THE COMPARATIVE ANALYSIS OF PERFORMANCE EVALUATION OF RECALIBRATED REFERENCE EVAPOTRANSPIRATION MODELS FOR DIFFERENT REGIONAL CLIMATIC CONDITIONS IN NIGERIA.

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ABSTRACT

The study evaluated some radiation based models in four different climatic regions (Coastal, Savannah, Midland and Sahel) in Nigeria. The models (Abtews, Hargreaves, Makkink and Priestly Taylor) were further calibrated for each of the region. This was done with a view to improving the accuracy of evapotranspiration (ET) estimates and determining suitable model(s) for the estimation of reference evapotranspiration for each region. The models were calibrated for each region by adjusting their respective coefficient across different climatic conditions in Nigeria on monthly timescale locations. The new regional adjusted coefficient include: Abtew (1.34,0.841, 1.072 and 10.637), Hargreaves (0.,026, 0.019, 0.024 and 0.022), Makkink (1.06, 1.12, 0.024 and 0.88) and Priestly and Taylor(3.62, 2.67, 2.63 and 2.65) for the Arid, Midland, Guinea savannah and Coastal regions respectively as were arranged in the parenthesis. These new adjusted coefficients were greater in the arid than the other region. The most suitable model determined and recommended for each region based on the highest coefficient of determination (R^2) and least standard error of estimate (SEE) were Abtew (R^2 = 0.88, SEE = 1.62), Makkink (R^2= 0.80, SEE = 2.06) and Priestly Taylor (R^2 =0.80, SEE =2.06) for the Arid. In the Midland, the models were Priestly Taylor (R^2 =0.84, SEE=1.03) and Makkink (R^2=0.84, SEE = 1.05). Priestly and Taylor (R^2 = 0.84, SEE=0.83 was the only suitable model found for Guinea Savannah while Priestly and Taylor (R^2 = 0.84, SEE=0.47) and Hargreaves (R2= 0.84, SEE = 0.47) were the most suitable for the Coastal environment. The study concluded that the adjusted coefficient of the models for each region performed better compared with the non-adjusted models.

INTRODUCTION

Evapotranspiration (ET) is an essential component of water balance and hydrological cycles. It is a key variable in yield models, water balance, drought prediction, irrigation scheduling and soil traffic ability estimates (karim, 1991; Tyagi *et al.*, 2003; Sabziparvar *et al.*, 2009, 2011). It is also relevant in environmental assessment to quantify and estimate the amount of greenhouse gases in terms of water vapour-induced greenhouse warming and hence determine the trend of global warming (Irmak, *et al.,* 2003).

Evapotranspiration is the release of water from the surface to the atmosphere. It consists of evaporation and transpiration, the latter is the vaporization process through botanical organ. The concept of reference evapotranspiration was introduced by irrigation engineers in the 1970s and early 1980s (as was reported by Allen *e. al.,* 1998) to avoid ambiguities that existed in the definition of potential evapotranspiration, which was introduced by Penman (1948) to describe the amount of water transpired in a given time by a short green crop, completely shading the ground, of uniform height with adequate status in the soil. However, Reference evapotranspiration is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well watered and completely shading the ground (Chong-yu Xu, 2005). Reference crop evapotranspiration is a reflection of climate effects (Houshang *e. al.*, 2011).

The direct method of measuring ET often involves the use of lysimeter and Pan evaporimeter among others. These instruments are expensive to acquire and difficult to maintain hence the adoption of the alternative methods which are empirical. Over the years, scientists and hydrologists have resorted to the use of various empirical methods to determine reference evapotranspiration (Irmak, 2003;Lopez-Urrea *et al.*, 2006; Murugappan *et al.*, 2011) and these are classified according to the dominant atmospheric variable inputs. The general classification, according to some scientists (Xu and Singh, 2000 and Slavisa and Srdjan, 2009) includes temperature-based, radiation-based, combination-based, energy and water budget and mass transfer among others. The results obtained from the empirical method are site and location sensitive.

The Penman-Monteith (P-M) technique requires four meteorological parameters: relative humidity, wind air temperature and net radiation. The Food and Agricultural Organization (FAO) of the United Nations recently adopted a standardized form of the Penman-Monteith equation (FAO56-PM) in an effort to provide a common, globally valid standard for estimating ET, developing crop coefficients, and evaluation/calibration of other ET methods when lysimeter measurements are unavailable It is considered to be a standard model that is most reliable method and was recommended by the FAO (Allen, *et al.*, 1998) as the sole standard to verify other empirical methods. However, the input parameters may not always be available in a given location (Smith *et al.*,1991; Allen *et al.*, 1998; Camargo and Camargo, 2000; Bautista *et al.*, 2009). In spite of its robustness and accuracy, the application of FAO56-PM method suffers constraint in many regions due to lack of necessary weather parameters. Hence, in such circumstance, other empirical equations that are based on either temperature or radiation based are often suggested to estimate reference evapotranspiration (Trajkovic, 2005; Ventura *et al.*, 1999). However, studies carried out under diverse climatic conditions (Ogolo, 2009; Shahidian *et al.*, 2011) have revealed a widely varying performance of these alternative equations which require local calibration. According to Xu and Singh (1989), all the evapotranspiration models require that their constants or coefficient should be modified before they can be applied for the estimation of evapotranspiration in another location different from the locations where they were developed. Large errors can result where their coefficients are not properly calibrated for the new location. This was also corroborated by Smith *et al.*, (1991) who suggested that the alternative method should be subjected to rigorous local calibration before they can be used for the estimation of evapotranspiration in an environment other than where they have been developed.

In Nigeria, we have over forty (40) weather observatories located at different stations which are controlled by the Nigerian Meteorological Agency. None of this stations measure evapotranspiration except in some few research institutes. Thus, any pieces of information on ET can only be obtained by the alternative method and where such is done, the accuracy of ET values obtained is questionable because the coefficients of these models have not been calibrated for such region where they are applied. In view of this, this study will develop new regional coefficients for the monthly estimation of ET in Nigeria using the radiation-based models (Abtew1996; Hargreaves 1975; Makkink,1957 and Priestly-Taylor,1972) and hence calibrate the radiation-based models for different climatic regions in Nigeria and in addition, determine suitable models for each region.`.

MATERIALS AND METHOD OF STUDY

The data used in this study were obtained from the archive of the Nigerian Meteorological Agency (NIMET). NIMET is a weather agency having over 40 weather stations spread across different climatic conditions in Nigeria. Meteorological variables (minimum and maximum temperature, relative humidity, precipitation, solar radiation, wind speed), as shown on Table 1, were acquired spanning two and half decades. The quality assurance of the meteorological measurements was determined by checking the overall consistency of the monthly average of the climatic parameters (wind speed, minimum and maximum relative humidity, minimum and maximum temperature, and solar radiation). Two decades data (1975-1995) were used for the regional recalibration of the models while the rest five years data were used for validation.

The climate of Nigeria has been classified in this study according to vegetation and precipitation distribution (Olaniran and Sumner, 1989; Keay, 1959). The four climates identified in Nigeria starting from the southern part is coastal, savannah, Midland and Sahel in the arid region respectively. According to Keay (1959), the vegetation of Nigeria is determined by the climate, and in particular by the mean annual rainfall and the severity of the dry season and further determined by minimum relative humidity and length of the rainless period.

Table 1.0: Geographical Location and Average Monthly Weather Condition in each of the Locations for Three Decades

Station	Lat. N	Long. E	Elevation (m)	Air Temp. (°C)	Relative Humidity (%)	Wind Speed(m/s)	Rainfall (mm)	Solar Rad. Mj/m²/day	Vapour Pres. Deficit (kPa)	Influence
Sokoto	13.02	5.25	350.75	29.1±2.8	38.1±20.5	7.7±1.6	51.6±71.0	16.8±1.5	4.4±0.7	Arid
Kano	12.05	8.53	472.14	27.0±3.1	40.1±20.8	8.6±2.3	60.8±85.7	18.2±1.2	2.4±0.8	Arid
Maiduguri	11.85	13.08	353.8	27.9±3.5	35.9±21.2	4.9±1.5	43.7±61.4	14.9±3.5	3.6±0.7	Arid
Yola	9.23	12.47	324.2	28.8±2.5	46.9±21.8	1.8±0.6	73.5±77.8	17.7±2.3	2.4±1.1	Arid
Lagos	6.58	3.33	39.35	27.6±1.4	76.6±6.3	4.8±0.9	116.6±77.9	9.9±2.3	1.0±0.3	Coastal
PH	4.85	7.02	195.5	27.1±1.2	76.4±8.2	2.8±0.8	191.2±115.0	17.1±2.4	1.1±0.5	Coastal
Benin	6.32	5.6	77.52	27.1±1.1	76.4±8.2	2.8±0.8	191.±120.1	14.6±1.7	1.0±0.5	Coastal
Minna	9.62	6.53	186.05	27.8±2.1	22.±1.7	8.8±1.6	104.3±109.3	15.6±1.9	2.0±1.0	Midland
Jos	9.87	4.97	1285.6	22.±1.7	49.9±23.9	8.8±1.6	99.1±98.2	17.1±2.4	1.5±0.7	Midland
Ibadan	7.43	3.9	227.23	27.3±1.7	74.3±8.6	4.2±0.6	103.8±69.2	1.6±0.7	1.6±0.7	Guinea Savannah
Osogbo	7.73	4.48	304.7	26.0±1.5	69.1±13.2	3.5±0.8	109.6±75.0	3.1±0.6	3.1±0.6	Guinea Savannah

