried in the ground at depths of 2 cm, 10 cm, and 30 cm, with the one at the topmost used in this study.

Data acquisition of these meteorological variables was programmed using the LOGGERNET® software supplied by Campbell Scientific, sampled at 10s intervals, and stored as 1-min. averages, using a Campbell Scientific datalogger, model CR1000. Acquisition of data at the site started in June 2014 and it is continuous but for the purpose of this study, the period between 1st and 29th July 2014 was used. Data for the period were subsequently and carefully checked for instrumental errors while a stringent QA/QC procedure was introduced to remove spurious data and replace missing values.
A standardized data analysis software package was used for the analysis of the variations of the measured parameters.

3. EVAPOTRANSPIRATION MODELS EMPLOYED IN THE STUDY

The theoretical framework of the eight (8) ET models requiring less input parameters which were evaluated in this study together with that of the benchmark method, the Penman-Monteith (*FAO – 56 PM*) model are presented in Table 1

Table 1: The Evapotranspiration Models used in this Study

Models	**Reference(s)**	**Formulations**
FAO–56 PM	Qui et.al., (2002)	$ET_{PM} = \frac{0.408\Delta(R_n - G) + \frac{\gamma 670 U_z(e_s - e_a)}{T_m + 273}}{\Delta + \gamma(1 + 0.602U_z)}$
FAO 24 Radiation	Doorenbos and Pruitt (1977)	$\mathrm{ET_{FAO24}} = a + b\left[\frac{\Delta}{\Delta + \gamma}\right]R_s$
Turc	Turc (1961)	$ET_{TURC} = a_T 0.013 \frac{T_m}{T_m + 15} \times \frac{23.9R_s + 50}{\lambda}$
Makkink	Makkink (1957)	$ET_{MAKK} = 0.61 \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2.45} - 0.12$
Jensen-Haise	Rosenberg *et al.* (1983)	$ET_{JH} = \frac{R_S}{2.45} \times [(0.025 \times T_m) + 0.08]$
Priestly–Taylor	Priestley and Taylor (1972)	$ET_{PT} = \alpha \frac{\Delta}{\Delta + \gamma}(R_n - G)$
Hargreaves-Samani	Hargreaves and Samani (1985) Hargreaves and Allen (2003)	$\mathrm{ET}_{HS} = 0.0135 \times R_s \times 0.4082 \times (T_m + 17.8)$
Ivanov	Romanenko (1961)	$\mathrm{ET_{IVA}} = 0.000036 \times (25 + T_m)^2 \times (100 - RH_m)$
Modified Romanenko	Oudin *et al*. (2005)	$ET_{MROM} = 4.5\left[1 + \left(\frac{T_m}{25}\right)\right]^2\left[1 - \frac{e_a}{e_s}\right]$

where ET_{PM} is the evapotranspiration ($mm\ day^{-1}$) using the FAO-56 PM model, R_n is net radiation (Wm^{-2}), G is soil heat flux (Wm^{-2}), γ is the psychrometric constant ($= 0.000665 kPa\ °C^{-1}$), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), Δ is the slope of the saturation vapour pressure-temperature curve ($kPa\ °C^{-1}$), T_m -mean daily air temperature, RH_m - daily mean relative humidity, R_s is solar radiation, α (= *1.26*)

Moreover, from the ET estimates that were obtained from the model equations, a regression analysis based on least square techniques was used to adjust (recalibrate) the original coefficients involved in their formulation. This essentially will provide an adjusted constant that will enhance the suitability of the models for ET estimation under tropical conditions such as the study area. Hence, in this study, the selected ET models, *FAO 24, TURC, MAKK, JH, PT, HS, IVA, and MROM*, were recalibrated using the reference, *FAO - 56 PM*. Thus, the intercept, a, and slope, b, of the line of best fit obtained between the benchmark method and other models were used as site-dependent modification coefficients equation (1) (Tabari *et al*., 2011; Houshang *et.al*., 2012):

$$ET_{PM} = b(ET_{model}) + a \qquad 1$$

To quantitatively examine the performance of the model equations before and after their coefficients were adjusted, error estimates and some statistical indices were calculated Table 2

Table 2: Performance Evaluation of the Selected Models

Statistcal Indices	**Expression**
Mean Bias Error	$\mathrm{MBE} = \mathrm{N}^{-1}\sum_{i=1}^{N}(P_i - O_i)$
Root Mean Square Error	$\mathrm{RMSE} = [\mathrm{N}^{-1}\sum_{i=1}^{N}(P_i - O_i)^2]^{0.5}$
Index of Agreement	$d = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}[/\mathrm{Pi} - \bar{\mathrm{O}}/ + /\mathrm{Oi} - \bar{\mathrm{O}}/]^2}$

