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Multi-Parameter Based Models for Estimating Global Solar Radiation in Selected Locations in Ebonyi State, Southeastern Nigeria

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This study aims to develop hybrid empirical models for estimating global solar radiation in selected locations across Ebonyi State, Nigeria, to enhance photovoltaic energy generation and support climate change mitigation and adaptation. The research is designed to create empirical models for calibrating and modeling global solar radiation using meteorological parameters at Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State University Abakaliki and Akanu Ibiam Federal Polytechnic Unwana, all in Ebonyi State, Southeastern Nigeria. The long term monthly mean daily global solar radiation on the horizontal surface, sunshine hours, relative humidity, minimum and maximum temperature at 2 m height for the period of 1984-2019 for the selected stations were obtained from the National Aeronautics and Space Administration (NASA) atmospheric science data centre. A multi-parameter based model was used to estimate the global solar radiation in each of these locations using Angstrom-Prescott-Page Model. Model performance was evaluated using statistical metrics, including Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE). Additionally, the correlation coefficient (r) and coefficient of determination (r^2) were calculated. Results indicate that the developed empirical models demonstrate a high level of accuracy in estimating daily global solar radiation. Comparisons with existing models in the literature show that the locally calibrated models perform better on monthly and yearly timescales. Therefore, these models can be applied for solar radiation forecasting across Ebonyi State. However, routine recalibration is recommended, as climate variability over time may affect model stability and performance.

Keywords: Global solar radiation; Multi-parameter models; Meteorological parameters; Statistical performance indicators; Ebonyi State Nigeria

1. Introduction

1.1 Background

Global solar radiation is a vital parameter necessary for most ecological models and serves as input for different photovoltaic conversion systems. Hence it is of economic importance to renewable energy alternative. The solar radiation reaching the earth's

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surface depends upon climatic conditions of a location which is essential to the prediction and design of a solar energy system [1]. Although solar radiation data are available in most meteorological stations, many stations in developing countries such as Nigeria experience a shortage of facilities required for solar radiation measurements. As a result, we resort to estimation of the solar radiation to provide the information where measured data are not available. This paper aims to develop regression line equations based on Angstrom-Page model that correlate mean daily global solar radiation on horizontal surface in three selected locations in Ebonyi State (Alex Ekwueme Federal University Ndufu-Alike (AE-FUNAI), Ebonyi State University Abakaliki (EBSU) and Akanu Ibiam Federal Polytecnic Unwana (AIFPU) Southeastern Nigeria, using three meteorological parameters namely, maximum air temperature, relative humidity and relative sunshine hours.

Wide range of solar energy applications including modeling, design of solar crop dryers and photovoltaic system sizing require robust knowledge of global solar radiation whose intensity is normally among the variables collected by weather stations. The important role played by knowledge sharing on the subject of solar radiation and its subsequent exploitation have necessitated the need to develop ways of predicting the incident solar radiation in the interest of the regions of the globe like tropical Africa, where routine measurements are lacking in spite of the huge availability of solar energy in the region. As the fossil fuel reserves suffer severe depletion coupled with environmental concerns, it becomes imperative that alternative energy resources should be explored and utilized with high conversion efficiency to help bridge the wide gap between energy supply and energy demand [2].

For sub-Saharan African countries such as Nigeria, the economic and efficient utilization of solar energy has become inevitable because of the abundance and reliability of solar energy resource. Augustine and Nnabuchi [3] estimated about 3,000 hours of annual sunshine in Nigeria. This, however, depends on the location and the time of the year. In spite of this huge amount of solar energy, Nigeria with a dominant rural population still has her residents suffering deprivation from conventional energy due to poor infrastructural facilities and subsequent unreliability in energy supply. Having vast knowledge of the distribution of solar energy at a geographical location is significant for the creation and advancement of new solar energy devices with improved efficiency. Data on solar radiation is a basic requirement for conducting feasibility studies with respect to solar energy systems. Augustine and Nnabuchi [4] opined that knowledge of solar energy acquired over a long period ought to be applicable not only to the site where the radiation data was collected but also to other locations with similar climate.