The location used for the study in each region is shown in Table 1. The study covered about fourteen (14) tropical stations fairly distributed into different climatic conditions (Arid, Midland, Guinea Savannah and Coastal) in Nigeria (see Figure 1). More stations would have been involved in the study but for the dearth of the required data set. The mean monthly temperature varies between 29.1°C in Sokoto (Arid condition) and 22.0°C in Jos (Midland).This is because Jos is characterized with hills and mountain: a physical feature which influences the weather condition around Jos. The temperature is generally low compared with other tropical stations in Nigeria. All the coastal stations are characterized with high relative humidity; the relative humidity in the region exhibited approximately a mean value of 74.0 % while Minna in the Midland region had the least of about 22.0 %. Jos and Minna experienced the highest wind speed of about 8.8 m/s while Yola had the lowest value of 1.8 m/s. The record also indicated that Port Harcourt and Benin enjoyed the highest monthly mean rainfall of about 191mm while Maiduguri receives the lowest rainfall of 43.7 mm. This confirms Maiduguri as one of the areas in the arid region noted for deficient rainfall and where irrigation practices is predominant. The clear sky condition that often prevails in the arid region had favoured the region for highest receipt of solar radiation while places like the coastal and rainforest regions experience low receipt of solar irradiance because of the intense cloud cover that prevail over the atmosphere. In this study, the solar radiation ranges from 1.6 Mj/m^2/day in Ibadan to 18.2 Mj/m^2/day in Sokoto. Ibadan is situated in the boundary between the rainforest and the arid region, which had consequently influenced the observed low value of solar receipt. In addition, Ibadan experienced flooding event in the recent time. The ability of the atmosphere to sustain any amount of moisture is determined by the magnitude of its vapour pressure deficit. This is the ratio of its actual vapour pressure to the saturated vapour pressure. This ranges from the lowest value of 1.0 both in Lagos and Benin (Coastal/Rainforest) to the highest value of 4.4 in Sokoto (Arid).

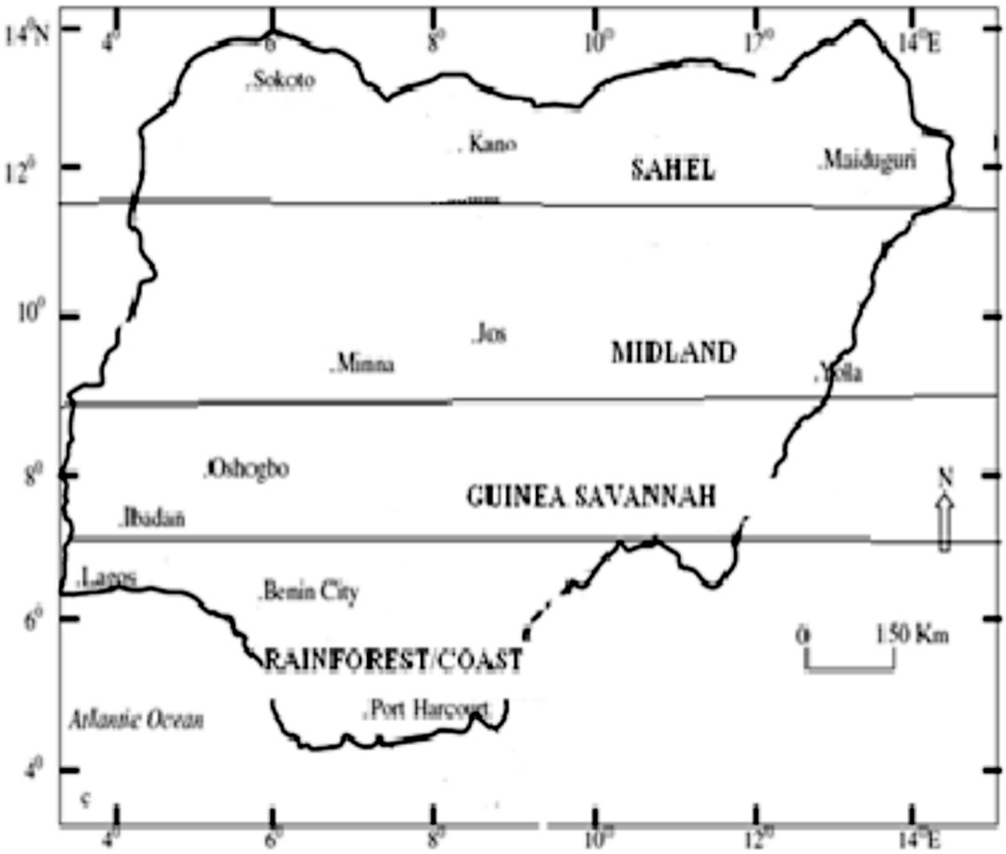

Figure 1: Map of Nigeria Showing the Different Climatic Regions(*After Ogolo,2010)*

Evapotranspiration Equation/Description of Models

All the models used in this study were basically radiation-based. This is because, they are versatile and reliable tools used for the estimation of land areas and many other empirical methods have been developed based on this type of model (Xu and Singh, 2000, 1989; Jose *et al.,* 2008). Below is the concise description of all the ET models used in this study:

Penman-Monteith (1998)

Penman-Monteith approach was recommended by the United Nation Food and Agricultural Organization (FAO) and is widely used over the globe. The Penman-Monteith technique is generally considered as the best method for the estimation of reference evapotranspiration in all climatic conditions. This has been confirmed by many field studies in the last ten years (Ventura *et al.,* 1999; Hussein, 1999; Abdelhadi *et al.,* 2000; Beyzgul *et al.,* 2000; Hargreaves and Allen 2003; DelghaniSanij *et al.,* 2004; Tarajkovic, 2005; Tyagy *et al.*, 2003; Irmak *et al.,* 2003; Beregena and Gavilian,2005; Lopez-Urrea 2006; Trajkovic 2007; Trajkovic and Kolakovi 2009; Murugappan, 2011). In view of this, FAO56-PM method is often recommended as a standard procedure for accurate estimation of reference ET where there is no measured lysimeter data on reference evapotranspiration. The ET values obtained from the derived equations were compared against this method. The FAO56-PM equation as given by FAO Irrigation and Drainage paper No. 56 (Allen *et al.,* 1998) is

$$ET = \frac{0.408\Delta(R_n - G + \gamma\frac{900}{T_m+273}U_2(e_s - e_a)}{\Delta+\gamma(1+0.34U_2} \qquad 1$$

Where ET is the reference estimated evapotranspiration ($mm^{-2}day^{-1}$); Δ slope of the saturation vapour pressure function ($kPa^{o}C^{-1}$); Rn net radiation($MJm^{-2}day^{-1}$); G = soil heat flux density, ($MJm^{-2}day^{-1}$); γ psychrometric constant ($kPa^{o}C^{-1}$); T_m = mean daily temperature (^{o}C); U_2 =

mean 24-h wind speed at 2-m height (ms^{-1}); and vapour pressure deficit (e_s-e_a) (kPa).

The FAO56-PM method requires a large number of meteorological parameters (such as air temperature, solar radiation wind speed, relative humidity) as can be confirmed from equation (1). There are few locations, particularly in Nigeria, where a complete and reliable dataset can be obtained, hence, the motivation to seek for the alternative methods which require one or only two parameters to estimate ET that would be well compared with measured ET values.

Abtew Method (1996)

Abtew (1996) utilized a simple empirical equation which expresses reference evapotranspiration (ET) as a function of solar radiation only. The equation is expressed as follows:

$$ET = 0.53Rs/\lambda \qquad 2$$

Where λ is the latent heat flux and R_s, the solar radiation ($MJm^{-2}day^{-1}$).

Abtew method was cross validated by comparing the estimates to four years of Bowen-Ratio ET measurement at nine sites in the Everglades of South Florida (Abtew, 2005) and the results revealed a very good correlation of ET estimated by Abtew method and that obtained by Bowen-Ratio over a wetland.