4. RESULTS AND DISCUSSION

The daily mean values of evapotranspiration, ET estimates obtained from the study carried out are presented in Table 3. The values in mm/day estimated, ranges from 0.43 to 2.24; 1.92 to 6.50; 0.19 to 0.58; 0.59 to 1.75; 0.65 to 2.21; 1.32 to 6.94; 0.54 to 1.76; 0.62 to 1.83 and 1.24 to 3.66 for FAO-56 PM, FAO-24 RAD, TURC, MAKK, JH, PT, HS, IVA and MROM models respectively for the period of study (July 2014). The results obtained are presented graphically in Figure 3. The figure displayed the diurnal variation of ET estimates obtained from the models at the study site. From the graph, the values obtained from the models showed a similar pattern of fluctuations over the diurnal course. As shown in the Figures, during the nocturnal periods and early morning before sunrise (at about 19:00LT to about 09:00LT), significant evapotranspiration does not occur. The ET values obtained at these periods are nearly zero. This is as a result of the fact that there is no sufficient available energy from sunlight and wind to drive the process significantly at such times under stable/neutral atmospheric boundary layer conditions. During the daytime, however, as the surface becomes sufficiently warm and unstably stratified, the rate of *ET* occurrence gradually rises until it reaches peak values around the solar noon (13:00LT). From the result presented in both Table 3 and Figure 3, estimated values of *ET* given by JH model are closest to those of FAO-56 PM chosen as benchmark method. Meanwhile, the estimates are given by PT and FAO-24 RAD significantly overestimated the reference ET values by more than 100% while TURC, MAKK, IVA, and HS underestimated the reference values.

Table 3 showing the daily values of ET estimate obtained from the methods

DATE JULY,2014	DOY	PM (mm/day)	FAO 24 (mm/day)	TURC (mm/day)	MAKK (mm/day)	JH (mm/day)	PT (mm/day)	HS (mm/day)	IVA (mm/day)	MROM (mm/day)
1st	182	1.67	5.26	0.47	1.40	1.79	5.18	1.42	1.37	2.74
2nd	183	2.24	6.27	0.58	1.75	2.21	6.94	1.76	1.67	3.33
3rd	184	1.37	4.29	0.41	1.21	1.51	4.23	1.21	1.36	2.72
4th	185	1.68	4.29	0.40	1.23	1.46	5.19	1.19	1.35	2.70
5th	186	1.90	5.84	0.51	1.55	1.88	5.91	1.52	1.46	2.93
6th	187	1.97	6.50	0.55	1.67	2.06	6.11	1.66	1.81	3.62
7th	188	0.86	3.14	0.29	0.90	1.03	2.68	0.85	0.89	1.78
8th	189	1.10	3.26	0.30	0.93	1.08	3.40	0.89	1.24	2.47
9th	190	1.17	3.79	0.34	1.04	1.23	3.62	1.00	1.39	2.77
10th	191	1.49	4.78	0.46	1.39	1.71	4.60	1.37	1.63	3.26
11th	192	1.60	5.37	0.49	1.47	1.85	4.97	1.48	1.77	3.55
12th	193	1.72	5.87	0.53	1.57	1.99	5.33	1.58	1.83	3.66
13th	194	0.69	2.68	0.27	0.82	0.95	2.14	0.78	0.99	1.97
14th	195	1.82	5.72	0.53	1.58	2.01	5.63	1.60	1.72	3.44
15th	196	1.55	4.91	0.46	1.36	1.74	4.80	1.38	1.60	3.20
16th	197	0.90	2.87	0.28	0.86	0.97	2.78	0.80	1.04	2.08
17th	198	0.43	1.92	0.19	0.59	0.65	1.32	0.54	0.62	1.24
18th	199	1.46	5.14	0.44	1.34	1.62	4.55	1.31	1.40	2.81
19th	200	1.63	5.07	0.44	1.34	1.62	5.06	1.31	1.49	2.97
20th	201	1.57	4.95	0.45	1.34	1.66	4.87	1.34	1.44	2.87
21st	202	0.92	3.43	0.32	0.97	1.16	2.86	0.94	1.07	2.15
22nd	203	0.92	2.75	0.25	0.76	0.89	2.85	0.73	1.05	2.10
23rd	204	1.49	2.82	0.25	0.76	0.90	4.62	0.74	1.40	2.80
24th	205	0.69	2.52	0.25	0.75	0.87	2.15	0.72	1.03	2.07
25th	206	0.80	2.80	0.26	0.80	0.93	2.50	0.76	1.00	2.00
26th	207	0.97	3.16	0.30	0.92	1.10	3.01	0.89	1.11	2.22
27th	208	1.93	5.11	0.48	1.42	1.79	5.98	1.43	1.45	2.89
28th	209	1.53	4.13	0.40	1.21	1.44	4.74	1.17	1.04	2.09
29th	210	1.14	3.30	0.32	0.96	1.15	3.52	0.93	1.22	2.44