Nigeria is located between Latitude 4°N and 14°N. This vantage position enables the country to receive a vast amount of solar energy throughout the year. Solar radiation data can be accessed in a variety of forms depending on choice and application. Several scholars have emphasized the importance of solar radiation data in the design and operation of efficient solar energy devices which are anchored on accurate and detailed information of solar radiation climatology. Countless empirical models based on the Angstrom-Prescott-Page type model and other modified models such as exponential form, logarithm form, second order, third order and power form etc have been applied across the globe for estimating global solar radiation in the literature. The temperature-based computing models are especially interesting due to their needed input data (air temperature) which is easily measured globally. Hargreaves and Samani [5] firstly developed a temperature-based model for estimating global solar radiation using maximum and minimum temperature, and extraterrestrial solar radiation as input parameters and obtained an empirical coefficient of 0.17 using Eq. 1. Since then, it has been recognized as one of the famous, simplest and accurate temperature model for estimating global solar radiation and can be employed for short-term forecasting of global solar radiation. Ohunakin *et al*. [6] recorded a coefficient of 0.1141 in Osogbo while Adaramola [7] obtained a coefficient of 0.1945 at Akure, Nigeria.

$$\frac{H}{H_o} = AHC\left(T_{\max} - T_{\min}\right)^{0.5} \qquad 1$$

where T_{max} is the maximum temperature, T_{min} is the minimum temperature with the value of AHC of 0.17 for arid and semi-arid regions. However, calibrations are site-specific and cannot be extrapolated to other sites where weather conditions are different; also some calibrated Hargreaves-Samani (HS) models are more complicated compared to the original HS model. However, routine calibration of this computing model should be carried out to guarantee good performances over subsequent years because the historical data used to calibrate HS model directly ignores the ever-changing climate over the time; when data set extends, instability of the calibrated HS model may appear. Therefore, this present study is aimed at developing hybrid parameter-based models for calibrating HS empirical coefficient in three locations in Ebonyi State, Southestern Nigeria (AE-FUNAI, EBSU and AIFPU), using 35 years data (1984–2019). This would improve the applicability of HS model for accurate global solar radiation estimation in the Nigerian environment.

1.2 Scope and Significance of the Study

The study is designed to use the monthly mean daily data of global solar radiation, minimum temperature, maximum temperature and relative humidity for the period of thirty-five years (1984-2019) to evaluate the original Hargreaves-Samani coefficient in the three locations in Ebonyi State, Nigeria. The accuracy of the original and calibrated Hargreaves-Samani models was evaluated using the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) statistical indicators. The performance of the original and the calibrated Hargreaves-Samani models in the three locations were compared using statistical indicators. With the increased application of Empirical methods in estimating global solar radiation in Nigeria, it has become important to study and compare the relevance of empirical models for global solar radiation over other methods. Therefore, this research is intended to calibrate and model the global solar radiation using the conventional empirical models in AE-FUNAI, EBSU and AIFPU in Ebonyi State, Nigeria.

1.3 Fundamental Parameters

The fundamental parameters of sunshine duration fraction and daily extraterrestrial radiation on the horizontal surface are significant for the estimation of global solar radiation. Sunshine duration fraction is the ratio of actual sunshine duration to maximum possible sunshine duration expressed mathematically by Yaniktepe and Genc [8] as:

$$S_o = \frac{2}{15}\cos^{-1}\left(-\tan\varphi\tan\delta\right) \qquad 2$$

$$\delta = 23.45 \sin\left[\frac{360(n+284)}{365}\right] \quad 3$$

where ϕ is the latitude, δ is the solar declination given by Yaniktepe and Genc [8] and n, the number of days of the year starting from first January. The daily extraterrestrial solar radiation is the solar radiation intercepted by horizontal surface during a day without the atmosphere expressed theoretically as given by Yaniktepe and Genc [8]:

$$H_O = \frac{24}{\pi} I_{SC}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega_S + \frac{2\pi\omega_S}{360}\sin\phi\sin\delta\right) \quad 4$$

where the mean sunrise hour angle (ω_s) can be evaluated as:

$$\omega_s = \cos^{-1}[\tan\delta\tan\phi] \quad 5$$

I_{SC} is the solar constant and other symbols retain their usual meaning.