Hargreaves Method (1975)

According to Shanhidian *et al.* (2011), Hargreaves (1975) analyzed eight years of grass evapotranspiration data from a precision lysimeter kept in Davis, California using regressions for 5-day time step and found that 94% of the variance in measured ET could be explained by average temperature and radiation. Hargreaves (1975) published this result in 1975 expressing ET as a function of the two atmospheric variables expressed as:

$$ET = 0.0135(T + 17.8)Rs/\lambda \qquad 3$$

Where Rs and λ are as earlier defined and T the monthly temperature (°C)

Hargreaves and Allen (2003) attempted to modify the above by using wind speed and relative humidity but the results were not encouraging. The referenced equation was developed based on an 8 year field measurements carried out with a lysimeter during a cool season in Davis, California.

Priestly and Taylor Method (1972)

The method of Priestly and Taylor (1972) is a simple method requiring only radiation and temperature for the estimation of evapotranspiration. The idea for this simple equation is based on the fact that the radiation is the major source of energy and hence a potential factor compared with other factors (wind speed, relative humidity etc.) for the estimation of evapotranspiration. Priestly found that about two-third radiation component contributes to the evolution of evapotranspiration. Hence, it was proposed that estimation of ET can be done using the radiation component as define below:

$$ET = 1.26 \frac{\Delta}{\Delta+\gamma} \frac{R_n}{\gamma} \qquad 4$$

Where all parameters are as earlier defined.

Makkink Method (1975)

Makkink (1975) model, according to Xu and Singh (2000) was developed from a study conducted over a grassed surface under a cool climatic condition of Netherlands. It is simplified method of the Priestly Taylor and this also requires radiation and temperature for the estimation of evapotranspiration. The main difference in variable input is that Makkink utilizes solar radiation instead of net radiation used by Priestley-Taylor. This is reasonable because there is a good relationship between the two radiation components. This model equation is expressed as:

$$ET = 0.61 \frac{\Delta}{\Delta+\gamma} \frac{R_s}{58.5} - 0.012 \qquad 5$$

Where all parameters are as earlier defined.

Calibration of Models and Validation of Results

According to Hossein and Parisa (2011), numerous scientists working on evapotranspiration under different climates have revealed a widely varying performance of alternative equations indicating that these equations require local calibration (Allen *et al*., 1998; Pereira *et al*., 2006; Wang *et al*., 2009). Hence, they suggested that the calibration of other simple models against a more reliable reference model such as the FAO56-PM may be relevant with a view to estimating more accurate ET for useful application in Agriculture and environmental studies (Fontenot, 2004).

The method of least square was used for the calibration of the models. This techniques had been tested and applied to similar studies in other locations and had been found satisfactory (Hossein and Parisa, 2011; Shahidian *et al*., 2011). The aforementioned radiation-based methods were calibrated on the basis of FAO56-PM for the four different regions in Nigeria on monthly time scale. The calibration was done according to Houshang *et al*. (2011) as follows.

$$ET_{PMo} = \mu \times ET_{originalmodel\,(Xo)} \qquad 7$$

where μ is the slope of the correlation of ET obtained by each of the methods in turns. Thereafter, new coefficient, C was obtained for each of the methods and was corrected for each station and the regions for each month of the year

$$C = \mu \times C_o \qquad 8$$

Where C is the monthly corrected and adjusted coefficient and C_o, the unadjusted coefficient of each of the radiation methods for each stations and the region under consideration.

Hence, the new coefficient, C_n is obtained as:

$$C_n = u \times C_o \qquad 9$$

Where C_n is the new monthly corrected for the stations for that particular month.

Twenty years (1975-1995) data were used for the calibration while five years data (except the Midland region with four years available data) were used for the validation of the results.

Validation of Models Using Performance Indicators

The comparison between the adjusted and the non-adjusted models with the FAO P-M equation was carried out by using a linear regression equation (Y=*m*X +c), through the least square regression (*m* and *c* are the slope and the intercept of the regression equation, respectively and the correlation coefficient); The following statistical indicators were also used in this study for the validation: the means bias error (MBE), root mean square error (RMSE), the RMSE – observation standard deviation ratio(RSR) including average ratio, AR and the coefficient of determination,(R^2.)

RESULTS AND DISCUSSION

Tables 2-4 are the respective results of the new coefficient for Abtew, Hargreaves, Makkinks and Priestley and Taylor empirical methods for some tropical stations situated in different climatic conditions in Nigeria. It is observed that the results exhibited large variation over different months at all the stations involved in the study.

Table 2: Adjusted Coefficients of the Abtew Equation for Each Month at some Stations in different Climatic Regions in Nigeria

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sokoto	1.988	1.985	1.845	1.988	2.157	2.180	1.903	1.615	1.478	1.710	2.219	2.083	1.929
kano	1.189	1.257	1.281	1.351	1.210	1.024	0.795	0.722	0.735	1.015	1.177	1.245	1.083
Maiduguri	1.013	0.947	1.128	1.337	1.450	1.160	0.896	0.680	0.669	0.751	0.984	1.120	1.011
Arid	1.397	1.396	1.418	1.559	1.606	1.455	1.198	1.006	0.960	1.159	1.460	1.483	1.341
Yola	0.911	0.984	1.109	1.049	0.881	0.771	0.706	0.641	0.582	0.632	0.823	0.873	0.830
Minna	1.207	1.143	1.024	0.876	0.718	0.632	0.594	0.565	0.550	0.588	0.775	1.048	0.810
Jos	1.072	1.087	1.107	0.982	0.956	0.652	0.576	0.651	0.596	0.863	0.987	1.069	0.883
Midland	1.063	1.071	1.080	0.969	0.851	0.685	0.625	0.619	0.576	0.694	0.862	0.997	0.841
Ibadan	0.839	0.938	1.004	0.940	0.799	0.767	0.874	0.745	0.683	0.612	0.620	0.771	0.799
Osogbo	1.849	1.778	1.638	1.426	1.116	1.140	1.158	1.118	0.987	0.988	1.306	1.640	1.345
Guinea Savannah	1.344	1.358	1.321	1.183	0.957	0.953	1.016	0.931	0.835	0.800	0.963	1.206	1.072
Lagos	0.561	0.554	0.534	0.546	0.502	0.499	0.576	0.596	0.525	0.485	0.481	0.524	0.532
PH	0.885	0.867	0.788	0.732	0.680	0.635	0.635	0.650	0.639	0.631	0.671	0.765	0.715
Benin	0.777	0.774	0.737	0.666	0.620	0.598	0.618	0.623	0.619	0.625	0.627	0.705	0.666
Coastal	0.741	0.732	0.686	0.648	0.601	0.577	0.610	0.623	0.594	0.580	0.593	0.655	0.637

Table 2 is the adjusted coefficient of Abtew method for some tropical stations and all the climatic regions in Nigeria. The coefficient as was developed originally for Abtew was 0.53. However, the new adjusted coefficients which have been developed in this study varied both temporarily and spatially as shown on Table 2. A maximum of 2.22 was found for Sokoto in the month of December while the least adjusted coefficient was 0.67 for Maiduguri in the month of September. On the regional scale, the new adjusted coefficient for Abtew method varied from 1.34 (September) to 1.6 (May) and greater than the non-adjusted value by 153%. In the Midland, the new coefficient varied from 0.55 (Minna) in September to 1.207 (Minna) in January. The mean regional value of the new coefficient for Midland was found to be 58.7% greater than the original values and this ranged from 0.57 in September to 1.08 in March, For Guinea Savannah, the lowest adjusted coefficient is 0.612 (October) in Ibadan while the peak value of 1.84 (January) was found for Osogbo. The regional value of the adjusted coefficient for Abtew for Midland ranges from 0.80 (October) to 1.36 (February) and which is greater than the original by 102%. For the coastal climate that is often characterized with high relative humidity, the regional adjusted coefficient was found to be 0.900 which was 69.8% greater than the original coefficient. The highest adjusted coefficients ranged from 0.481(Lagos) in October to 0.885 (PH) in January. Generally, all the adjusted coefficients were generally greater than the non-adjusted values. The implication of this is that the ET values estimated by Abtew adjusted coefficients are higher than those obtain by Penman-Monteith scheme.