The performances of the ET models employed in the study were remarkably improved by adjusting their original coefficient using a simple technique based on regression analysis carried out between each model and the reference method (FAO-56 PM) and the results are presented in Figure 4. The coefficients obtained from the regression analysis carried out were used as new empirical constants to adjust the ET model equations as presented in Table 4. The impact of this adjustment was then examined on an unused four days' dataset, the results before and after coefficient adjustment were presented in Figure

5, it can be observed that model results improved after the coefficient adjustment as the gaps between the models and the reference method closed up. To quantify this improvement some statistical indicators namely *MBE*, *RSME*, *d*, and slope *(b)* were calculated and presented in Table 5. From this table, error values reduced significantly, the index of agreement increased and the slope was near unity after the coefficients of the original model equations were adjusted.

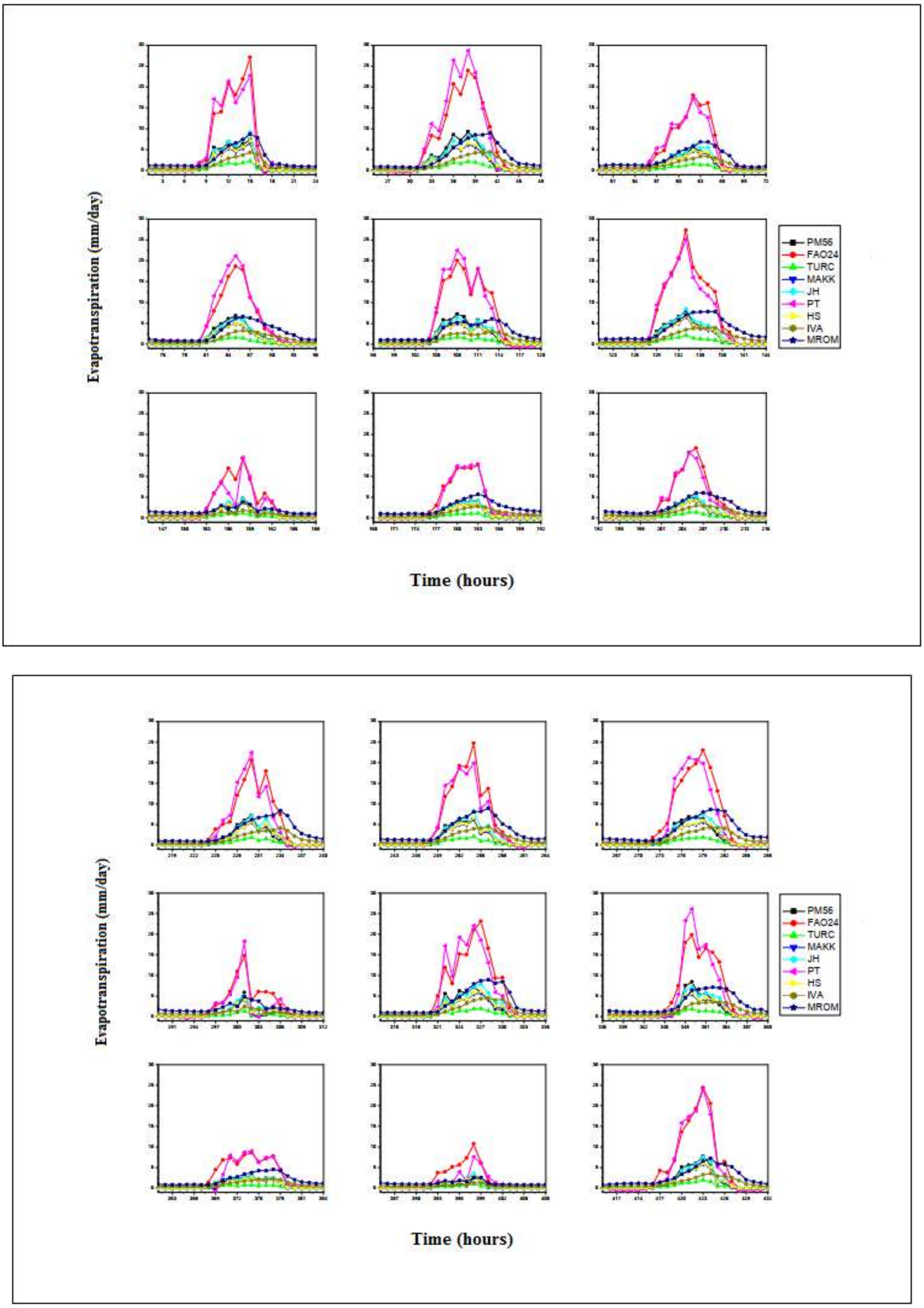

Fig. 3: Diurnal Variation of *ET* Estimation obtained from Nine Selected Models for (*a*): 25th July 2014 (DOY 206); (*b*): 26th July 2014 (DOY 207); (*c*): 27th July 2014 (DOY 208); (*d*): 28th July 2014 (DOY 209); and (*e*): 29th July 2014 (DOY 210).