1.4 Empirical models

An empirical model in the present context relates global solar radiation with other easily measureable variables such as sunshine duration, temperature, relative humidity, dew point temperature, precipitation and cloud cover by employing concise mathematical functions. As a result of its simplicity and high operability, the empirical model is much more convenient for engineering applications. Several empirical models have been reported in literature for estimating global solar radiation on the Horizontal surface (H) either on Daily mean Basis (DB) or Monthly mean Daily basis (MB) in Nigeria. In this review, the global solar radiation models are classified according to the basis of their input parameters applied in correlating with the clearness index. The clearness index (k_t) indicates the percentage depletion by the sky of the incoming solar radiation and therefore gives both the level of availability of solar radiation and changes in the atmospheric condition in a given environment [9, 10]. Mathematically, clearness index is the ratio of horizontal global solar radiation (often measured and collected from Nigeria Meteorological Station (NIMET), International Institute of Tropical Agriculture (IITA), National Aeronautics and Space Administration (NASA) atmospheric science data center by researchers in Nigeria) to the extraterrestrial solar radiation (H_o) on daily or monthly basis as found in literature expressed as [11-13]:

$$k_t = \frac{H}{H_o} \quad 6$$

It has been accepted that global solar radiation is relatively affected by meteorological parameters, astronomical factors, geographical factors, and geometrical factors [14,15]. This could be attributed to the uniqueness of local climate in determining the meteorological and atmospheric parameters that best fit that particular locality. The availability of input meteorological/atmospheric parameter(s) that a given radiometric station or an individual is capable of measuring routinely affects the quality of the solar radiation predictive model. Thus the accuracy of the resulting model is impacted by the input parameter at the disposal of the researcher for predicting global solar radiation in a location. Thus, in Nigeria, many models have been developed for estimating global solar radiation (*e.g.*, Nwokolo *et al*, [16], Nwokolo *et al*, [17], Nwokolo and Amadi, [11], Akpabio and Etuk, [18], Burari and Sambo, [1], Awachie and Okeke, [19], etc.).

2. Study Area

Ebonyi State has a tropical climate with wet and dry seasons. Two distinct wet seasons are observed: the more intense season is observed from April to July whereas a less intense one occurs from September to November. Ebonyi state experiences a dry season (when rain falls less than two days in a month) in August, as well as from December to March. This second part of dry season is accompanied by Harmattan winds which originate from the Sahara Desert and have their peak from December to early February. Ebonyi State has a fair small temperature range, generally between a 33°C and 21°C. The hottest month is March, when the mean diurnal temperatures reach about 29°C. July is the coldest month with a mean temperature of about 25°C [20]. The map showing the locations under study is shown in Figure 1.