Table 3: Adjusted Coefficients of the Hargreaves' Equation for each Month at some Stations in Different Climatic Regions in Nigeria

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sokoto	0.046	0.044	0.038	0.039	0.043	0.044	0.040	0.035	0.032	0.036	0.047	0.048	0.041
kano	0.029	0.029	0.027	0.027	0.025	0.022	0.018	0.016	0.017	0.023	0.028	0.030	0.024
Maiduguri	0.025	0.022	0.024	0.027	0.029	0.024	0.019	0.015	0.015	0.017	0.024	0.027	0.022
Arid	**0.030**	**0.029**	**0.028**	**0.029**	**0.029**	**0.027**	**0.023**	**0.020**	**0.019**	**0.022**	**0.029**	**0.031**	**0.026**
Yola	0.020	0.021	0.023	0.021	0.019	0.017	0.015	0.014	0.013	0.014	0.019	0.019	0.018
Minna	0.026	0.024	0.022	0.019	0.016	0.015	0.013	0.013	0.012	0.013	0.018	0.023	0.018
Jos	0.024	0.023	0.041	0.021	0.016	0.015	0.013	0.015	0.013	0.019	0.022	0.023	0.020
Midland	**0.023**	**0.023**	**0.028**	**0.021**	**0.017**	**0.016**	**0.014**	**0.014**	**0.013**	**0.015**	**0.019**	**0.022**	**0.019**
Ibadan	0.018	0.020	0.022	0.021	0.020	0.018	0.020	0.017	0.015	0.014	0.014	0.017	0.018
Osogbo	0.044	0.040	0.034	0.028	0.024	0.025	0.025	0.023	0.021	0.021	0.030	0.039	0.029
Guinea Savannah	**0.031**	**0.030**	**0.028**	**0.025**	**0.022**	**0.021**	**0.022**	**0.020**	**0.018**	**0.017**	**0.022**	**0.028**	**0.024**
Lagos	0.012	0.012	0.012	0.012	0.011	0.011	0.013	0.013	0.012	0.011	0.011	0.011	0.012
PH	0.020	0.019	0.017	0.016	0.015	0.014	0.015	0.015	0.015	0.014	0.015	0.017	0.016
Benin	0.017	0.017	0.016	0.015	0.014	0.014	0.014	0.014	0.013	0.014	0.014	0.015	0.015
Coastal	**0.026**	**0.025**	**0.026**	**0.023**	**0.021**	**0.020**	**0.019**	**0.017**	**0.016**	**0.018**	**0.022**	**0.025**	**0.022**

Table 3 is the seasonal distribution of the adjusted coefficient of Hargreaves for some tropical stations and the different climatic regions in Nigeria. The original coefficient of Hargreaves is 0.0135. The adjusted regional coefficients for Sahel, Midland, Guinea savannah and the coastal region are all greater than 0.0135, which is the non-adjusted coefficient of Hargreaves. The adjusted coefficient, like Abtew, also exhibited spatial and temporal variations among all the tropical stations involved in the study. However, the adjusted coefficients for Lagos in the coastal region are less than the non-adjusted coefficient for all the months. This also confirmed previous study (Foolandmand and Haghighhat, 2007) as was reported by Hossein and Parisa (2011), that Hargreaves equation coefficients at the coastal and humid environment are generally low compared with what is obtainable in the arid and semi-arid environment. It is higher in the arid environment because of the prevalent windy condition (Gavilan et al., 2006)

Table 4.0 shows the regional distribution of the adjusted coefficients of Makkink for different stations and each of the regional climates in Nigeria. The adjusted coefficients ranged from 1.00 and above but less than 1.00 in some coastal and midland stations. It is observed that the equation coefficients in the arid environment are higher than in the coastal stations and humid conditions.

Table 4: Adjusted Coefficients of the Makkink Equation for Each Month at some Stations in Sub-Sahelian Region in Nigeria

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sokoto	2.68	2.58	2.30	2.41	2.63	2.72	2.45	2.09	1.90	2.15	2.86	2.80	2.46
Kano	1.67	1.69	1.63	1.66	1.50	1.29	1.03	0.93	0.95	1.30	1.56	1.73	1.41
Maiduguri	1.46	1.34	1.77	2.15	2.09	1.39	1.01	0.72	0.70	0.80	1.18	1.55	1.35
Arid	**1.18**	**1.16**	**1.19**	**1.26**	**1.23**	**1.07**	**0.91**	**0.77**	**0.72**	**0.85**	**1.12**	**1.22**	**1.06**
Yola	1.23	1.28	1.39	1.30	1.12	1.00	0.93	0.85	0.77	0.83	1.09	1.17	1.08
Minna	1.58	1.46	1.30	1.12	0.94	0.84	0.80	0.76	0.74	0.78	1.02	1.39	1.06
Jos	1.53	1.49	1.48	1.30	1.31	0.90	0.81	0.92	0.82	1.18	1.38	1.51	1.22
Midland	**1.45**	**1.41**	**1.39**	**1.24**	**1.12**	**0.91**	**0.85**	**0.84**	**0.78**	**0.93**	**1.16**	**1.36**	**1.12**
Ibadan	1.10	1.21	1.29	1.22	1.05	1.02	1.19	1.01	0.92	0.82	0.82	1.02	1.06
Osogbo	2.53	2.35	2.07	1.76	1.38	1.44	1.51	1.47	1.29	1.26	1.71	2.24	1.75
Guinea Savannah	**0.90**	**0.88**	**0.81**	**0.75**	**0.69**	**0.65**	**0.66**	**0.67**	**0.66**	**0.64**	**0.68**	**0.78**	**0.73**
Lagos	0.74	0.72	0.69	0.71	0.66	0.66	0.78	0.81	0.71	0.65	0.01	0.69	0.65
PH	0.90	0.88	0.81	0.75	0.69	0.65	0.66	0.67	0.66	0.64	0.68	0.78	0.73
Benin	1.02	1.01	0.96	0.87	0.82	0.81	0.84	0.84	0.83	0.83	0.82	0.93	0.88
Coastal	**1.02**	**1.01**	**0.96**	**0.87**	**0.82**	**0.81**	**0.84**	**0.84**	**0.83**	**0.83**	**0.82**	**0.93**	**0.88**

The adjusted coefficients of the Priestly Taylor for all the climatic regions are also shown in Table 5. It is observed that the adjusted values are generally greater than 1.26 across the entire regions in Nigeria. However, there are few exceptional cases where the adjusted coefficients ranged from 1.20 to 1.27 and were found to be predominant in the coastal region. It is observed that the maximum values of the adjusted coefficient for the Priestly and Taylor equation are generally higher in the arid than in the coastal stations where precipitation had been found to be less than 100 mm. On the annual timescale, the regional mean coefficients for Abtew, Hargreaves, Makkink and P-T were respectively (1.341, 0.841, 1.072, 0.637), (0.026, 0.019, 0.024, 0.022), (1.06, 1.12, 0.73, 0.88) and (3.62, 2.67, 2.63, 1.35) for the arid, semi-arid, guinea savannah and coastal conditions in Nigeria.

Table 5: Adjusted Coefficients of the Priestly-Taylor Equation for Each Month at some Stations in Sub-Sahelian Region in Nigeria

Locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sokoto	6.35	5.46	4.30	4.15	4.52	4.74	4.30	3.76	3.58	4.19	6.00	6.78	4.84
Kano	5.43	5.94	5.22	4.18	3.08	2.40	1.82	1.62	1.86	3.35	5.16	5.63	3.81
Maiduguri	2.67	2.59	3.10	3.30	2.94	1.99	1.53	1.21	1.28	1.43	1.92	2.61	2.21
Arid	**4.82**	**4.67**	**4.21**	**3.88**	**3.51**	**3.04**	**2.55**	**2.19**	**2.24**	**2.99**	**4.36**	**5.01**	**3.62**
Yola	3.96	4.50	3.93	2.79	2.01	1.72	1.55	1.42	1.35	1.64	2.96	3.57	2.62
Minna	4.70	4.23	2.99	2.18	1.69	1.46	1.32	1.25	1.29	1.54	2.76	4.23	2.47
Jos	4.70	4.71	3.95	2.79	1.86	1.51	1.30	1.33	1.53	2.53	4.07	4.71	2.92
Midland	**4.45**	**4.48**	**3.62**	**2.59**	**1.85**	**1.56**	**1.39**	**1.33**	**1.39**	**1.90**	**3.26**	**4.17**	**2.67**
Ibadan	2.16	2.58	2.66	2.32	1.86	1.71	1.84	1.55	1.52	1.40	1.45	1.90	1.91
Osogbo	4.97	5.38	4.52	3.51	2.57	2.43	2.14	2.06	2.10	2.39	3.60	4.56	3.35
Guinea Savannah	**3.56**	**3.98**	**3.59**	**2.92**	**2.22**	**2.07**	**1.99**	**1.80**	**1.81**	**1.89**	**2.53**	**3.23**	**2.63**
Lagos	1.31	1.23	1.18	1.16	1.08	1.07	1.17	1.20	1.13	1.08	1.10	1.22	1.16
PH	1.97	1.82	1.56	1.43	1.34	1.25	1.20	1.23	1.23	1.25	1.38	1.69	1.44
Benin	1.84	1.80	1.63	1.46	1.35	1.29	1.24	1.23	1.27	1.33	1.41	1.68	1.46
Coastal	**1.71**	**1.62**	**1.46**	**1.35**	**1.26**	**1.20**	**1.20**	**1.22**	**1.21**	**1.22**	**1.30**	**1.53**	**1.35**

Table 6: Regional Analysis of the New Adjusted Coefficients of the Radiation Models for Nigeria.