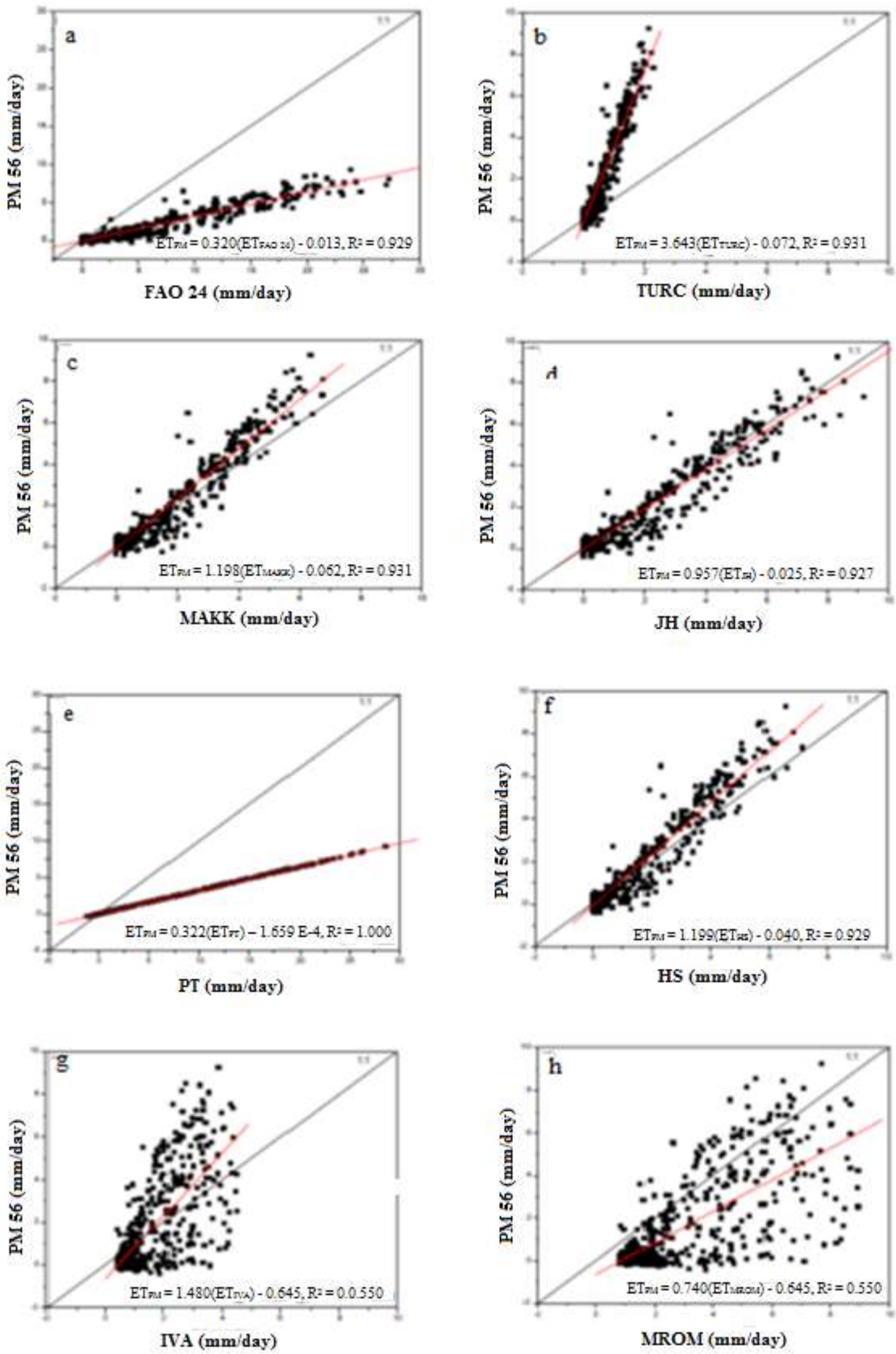

Figure 4: *FAO-56 PM* Model Estimated *ET* Values against Empirical Methods [(*a*): FAO 24 Radiation (*FAO 24 RAD*); (*b*): Turc (*TURC*); (*c*): Makkink (*MAKK*); (*d*): Jensen Haise (*JH); (e)*: Priestley-Taylor (*PT*); (*f*): Hargreaves-Samani (*HS*); (*g*): Ivanov (*IVA*); and (*h*): Modified Romanenko (*MROM*)] estimated values using the original constant values involved in each equation

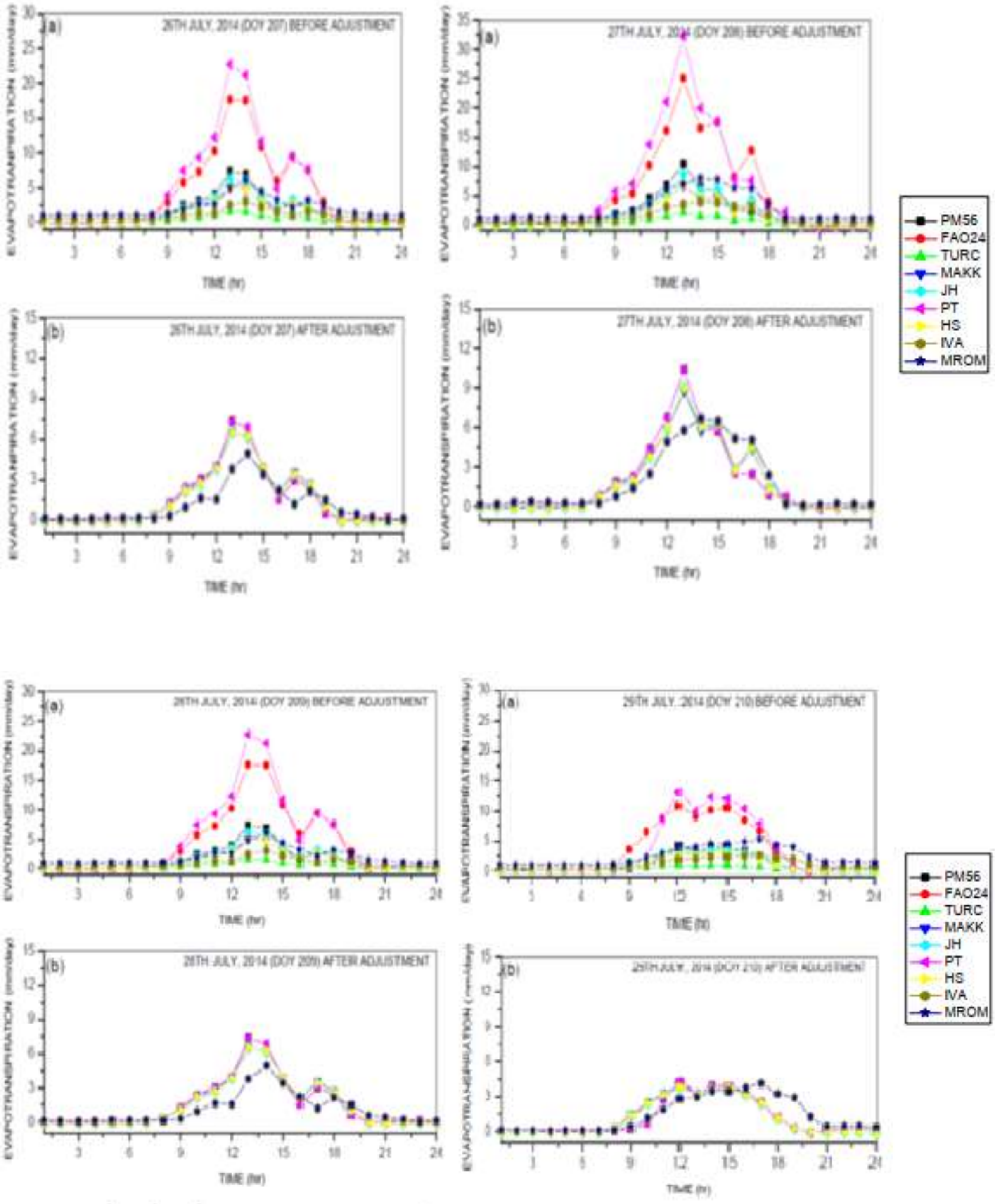

Figure 5: Plot of *ET* Estimated by the *FAO-56 PM* Method and Eight Empirical Methods with (*a*): Original constant and (*b*): Recalibrated constant values involved in each equation for 26th 27th 28th 29th July, 2014