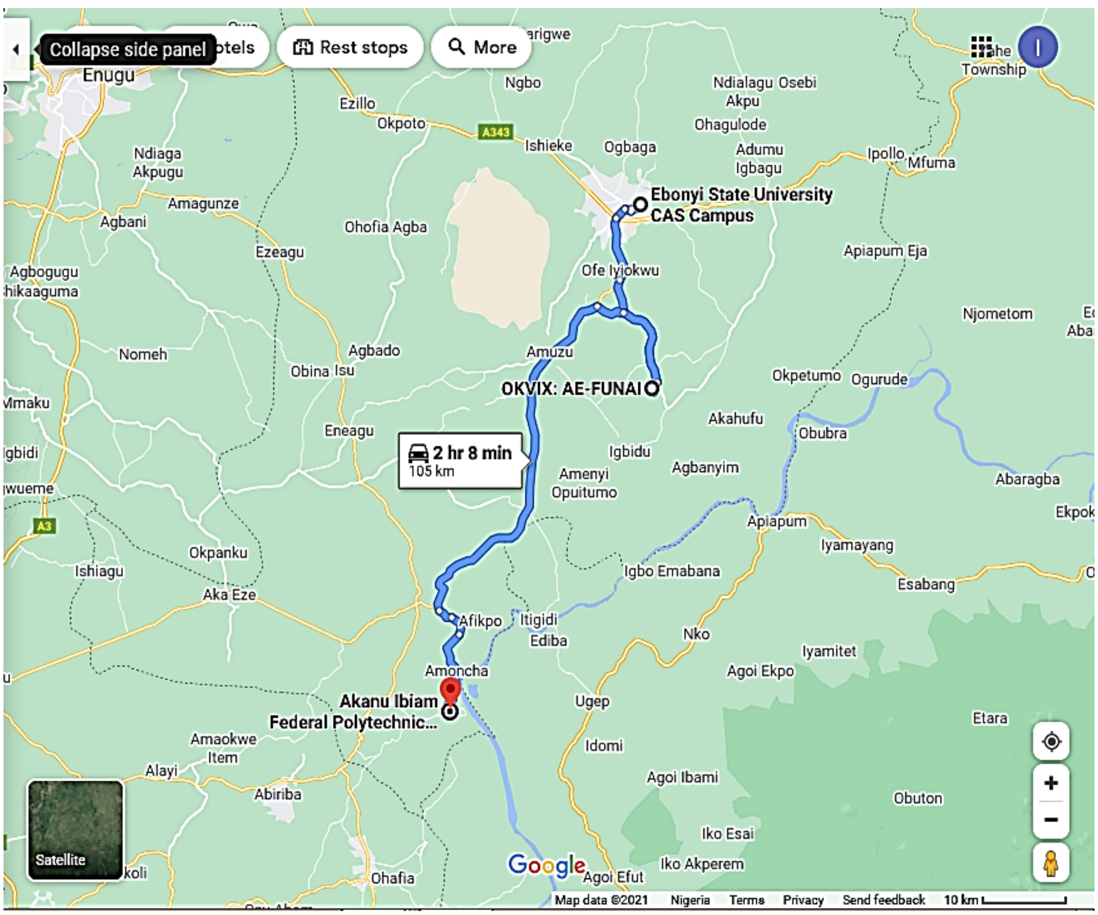

Figure 1. Map showing the locations and relative positions of Alex Ekwueme Federal University Ndufu-Alike, Ebonyi State University Abakaliki and Akanu Ibiam Federal Polytechnic Unwana

3 Materials and Method

3.1 Climate and Meteo-Solar Datasets

A set of historical climate data such as monthly mean solar radiation, average minimum and maximum air temperature, and relative humidity were obtained from the

NASA database (http://power.larc.nasa.gov/data-access), and are used in this study. The records of sunshine duration were obtained from the International Institute of Water Management (http://www.iwmi.cgiar.org/). The topographical features of the weather stations used in this study are presented in Table 1.

Table 1. Geographical, climatological and meteorological details of the selected locations

Location	Lat. [^{o}N]	Long. [^{o}E]	Ele [m]	Data Range	S	So	S/So	H	Ho	H/Ho	RH	T_{min}	T_{max}	ΔT
AIFPU	5.829	7.927	107m	1984 – 2019	4.832	12.12	0.4000	16.78	35.67	0.4701	84.52	22.22	29.04	6.83
AEFUNAI	6.066	8.083	55m	1984 – 2019	4.99	12.12	0.4133	18.25	35.58	0.5083	82.84	22.12	29.35	7.25
EBSU	6.395	8.014	72m	1984 – 2019	4.99	12.12	0.4100	17.94	35.46	0.5083	82.84	22.12	29.35	7.24

H represents the monthly mean daily global solar radiation (MJm^{-2}/day^{-1}), H_o represents monthly mean daily extraterrestrial solar radiation (MJm^{-2}/day^{-1}), kt is a dimensionless parameter known as monthly mean daily clearness index, S/S_o is a dimensionless parameter known as the monthly mean daily sunshine fraction, S is the monthly mean sunshine hours (in hours), S_o is the monthly mean maximum sunshine hours (in hours), RH is the monthly mean relative humidity (in %), T_{min} is the monthly mean minimum temperature (in ^oC), T_{max} is the monthly mean maximum temperature (in ^oC), ΔT is the difference between the monthly mean maximum and minimum temperature (in ^oC).