Models	Climatic Zone	New Adjusted Coefficient	% difference between New and Old Coefficient
Abtew	Arid	1.341	153.0
σAb = 0.53	Midland	0.841	58.7
	Guinea Savannah	1.072	102.3
	Coastal	0.67	25.7
	Average	0.98	84.9
Hargreaves	Arid	0.026	92.6
σHa = 0.0135	Midland	0.019	40.7
	Guinea Savannah	0.024	77.8
	Coastal	0.022	63.0
	Average	0.02275	68.5
Makkinks	Arid	1.06	73.8
σMa = 0.61	Midland	1.12	83.6
	Guinea Savannah	0.73	19.7
	Coastal	0.88	44.3
	Average	0.9475	55.3
Priestly -Taylor	Arid	3.62	187.3
σPT = 1.26	Midland	2.67	111.9
	Guinea Savannah	2.63	108.7
	Coastal	1.35	7.1
	Average	2.57	103.97

where σAb, σHa, σMa and σPT represent the unadjusted coefficient for Abtew, Hargreaves, Makkink and Priestly Taylor Empirical Equations respectively.

Table 6 displays the percentage difference analysis between the regional adjusted and non-adjusted coefficients for all the models across all the regions. The percentage differences are also presented. The results showed that the percentage differences between the old and the new coefficients varied spatially. The highest percentage differences observed respectively for Abtew (0.53), Hargreaves, (0.0135) Makkink (0.61) and Priestly and Taylor (1.26) were153.0 % (Arid), 92.6% (Arid), 83.6% (Midland) and 187.3% (Arid); while the lowest percentage difference in the above order of the models include: 25.7% (coastal), 40.7% (Midland), 19.7% (Guinea savannah) and 108.3% (Guinea savannah) respectively. Notably, the percentage differences for Priestly and Taylor were characteristically higher than 100% for all the climatic regions.

The monthly ET estimates of FAO56-PM correlated with the other methods (both for the adjusted and non-adjusted coefficients) for each region are shown in Figures 2-5 for different climates in Nigeria. In the case of the perfect correlation without bias, labeled 1:1, $c = 0$ and m =1 and RMSE = 0. Generally, a large improvement on the accuracy of ET estimates by all the methods with the adjusted coefficient was observed. This is also reflected in the statistical comparison between the adjusted and the non-adjusted coefficient models shown in Table 7. Generally, the MBE, RMSE and SEE found are lower for the adjusted when compared with the non-adjusted.

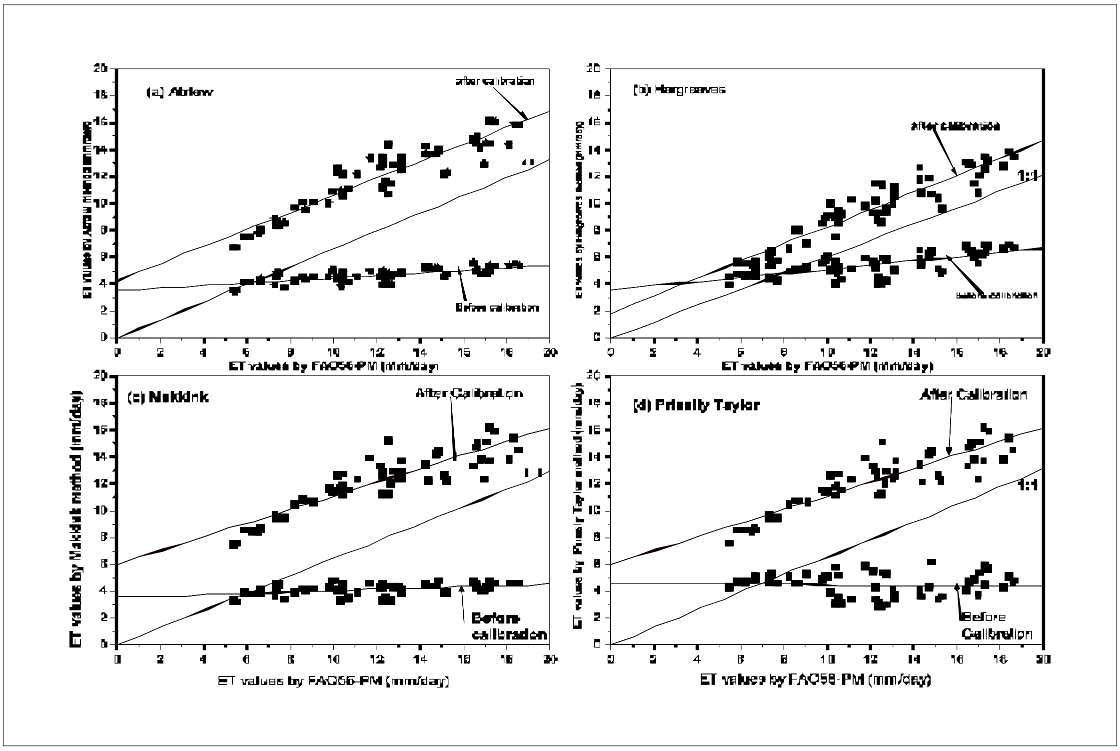

Figure 2.0: Comparison of FAO56-PM ET with estimated ETfor (a) Abtew (b) Hargreaves (c) Makkink and (d) Priestly Taylor both before and after calibration in the arid climate in Nigeria

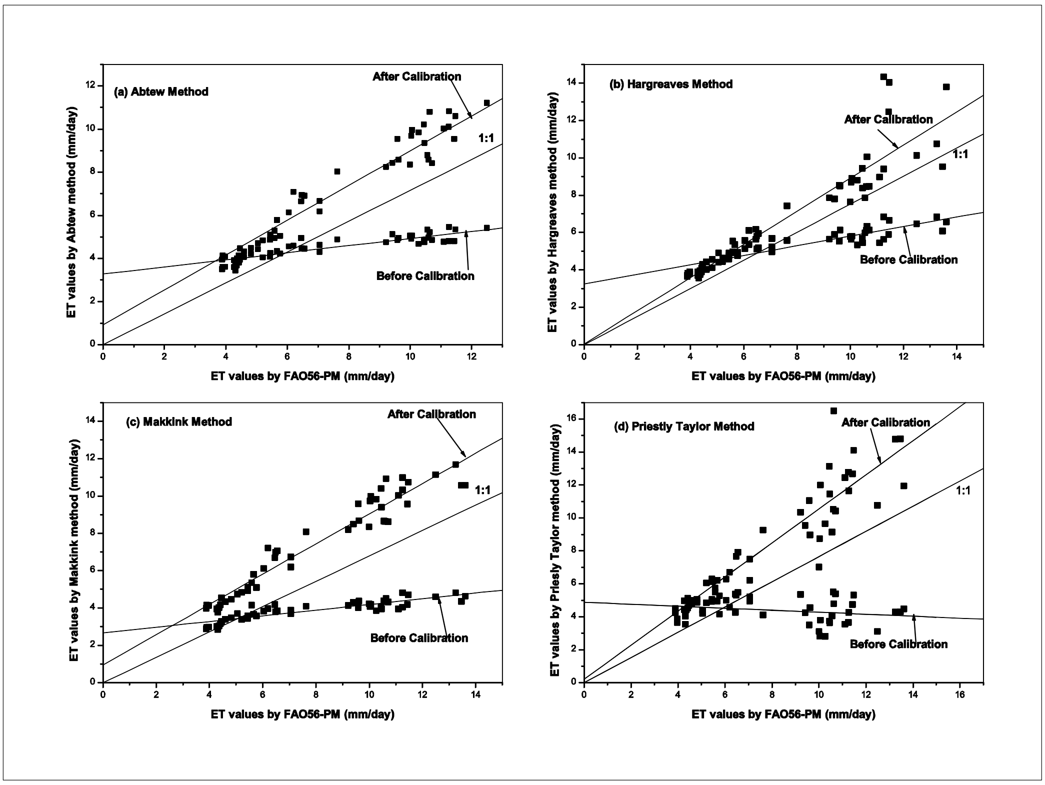

Figure 3.0: Comparison of FAO56-PM ET with estimated ET for (a) Abtew (b) Hargreaves (c) Makkink and (d) Priestly Taylor both before and after calibration in the midland climate in Nigeria.