Table 4: The Result of the Calibration Coefficient obtained from the Regression Analysis for Models Adjustment

Original Models	**Adjusted Models**
$\mathrm{ET}_{\mathrm{FAO24}} = a + b\left[\frac{\Delta}{\Delta+\gamma}\right]R_s$	-0.013+0.320$\left(a + b\left[\frac{\Delta}{\Delta+\gamma}\right]R_s\right)$
$ET_{TURC} = 0.013T_a * \frac{23.9R_s + 50}{T_a + 15}$	-0.072+3.643$\left(0.013T_a * \frac{23.9R_s+50}{T_a+15}\right)$
$ET_{MAKK} = 0.61\frac{\Delta}{\Delta+\gamma} * \frac{R_s}{\lambda} - 0.12$	-0.062+1.198$\left(0.61\frac{\Delta}{\Delta+\gamma} * \frac{R_s}{\lambda} - 0.12\right)$
$ET_{JH} = \frac{R_S}{2.45} * [(0.025 * T_m) + 0.08]$	0.025+0.957$\left(\frac{R_S}{2.45} * [(0.025 * T_m) + 0.08]\right)$
$ET_{PT} = 1.26\frac{\Delta}{\Delta+\gamma}(R_n - G)$	1.659E-4+0.322$\left(1.26\frac{\Delta}{\Delta+\gamma}(R_n - G)\right)$
$\mathrm{ET}_{HS} = 0.0135 * R_s * Conc(T_m + 17.8)$	-0.040+1.199$(0.0135 * R_s * Conc(T_m + 17.8))$
$\mathrm{ET}_{\mathrm{IVA}} = 0.00003 * [(25 + T^2) * (100 + RH)]$	-0.645+1.480$(0.00003 * [(25 + T^2) * (100 + RH)])$
$ET_{MROM} = 4.5\left[1 + \left(\frac{T_m}{25}\right)\right]^2\left[1 - \frac{e_a}{e_s}\right]$	-0.645+0.740$\left(4.5\left[1 + \left(\frac{T_m}{25}\right)\right]^2\left[1 - \frac{e_a}{e_s}\right]\right)$

Table 5: Statistical Analysis of ET Models before and after Recalibration

Before and after Recalibration

26th July, 2014 (DOY207)								
MODELS	**MBE**	**MBE$_a$**	**RMSE**	**RMSE$_a$**	**D**	**d$_a$**	**Slope (b)**	**Slope$_a$ (b$_a$)**
FAO 24	2.194	0.143	2.360	0.345	0.6511	0.005	0.307	0.843
TURC	-0.666	0.146	0.695	0.379	-6.9E-05	0.108	3.277	0.826
MAKK	-0.052	0.150	0.353	0.397	0.980	0.283	1.060	0.816
JH	0.133	0.142	0.325	0.357	0.960	-0.619	0.885	0.843
PT	2.037	0.001	2.037	0.001	0.808	0.093	0.322	0.999
HS	-0.075	0.144	0.329	0.370	0.953	0.245	1.092	0.833
IVAN	0.140	0.241	0.704	0.539	0.820	0.891	1.441	0.756
MROM	1.250	0.241	1.253	0.539	0.413	-0.052	0.721	0.756
27th July, 2014 (DOY208)								
MODELS	**MBE**	**MBE$_a$**	**RMSE**	**RMSE$_a$**	**D**	**d$_a$**	**Slope (b)**	**Slope$_a$ (b$_a$)**
FAO 24	3.180	-0.110	3.286	0.428	0.000	0.032	0.373	1.026
TURC	-1.455	-0.134	1.482	0.396	0.232	0.018	4.136	1.043
MAKK	-0.508	-0.156	0.626	0.393	0.786	0.067	1.377	1.060
JH	-0.143	-0.100	0.411	0.401	0.979	-1.360	1.070	1.019
PT	4.050	0.001	4.102	0.001	0.000	-0.027	0.323	1.000
HS	-0.502	-0.115	0.625	0.398	0.808	0.065	1.351	1.032
IVAN	-0.484	-0.078	1.183	0.879	0.750	-1.423	1.939	1.017
MROM	0.963	-0.078	1.383	0.879	0.000	0.056	0.969	1.017
28th July, 2014 (DOY209)								
MODELS	**MBE**	**MBE$_a$**	**RMSE**	**RMSE$_a$**	**D**	**d$_a$**	**Slope (b)**	**Slope$_a$ (b$_a$)**
FAO 24	2.601	-0.063	2.639	0.224	0.000	-0.052	0.385	1.057
TURC	-1.132	-0.047	1.147	0.210	0.075	0.058	4.145	1.045
MAKK	-0.321	-0.032	0.377	0.216	0.552	0.286	1.346	1.036
JH	-0.092	-0.067	0.218	0.209	0.833	1.000	1.113	1.060
PT	3.208	0.002	3.234	0.002	0.000	-0.071	0.323	0.999
HS	-0.359	-0.055	0.407	0.209	0.447	2.645	1.378	1.052
IVAN	-0.484	-0.443	1.122	0.753	0.000	0.436	2.789	1.463
MROM	0.560	-0.443	1.072	0.753	0.784	-0.002	1.394	1.463
29th July, 2014 (DOY210)								
MODELS	**MBE**	**MBE$_a$**	**RMSE**	**RMSE$_a$**	**D**	**d$_a$**	**Slope (b)**	**Slope$_a$ (b$_a$)**
FAO 24	2.158	0.024	2.245	0.256	0.601	0.066	0.353	0.970
TURC	-0.819	0.066	0.849	0.285	-5.6E-05	-1.295	3.777	0.952
MAKK	-0.174	0.041	0.399	0.300	0.000	0.093	1.215	0.953
JH	0.010	0.022	0.273	0.267	1.000	-2.348	1.029	0.980
PT	2.387	0.001	2.414	0.002	0.637	0.072	0.322	0.998
HS	-0.204	0.028	0.408	0.276	0.000	0.082	1.263	0.964
IVAN	0.083	0.282	0.829	0.573	0.000	0.827	1.689	0.886
MROM	1.302	0.282	1.331	0.573	0.000	-0.057	0.845	0.886