3.2 Evaluation of Meteo-Solar Parameters

Models based on sunshine hours were selected from among other types of models that are considered to estimate global solar radiation on a horizontal surface in EBSU, AIFPU and AE-FUNAI. The correlation of the datasets between monthly mean global solar radiation (H) and extraterrestrial solar radiation (H_o) often expressed as H/Ho or clearness index (k_t) was considered due to their simple functional form and rigid calculation skills. On this basis, calculations were made on the maximum monthly average solar length and extraterrestrial solar radiation. Therefore, the average extraterrestrial solar radiation is considered as [8, 12, 13, 16]:

$$H_o = \frac{24}{\pi} I_{sc}\left(1 + 0.033 \cos\frac{360n}{365}\right) \times \left(\cos\varphi \cos\delta \sin\omega + \frac{2\pi\omega}{360} \sin\varphi \sin\delta\right) \quad 7$$

$$\delta = 23.45\left[\frac{360(n+284)}{365}\right] \quad 8$$

$$\omega = \cos^{-1}[-\tan\delta \tan\varphi] \quad 9$$

The solar declination angle (δ) was calculated using equation (8) and the mean sunrise hour angle (ω) was evaluated using equation (9). n is the number of days of the year staring from first January, and (φ) is the latitude of the location. The monthly mean maximum sunshine period is evaluated as:

$$S_o = \frac{2}{15}\omega \quad 10$$

Equations 7 – 9 were used to evaluate the monthly mean meteorological solar radiation input and output parameters for EBSU, AIFPU and AE-FUNAI.

3.3 Development and Selection of Empirical Models

Consequent upon the need for empirical models to estimate global solar radiation in order to quantify the global solar radiation present in many remote and developing parts of Ebonyi State in the absence of an instrumentation network or measurement structures, six new empirical models were developed for statewide application of a similar correlation procedure classified as models based on sunshine, temperature, relative humidity, and hybrid parameter models using IBM SPSS version 22 software, as presented in Table 4. The sets of monthly average data were divided into training and test sets. 75% of the data set for the period from January 1984 to December 2010 were used for sample training and the remaining 25% of the data set for the period from January 2011 to December 2019 were used for testing. To validate the applicability of the proposed six models, two solar radiation models commonly applied by solar energy estimators were applied, as presented in Table 4. The two single parameter-dependent models were intentionally selected to confirm that the hybrid modeling are much better suited for estimating global solar radiation and for wider application for Ebonyi State locations with varying geographical and climatic conditions.

4. Results and Discussion

4.1 Descriptive Statistics of Meteo-Solar Parameter

Table 2. Descriptive statistics of meteo-solar parameters

Location	Statistic	Meteo-Solar Parameters									
		H	Ho	kt	Tmax	Tmin	ΔT	RH	So	S	S/So
EBSU	Range	6.37	4.92	0.221	3.31	4.83	5.61	21.79	0.73	3.16	0.28
	Minimum	14.34	32.58	0.39	27.92	19	5.41	68.03	11.8	2.96	0.24
	Maximum	20.71	37.5	0.611	31.24	23.82	11.03	89.83	12.5	6.12	0.52
	Mean	18.06	35.68	0.508	29.32	22.07	7.26	82.79	12.1	4.83	0.4
	Std. Error	0.63	0.46	0.021	0.35	0.44	2.07	2.33	0.08	0.33	0.029
	Std.deviation	2.19	1.58	0.074	1.21	1.54	12	8.07	0.27	1.13	0.099
AIFPU	Range	14.05	6.63	0.386	5.16	10.02	8.59	33.39	0.67	6.17	0.528
	Minimum	9.7	31.07	0.283	26.93	14.99	4.65	58.61	11.8	1.77	0.144
	Maximum	23.75	37.7	0.669	32.09	25.01	13.24	92	12.5	7.95	0.673
	Mean	16.78	35.81	0.47	29.05	22.22	6.83	84.49	12.1	4.83	0.4
	Std. Error	2.61	1.4	0.08	1.1	1.53	1.76	7.18	0.23	1.27	0.11
	Std.deviation	6.83	1.97	0.006	1.2	2.34	3.08	51.53	0.05	1.61	0.012
AE-FUNAI	Range	13.6	9.28	0.362	5.98	10.45	9.48	40.3	0.69	3.28	0.29
	Minimum	10.64	28.51	0.333	27.02	14.67	4.71	51.44	11.8	3.08	0.25
	Maximum	24.24	37.79	0.695	33	25.12	14.19	91.74	12.5	6.36	0.54
	Mean	18.06	35.68	0.508	29.36	22.12	7.25	82.79	12.1	4.99	0.413
	Std. Error	0.11	0.08	0.004	0.06	0.08	0.1	0.41	0.07	0.34	0.029
	Std.deviation	2.39	1.72	0.077	1.28	1.76	2.17	8.54	0.25	1.17	0.102