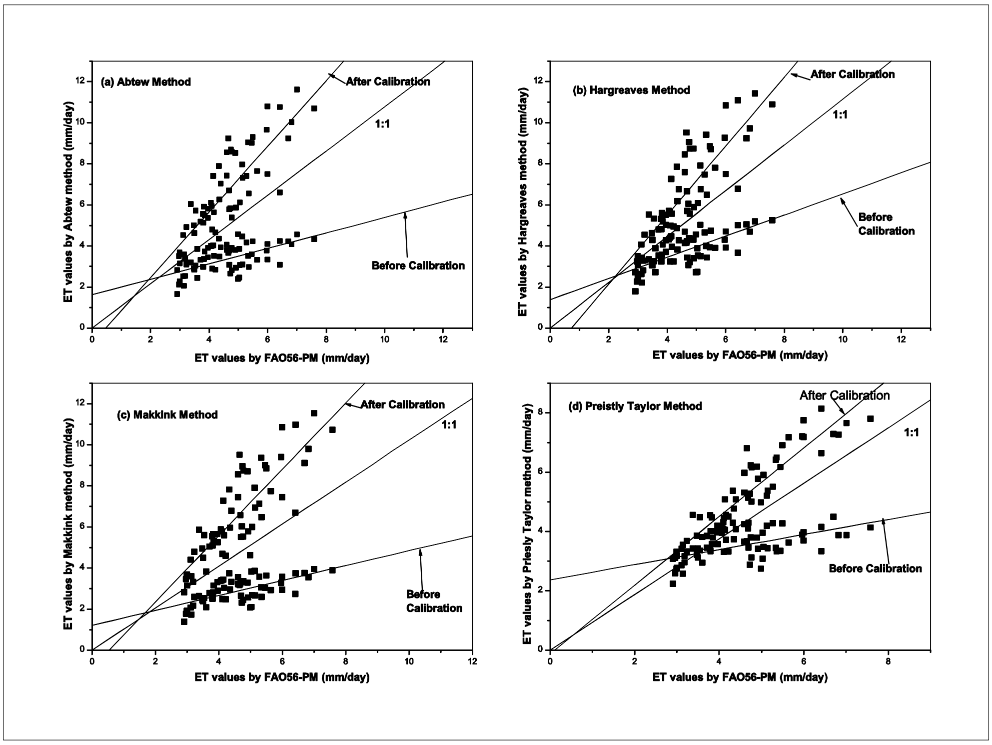

Figure 4.0: Comparison of FAO56-PM ET with estimated ET for (a) Abtew (b) Hargreaves (c) Makkink and (d) Priestly Taylor both before and after calibration in the guinea savannah climate in Nigeria.

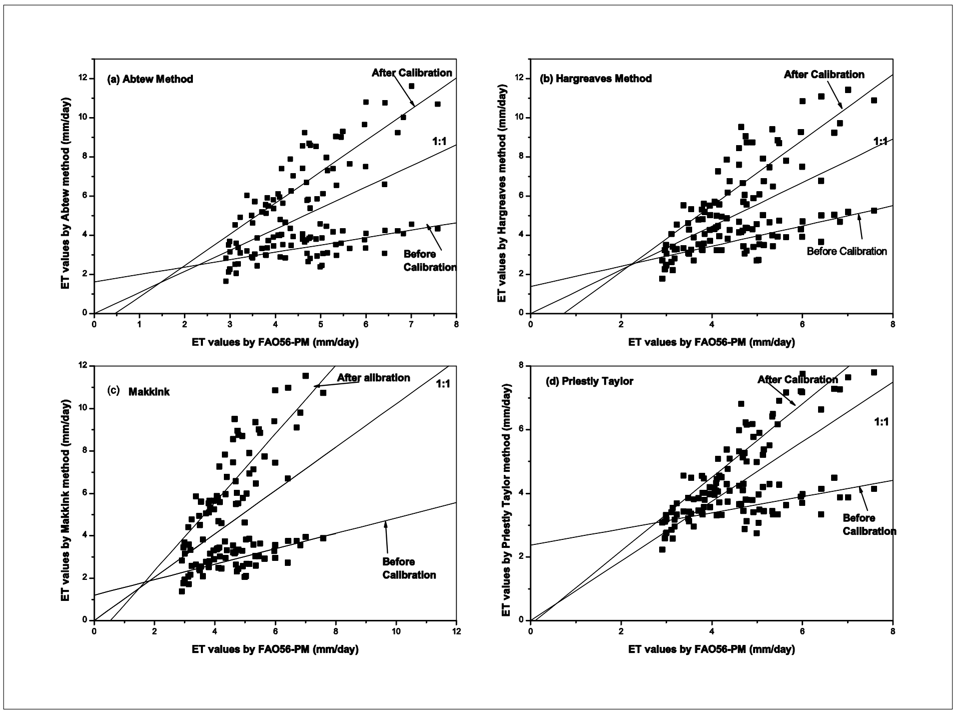

Figure 5.0: Comparison of FAO56-PM ET with estimated ET for (a) Abtew (b) Hargreaves (c) Makkink and (d) Priestly Taylor both before and after calibration in the coastal climate in Nigeria.

The level of collinearity between the measured and the predicted ET is assessed by the coefficient of determination. It is also considered as the variance in the measured data explained by the predictive model. It ranged between 0 and 1, with the highest value indicating less error variance. This is calculated for all the models in all the regions under consideration. Generally, it is found that the coefficient of determination for the adjusted coefficient is greater than the unadjusted for all the models across the entire climatic regions. This shows that errors have been greatly reduced in the model with original coefficient that was initially developed for another environment. The coefficient of determination (R^2) for the non-adjusted coefficient models for arid, midland, guinea savannah and coastal region staggered respectively from 0.01(Priestly and Taylor) to 0.54 (Abtew), 0.06 (Priestly and Taylor) to 0.77(Abtew), 0.32 (Priestly and Taylor) to 0.43(Makkink) and 0.31(Priestly and Taylor) to 0.49(Hargreaves). After the recalibration, R^2 increased significantly as stated in the above order: 0.79 (Makkink) to 0.94 (Hargreaves), 0.84(Abtew, Makkink and Priestly and Taylor) to 0.85 (Hargreaves), 0.68 (Abtew and Makkink) to 0.84(Priestly and Taylor). The error due to variance had become reduced in favour of more accurate ET estimates by the adjusted-coefficient model across all the regions under consideration

The slope and the y-intercept of the best fit regression line showed how well the predicted data matched the observed data. While the slope indicated the relative relationship between the two set of data, the intercept showed the presence of lag between the two. According to Wilmot (1981, 1982) as reported by Moriasi *et al.*, (2007), a slope of 1 and the y-intercept of 0 indicate that the model perfectly replicates the magnitude of the observed data. From Figures 2-5 and as shown in Table 7, it was observed that, the intercept reduces for the adjusted coefficient and tending toward zero while the slope increased above what was obtained for the non-adjusted for all the models. This is an evidence of improvement of the model on ET estimation in other geographical environments other than where they were developed if proper recalibration is carried out. (Xu and Singh, 2000). Under the arid climate, the slope for the adjusted coefficient increases appreciably when compared with the un-calibrated models (see Tables 7.0). However, the intercept for all the models except Hargreaves gave contrary expectation. The intercepts for the unadjusted coefficients (3.48, 3.54, and 4.68) for Abtew, Makkink and Priestly Taylor respectively were found to be higher than the adjusted coefficient (4.27, 6.00, and 6.00). The results generally reflect a tremendous improvement of ET estimates after modification of the ET models.