NOTE: MBE_a, $RMSE_a$, d_a, $Slope_a$ are adjusted values

5. CONCLUSION

Based on the findings of the study, JH model has a strong agreement with FAO-56 PM and can be adjudged suitable for *ET* estimation at tropical locations such as Ile-Ife, Nigeria.

Also, PT, FAO-24 RAD, TURC, MAKK, HS, and IVA models are considered suitable for tropical conditions only after their original constants are empirically adjusted. This information will be useful for irrigation schedulers, drought predictors, and agro-meteorologists.

6. REFERENCES

Abdelkrim, K., Abdelkader, K., and Abderrahmane, H. (2014): Using the Priestley-Taylor expression for estimating actual evapotranspiration from satellite Landsat ETM + data. Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions Proceedings of ICWRS2014, Bologna, Italy, IAHS Publ. 364.

Allen, R. G., Pereira, L.S., Reas D., Smith M. (1998): Crop evapotranspiration guidelines for computing requirements. Food and Agric Organization (FAO) Irrigation and Drainage paper 56, Rome, 326.

Allen, R.G., Pereira, L.S., Howell, T.A., and Jensen, M.E. (2011): Evapotranspiration information reporting 1: Factors governing measurement accuracy. Agricultural Water Management, 98(6):899-920.

Balogun, A.A., Jegede, O.O., Olaleye, J.O., (2003). Surface radiation budget over bare soil at Ile-Ife, Nigeria. Niger. J. Sol. Energy 14, 6–13.

Babatunde O.A. Abiye O.E Sunmonu L.A., Olufemi A.P., Ayoola M.A. Akinola O.E, Ogolo E.O (2017): A Comparative evaluation of four evapotranspiration models based on Eddy Covariance measurement over a grass covered surface in Ile – Ife, Southwestern Nigeria. Model Earth Syst. Environ.

Dingman, S.L. (1994): Physical Hydrology. Upper Saddle River, NJ: Prentice Hall

Doorenbos, J. and Pruitt. W.O. (1977): Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24. Food and Agriculture Organization. Rome

Drexler, J.Z., Bedford, B.L., DeGaetano, A. and Siegel, D.I., (2004): Quantification of the water budget and nutrient loading for a small peatland in central New York. Journal of the American Water Research Association 34: 753–769.

Egwuonwu C.C., Okafor V.C., Ezeanya N.C., Nzediegwu C. and Okorafor O.O. (2011): A comparison of the reliability of six Evapotranspiration computing models for Abeokuta in South western Nigeria. Greener Journal of physical sciences 2(4):064-069.

Fontenot, R.L.B.S. (2004): an evaluation of reference evapotranspiration models in Louisiana State University and A&M College.