Table 7: Statistical Comparison between ET by FAO-PM and other Empirical Methods

Climatic Zones	Models	R	Rsqd	slope	I	IA	AR	MBE	RMSE	RSR	%decrease /increase	SEE
arid	Abto	0.73	0.54	0.10	3.48	-2.75	0.39	-7.25	8.00	4.53	-60.94	8.00
	Abtc	0.94	0.88	0.63	4.27	0.93	0.99	-0.08	1.62	0.92	-0.69	1.62
	Hargo	0.70	0.49	0.15	3.57	-1.70	0.45	-6.50	7.24	4.10	-54.60	7.24
	Hargc	0.94	0.89	0.64	1.88	0.78	0.80	-2.41	2.89	1.63	-20.25	2.89
	Makko	0.43	0.18	0.05	3.54	-0.74	0.35	-7.77	8.54	4.83	-65.23	8.54
	Makkc	0.89	0.79	0.52	6.00	0.87	1.01	0.16	2.06	1.17	1.34	2.06
	PTo	-0.08	0.01	0.02	4.68	-2.89	0.38	-7.44	8.38	4.74	-62.45	8.38
	PTc	0.89	0.80	0.51	6.00	0.87	1.01	0.16	2.06	1.17	1.34	2.06
Midland	Abto	0.88	0.77	0.17	3.72	0.24	0.57	-3.43	4.25	2.27	-42.73	4.25
	Abtc	0.92	0.84	0.81	0.92	0.97	0.92	-0.62	1.05	0.56	-7.77	1.05
	Hargo	0.90	0.81	0.26	3.24	0.52	0.66	-2.72	3.54	1.89	-33.94	3.54
	Hargc	0.92	0.85	0.89	0.04	0.95	0.89	-0.87	1.46	0.78	-10.82	1.46
	Makko	0.87	0.76	0.15	2.67	-0.01	0.48	-4.14	4.86	2.60	-51.52	4.86
	Makkc	0.92	0.84	0.81	0.95	0.97	0.93	-0.58	1.03	0.55	-7.19	1.03
	PTo	-0.25	0.06	-0.06	4.88	0.05	0.55	-3.63	4.87	2.60	-45.19	4.87
	PTc	0.92	0.84	1.03	0.21	0.96	1.06	0.48	1.44	0.77	5.95	1.44
Grassland	Abto	0.61	0.37	0.38	1.62	0.20	0.73	-1.24	1.52	1.62	-27.01	1.52
	Abtc	0.82	0.68	1.60	-0.74	0.40	1.44	2.00	2.43	2.59	43.53	2.43
	Hargo	0.70	0.49	0.52	1.39	0.61	0.82	-0.84	1.15	1.23	-18.29	1.15
	Hargc	0.84	0.70	1.68	-1.22	0.46	1.41	1.90	2.37	2.52	41.36	2.37
	Makko	0.66	0.43	0.36	1.21	-0.36	0.63	-1.72	1.91	2.03	-37.36	1.91
	Makkc	0.82	0.68	1.61	-0.88	0.43	1.42	1.94	2.39	2.55	42.18	2.39
	PTo	0.56	0.32	0.25	2.37	0.15	0.77	-1.05	1.40	1.49	-22.90	1.40
	PTc	0.92	0.84	1.16	-0.12	0.89	1.13	0.59	0.83	0.88	12.95	0.83
Coastal	Abto	0.61	0.37	0.74	1.59	0.40	0.78	-0.90	1.12	1.24	-21.91	1.12
	Abtc	0.82	0.67	0.38	1.62	0.97	1.01	0.04	0.34	0.38	0.92	0.34
	Hargo	0.70	0.49	0.52	1.39	0.81	0.90	-0.43	0.70	0.78	-10.43	0.70
	Hargc	0.84	0.70	1.68	-1.22	0.97	1.03	0.11	0.32	0.35	2.58	0.32
	Makko	0.66	0.44	0.36	1.21	0.39	0.77	-0.94	1.14	1.26	-22.81	1.14
	Makkc	0.82	0.67	-1.61	-0.88	0.97	1.02	0.07	0.34	0.37	1.63	0.34
	PTo	0.56	0.31	0.25	2.37	0.39	0.83	-0.69	1.05	1.17	-16.67	1.05
	PTc	0.92	0.84	1.16	-0.12	0.93	0.97	-0.14	0.47	0.53	-3.38	0.47

where abto, hargo, makko and PTo are acronyms used respectively for the Unadjusted coefficients of Abtew, Hargreaves, Makkink and Priestly Taylor; while abtc, hargc, makkc and PTc represent the new adjusted coefficient for Abtew, Hargreaves, Makkink and Priestly Taylor.

The index of agreement between FAO-PM and other ET models (both for the adjusted and non-adjusted) was calculated for all the regions as well. According to Wilmot, 1984, Index of agreement is the ratio between the mean square error and the potential error. The computed value of 1 indicates a perfect agreement between the measured and the predicted while 0 indicates no agreement between them. The results of the index of agreement computed for the entire region are shown on the Table 7. It is observed that the index of agreement for the adjusted values is extremely higher than the values for the non-adjusted. For the arid region, there is tremendous significant improvement in the index of agreement (IA) for all the models. For the non-adjusted, IA ranged from -2.75(Abtew unadjusted) to -0.74(Makkink unadjusted) while the IA values for the adjusted coefficients varied from 0.78 (Hargreaves unadjusted) to 0.93(Abtew adjusted).In the Midland region, the lowest IA for all the models with unadjusted coefficients was -0.1(Makkink) while the highest was 0.52 (Hargreaves). However, when the coefficient of the models became adjusted for the region, the IA increased sharply from 0.95(Hargreaves) to 0.97(Abtew and Makkink). In the grassland savannah, IA is generally low both for the adjusted and non-adjusted coefficients except for P-T. The IA values before adjustment has a minimum of -0.61(Makkink) and a maximum of 0.21(Abtew). The IA values for the adjusted coefficient were less than 0.5 except P-T that had 0.89. Finally, the IA calculated for the coastal increased appreciably for all the models after adjusting their coefficients. This ranged from 0.39(Makkink) to 0.40(Abtew). However, the improved IAs for the adjusted coefficient peaked at 0.97 for all models except Priestly Taylor that has 0.93. Generally, it was observed that the index of agreement determined for all the models showed that the models with adjusted coefficient will produce a better agreement with ET by the reference model compared with the non-adjusted coefficient models.

The bias of estimates by the model is determined by the statistical indicator known as the Mean Bias Error (MBE). This is used to determine the level of accuracy involved in the application of the models particularly in the estimation of evapotranspiration. Low values are desirable while the negative and positive values were indicative of over-estimation and underestimation respectively. The latter part of MBE which were mention above can be discussed parallel with the average ratio, which is a tool that is used to measure the latter relevance (overestimation and underestimation tendency) of MBE highlighted above. In the Midland Region, the MBE values are all negatives and this observation synchronized with the average ratio for all the models. The Average Ratio (AR) values were all less than 0.5 for all the non-adjusted coefficient models but the AR values increased appreciably, when the coefficients of the model were adjusted. This was found to be about 1.00±0.1 except Hargreaves that had the tendency to underestimate ET for this region. The MBE reduced significantly from the non-adjusted to adjusted coefficient models, which shows that ET estimates with the adjusted coefficient model will be more accurate in the present region under consideration. In the Midland region, the MBE gave negative values, which is an indication of underestimation as confirmed by the average ratio. However, there was an appreciable rise in the AR; The AR were insignificantly small before coefficient adjustment (0.48 -0.66) but were increased appreciably (0.89 -1.06) after coefficient adjustment. Priestly Taylor had the best AR of 1.06 with a corresponding lowest MBE of 0.48. However, in the Guinea savannah, MBE for all the models with non-adjusted coefficients were characterized negative and their corresponding AR (0.73, 0.82, 0.63 and 0.77) were less than 1.0. This is an indication of underestimation. Although, the MBE values were characteristically positive after coefficient adjustment having corresponding AR values (1.44, 1.41, 1.41 and 1.13) greater than 1.0; which was a sign of overestimation. Again, Priestly Taylor had the lowest MBE (0.59) and the least AR (1.13). Finally, in the Coastal region, the MBE have a similar result as obtained in the savannah region. All the models exhibited underestimations as MBEs were all negatives. The corresponding AR was less than 1.

However, the MBEs for all the models under consideration transformed to positive after coefficient adjustment except Priestly Taylor. The MBEs were generally low with Abtew (Adjusted coefficient) having 0.04 and AR of 1.01.

RMSE is an error index statistics (Chu and Shirmohammadi, 2004; Vasquez-Amabile and Engel, 2005; Moriasi et. al., 2007). The lower the RMSE values, the better the performance of the model. In all the regions under consideration, the RMSE values were generally lower for adjusted coefficient models than for the non-adjusted. (See Table 7.0). The lowest RMSE values determined for each region in this study include: 1.62 (Abtew), 1.03(Makkink), 0.83 (Priestly Taylor) and 0.32 (Hargreaves) for arid, midland, savannah and coastal region respectively. However, based on the recommendation of Singhet. al., (2004) as was reported by Moriasi (2007). A model evaluation statistics named RMSE-observations standard deviation ratio (RSR) was developed. This had also been calculated to evaluate the performance of the models that are being calibrated. RSR is calculated as the ratio of RMSE to the standard deviation of measured data. It varies from the optimal value of 0, which indicate zero RMSE. The lower the RSR, the lower the RMSE and the better the model simulation performance. Hence, equivalent discussion on RMSE can also be used to describe the behaviour of RSR. From the foregoing, it could be said that the same argument also follow as was given for RMSE calculated for all the regions. As expected, the readjusted coefficients resulted in sharp decrease in the RMSE, RSR and MBE values. The reduced RMSE (RSR) and the MBE shows that all the models produced an ET estimates that is closer to FAO56-PM for their respective regions for which they were calibrated.