Griffiths, J.F., (1974): World Survey of Climatology, in: J.F. Griffiths (Ed.), Climates of Africa 10, Elsevier, Amsterdam, 620.

Hayward, D.F. and Oguntoyinbo, J.S., (1987): The climatology of West Africa, Rowan and Littlefield, New York (1987), 271.

Hansen, V.E., Israelsen, O.W., and Stringham G.E. (1980): Irrigation principles and practices 4th edition. New York, NY: John Wiley and sons inc.

Hargreaves, G. H. and Allen, R. G. (2003): History and evaluation of Hargreaves evapotranspiration equation. Journal of Irrigation and Drainage Engineering, 129(1), 53–63.

Hargreaves, G. H. and Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2), 96.

Hill R. W., Johns, E. L. and Frevert. D. K. (1983). Comparison of equations used for estimating agricultural crop evapotranspiration with field research. Bureau of Reclamation, U. S. Dep. Of the Interior Eng. and Res. Ctr., Denver, Colo. 26 (12) 2937-2944

Houshang G., Vahid R., Erfan K., Hossein M., (2012): Time and place calibration of the Hargreaves equation for estimating monthly reference evapotranspiration under different climatic conditions. Journal of Agricultural Science, 4, 3.

Irmak, S., Irmak, A., Howell, T.A., Martin, D.L., Payero, J.O., and Copeland K.S. (2008): Variability analyses of alfalfa-reference to grass-reference evapotranspiration ratios in growing dormant seasons. J. Irrig. Drain eng., ASCE, 134 (2), 147-159.

Jegege O.O., (1998): A field study of the mean surface layer structure in sub-Saharan West Africa the Pre-monsoon (dry) season Mausam, 48 (1998), 361–370.

Jegede O.O., Ogolo E.O. and Aregbesola, T.O., (2006): Estimating net radiation using routine meteorological data at a tropical location in Nigeria. International Journal of Sustainable Energy, 25(2), 107-115.

Jensen, M. E., Burman, R. D., Allen, R. G., (1990): Evapotranspiration and irrigation water requirements Committee on Irrigation Water Requirements. American Society of Civil Engineers a manual, New York.

Makkink, G.F., (1957): Testing the Penman Formula by means of lysimeters. Journal of the institution of water engineering 11(3):277-288.

Ogolo E.O., (2014): The comparative analysis of performance evaluation of recalibrated reference evapotranspiration models for different regional climatic conditions in Nigeria. Ife Journal of Science (16): 2

Oudin, L.; Hervieu, F.; Michel, C.; Perrin, C.; Andreassian, V.; Anctil, F. & Loumagne, C. (2005). Which Potential Evapotranspiration Input for a Lumped Rainfall–Runoff Model? Part 2 - Towards a Simple and Efficient Potential Evapotranspiration Model for Rainfall–Runoff Modelling. Journal of Hydrology, 303, 290–306.

Priestly, C.H.B., and Taylor, R.J. (1972): On the assessment of surface heat flux and evaporation using large- scale parameters. Monthly weather review 100(2):81-92.

Qiu, G.Y., Miyamoto, K., Sase, S., Gao, Y., Shi, P. and Yano, T. (2002): Comparison of the Three Temperature model and conventional models for estimating transpiration. Japanese Agricultural Research Quarterly 36(2):73-82

Romanenko, V.A. (1961) Computation of the autumn soil moisture using a universal relationship for a large area. Proceeding, Ukrainian Hydro Meteorological Research Institute, 3.

Rosenberg, N.J., Blad, B.L, Verma, S.B. (1983): Microclimate the Biological Environment, 2nd Edition, John Wiley & Sons, New York.

Smith, M., Allen, R.G., Monteith, J.L., Pereira, L.S., Perrier, A., and Pruitt, W.O. (1991): Report on the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements. Land and Water Development Division, United Nations Food and Agriculture Service: Rome

Tabari, H., Grimser, M. and Trajkovic, S. (2011): Comparative analysis of 31 reference evapotranspiration methods under humid conditions. Irrig. Sci., 31 (2), 107-117.

Turc, L. (1961). Estimation of irrigation water requirements, potential evapotranspiration: A simple climatic formula evolved up to date. Annals of Agronomy. (12), 13-14.

Watson, I. and Burnett, A.D. (1995). Hydrology: An environmental approach. Boca Raton, FL: CRC Press.

Xu, C.-Y. and Singh, V. P. (2002). Cross comparison of empirical equations for calculating potential evapotranspiration with data from Switzerland. Water Resources Management, 16, 197–219.