The standard error of estimate was also calculated in order to access the performance of the adjusted coefficient models in comparison with the non-adjusted coefficient models. The lower the value, the higher is the level of performance. Comparing the SEE values of the adjusted with the non-adjusted across the entire region, the SEE values were lower for the adjusted than for the non-adjusted and having a mean difference which was above 50%. The lowest SEE were 1.62 (Abtew), 1.03 (Makkink), 0.83 (Priestly Taylor) and 0.32 (Hargreaves) for the arid, midland, savannah and the coastal regions respectively

The above discussion and result analysis had greatly revealed the large magnitude of error being introduced in the estimation of ET by using non-adjusted coefficient ET models in another climatic condition different from where they had been developed.

Regional Assessment of the performance of the Models.

The second objective of this study was to determine the suitable models for each climatic region in Nigeria. For the arid region, almost all the models had the tendency for good measurement performance after readjustment of their coefficient for each climatic region but Abtew model had been found to be more suitable for ET measurement. From Table 7, the coefficient of determination was significantly high (0.88), In addition, it had an average ratio of 1.00 which showed that the estimates are equivalent to the reference ET data. In addition, the index of agreement was considerably high (0.93) too and having minima error because it had the lowest SEE (1.62), Abtew method also had the lowest, MBE(0.08), RMSE (1.62) and RSR values compared with other models. The percentage difference between the simulated and the reference data was extremely low. Followed by this, is the Hargreaves method (see Figure 1.0 and 5.0) the index of agreement was higher than the rest. All the models exhibit good performance in the Midland region (see Table 7) but Priestly and Taylor had been found preferable in view of low error as exhibited by low MBE (0.48), RMSE (1.44), RSR (0.77) and the SEE which is 1.44. In addition, the index of agreement (0.96) was high and having the lowest percentage difference of 6%. The rest models are equally suitable for ET estimate in the region. They all had high correlation of determination (R2>0.80), index of agreement (IA>.90) and low MBE, RMSE and SEE. In the guinea savannah region, Priestly and Taylor had been found to be more suitable (see Table4) compared with others under consideration. It had the highest coefficient of determination (0.84) and better slope (1.06) when compared with others. The error was minimally low as confirmed by MBE (0.59), RMSE (0.83) and RSR (0.88) including the SEE (0.83) values are extremely low. The percentage difference between Priestly and Taylor ET estimates and the reference data was the least and the index of agreement was larger than the percentage difference for the rest models. From Figure 4.0, Priestly and Taylor had also been found to be more suitable when compared with others in the coastal environment. The level of agreement between ET estimates by PT and the FAO56-PM was confirmed by high IA (0.93).The rest models were also found suitable in view of the low error recorded. They have low MBE, RMSE and RSR including low SEE values (see Table7.0). Their index of agreement too was high (IA>90) and percentage difference low.

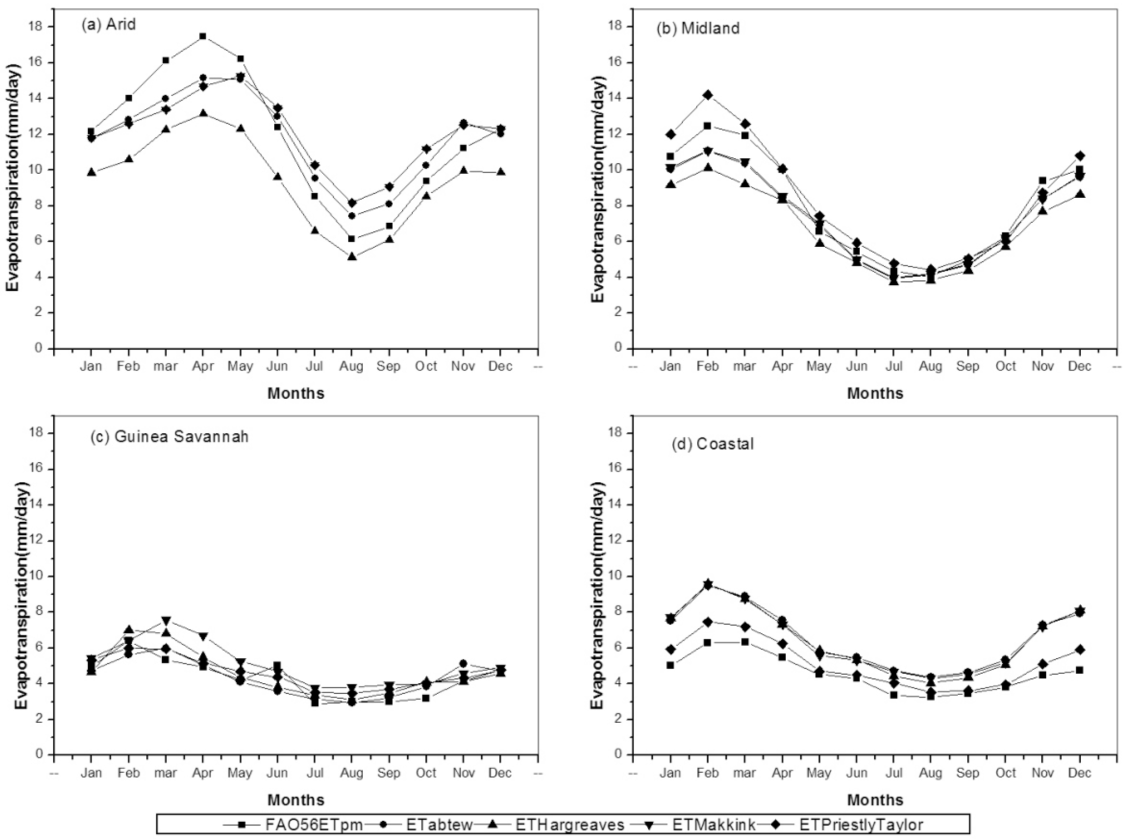

Figure 6: Comparative variation of Reference Evapotranspiration of (a) Arid (b) Midland (c) Guinea Savannah and (d) Coastal Region using all the Models (Abtew, Hargreaves, Makkink and Priestly and Taylor) and FAO56-PM

Finally, Figure 6 showed the monthly variation of the reference evapotranspiration of the calibrated models (Abtew, Hargreaves, Makkink and Priestly and Taylor) compared with FAO56-PM. There were two peaks and one trough of ET. The two peaks occurrences are predominant in the dry period; the first peak occurrence varied between February and March dry period while the second peak (though weak) occurred mostly during the onset of dry period, In the arid, all models underestimated FAO56-PM during the dry period but was overestimated by all the models; but for both seasons, Hargreaves underestimated PM. In the midland: There was wide difference in ET between the other methods and the FAO56-PM during the drying months. All the models underestimated Pm during this season. However, the values of ET were observed to be closer to PM in the wet months. This same trend was observed for all the models as compared with the PM in the Coastal environment. In this case, all the models overestimated PM with Hargreaves and Abtew, which were observed to be larger than PM during the dry season. In the Guinea Savannah, the ET estimates by all the models appeared to be closer to that of PM for all the dry and wet periods.

CONCLUSION

The main focus of this work was to obtain specific calibration coefficients for the common evapotranspiration models (being used for ET estimates) for different climatic regions in Nigeria. Studies had shown that models developed for a particular climatic condition may not be suitable for another place far from where it had been developed. This is because a large error could be introduced. In view of this observation, some radiation based evapotranspiration models (Abtew, Hargreaves, Makkinks and Priestly and Taylor) had been calibrated for different climatic regions (arid, midland, guinea savannah and coastal) in Nigeria.

In this study, the coefficients of the models considered had been appropriately calibrated for each of regions. New coefficients on monthly time scale had been developed for all the models and for the estimation of ET from any part that fell within any of the climatic regions in Nigeria. There was a large spatial (Region to region) and temporal (month to month) variations among the new coefficients. They were higher in the arid condition compared with the coastal region. There was a significant improvement that followed the adjustment of coefficients on ET estimates as indicated by a large reduction in the error (SEE, RPR) and levels of bias (MBE) and the increase in the index of agreement. However, overall result showed that the entire developed coefficients could be improved upon if the size of weather stations should be increased coupled with a more reliable dataset.

In addition, this study had also revealed a widely varying performance of alternative equations with local calibration. For the arid region, Abtew, P-T and Hargreaves were found suitable, while Makkink and P-T performed better than the other models in the midland. P-T was distinguished as the best model for ET estimation in the guinea savannah while Hargreaves and P-T gave better results than the rest in the coastal environments in Nigeria.

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