The histogram diagram shown in Figures 2-4 indicate that the amplitude variations of the meteo-solar parameters such as the clearness index (k_t), the hours of sunshine (S), the fraction of sunshine (S/S_o) and the maximum temperature (T_{max}). Response for strong insolation in AE-FUNAI, EBSU, and AIFPU recorded a similar stable normal curve corresponding to that of global solar radiation on a horizontal surface (H). It can be observed that the AIFPU site reported a higher normal curve for meteo-solar parameters such as relative humidity, minimum temperature, maximum duration of the sunshine and extraterrestrial solar radiation compared to the EBSU and AE-FUNAI sites. Therefore, the AIFPU site recorded lower global solar radiation than EBSU and AE-FUNAI. This indicates that the greater the amplitude curvature of these meteo-solar sites, the lower the monthly average global solar radiation of the ground recorded in EBSU, AIFPU and AE-FUNAI, as well as in other geographic and climatic locations similar to those of Nigeria as presented in Table 2.

4.2 Diurnal Fluctuations of Meteo-Solar Parameters

Values of monthly and annual meteo-solar parameters observed as global solar radiation on a horizontal surface (H), extraterrestrial solar radiation (H_o), clearness index (k_t), maximum hour of daylight (S_o), sunlight hours (S), sunlight fraction (S/S_o), relative humidity (RH), maximum temperature (T_{max}) and minimum temperature (T_{min}), for EBSU, AIFPU and AE-FUNAI are presented in Table 3 and Figure 5. Diurnal fluctuations in solar-meteorological parameters in response to seasonal changes of the year due to Earth's rotation around the Sun brought about observable changes in the monthly and annual datasets. During the rainy season months (April to October), meteo-solar parameters such as global solar radiation on a horizontal surface (H), the clearness index (k_t), hours of sunshine (S), fraction of sunlight (S/S_o) and maximum temperature (T_{max}) values are lower than in the dry season (from November to March) as presented in Table 3 and Figure 5. On the contrary, the meteorological-solar parameters such as relative humidity, minimum temperature, maximum solar duration and extraterrestrial solar radiation record the highest values in the rainy season months (April to October) compared to the dry season (November to March) as presented in Table 3 and Figure 5. High values of global solar radiation on a horizontal surface (H), clearness index (k_t), hours of sunshine (S), fraction of sunlight (S/S_o) and maximum temperature (T_{max}) obtained during the dry season can be as a result of low relative humidity and cloud cover, low absorption of diffuse solar radiation and near-infrared radiation in the solar spectrum, long dry season with associated latitude and widespread cloud and atmospheric humidity associated with the movement of Hadley cell circulation system along the equatorial path during this period on Ebony State and its environs, thus improving these meteo-solar parameters obtained for EBSU, AIFPU and AE-FUNAI. However, the low values of these meta-solar parameters obtained during the rainy season may be due to relatively higher cloud cover, relative humidity, long rainy season and greater diffuse and near-infrared radiation absorption in the solar spectrum, resulting in a low global solar radiation received at the site. These trends are similar to the report of some solar energy researchers in the region of tropical rainforest and semi-arid climates of Nigeria (Nwokolo and Ogbulezie [20] for 23 locations sparsely selected in Nigeria; Maduekwe and Chendo [21] for Lagos; Fagbenle [22] for Ibadan; Adaramola [7] for Akure; Ohunakin *et al*. [6] for Osogbo; Okundamiya *et al*. [23] for Ibadan). Maximum and minimum values of the daily average duration of the sunshine occurred in December and August at these three locations respectively as shown in Table 3 and Figure 5. For instance, EBSU recorded maximum of 6.36 hours of sunshine hours and minimum of 3.08 hours with corresponding overall annual average value of 4.99 hours. AIFPU recorded a maximum of 6.13 sunshine hours and a minimum of 2.95 hours with corresponding average values of 4.83 hours.

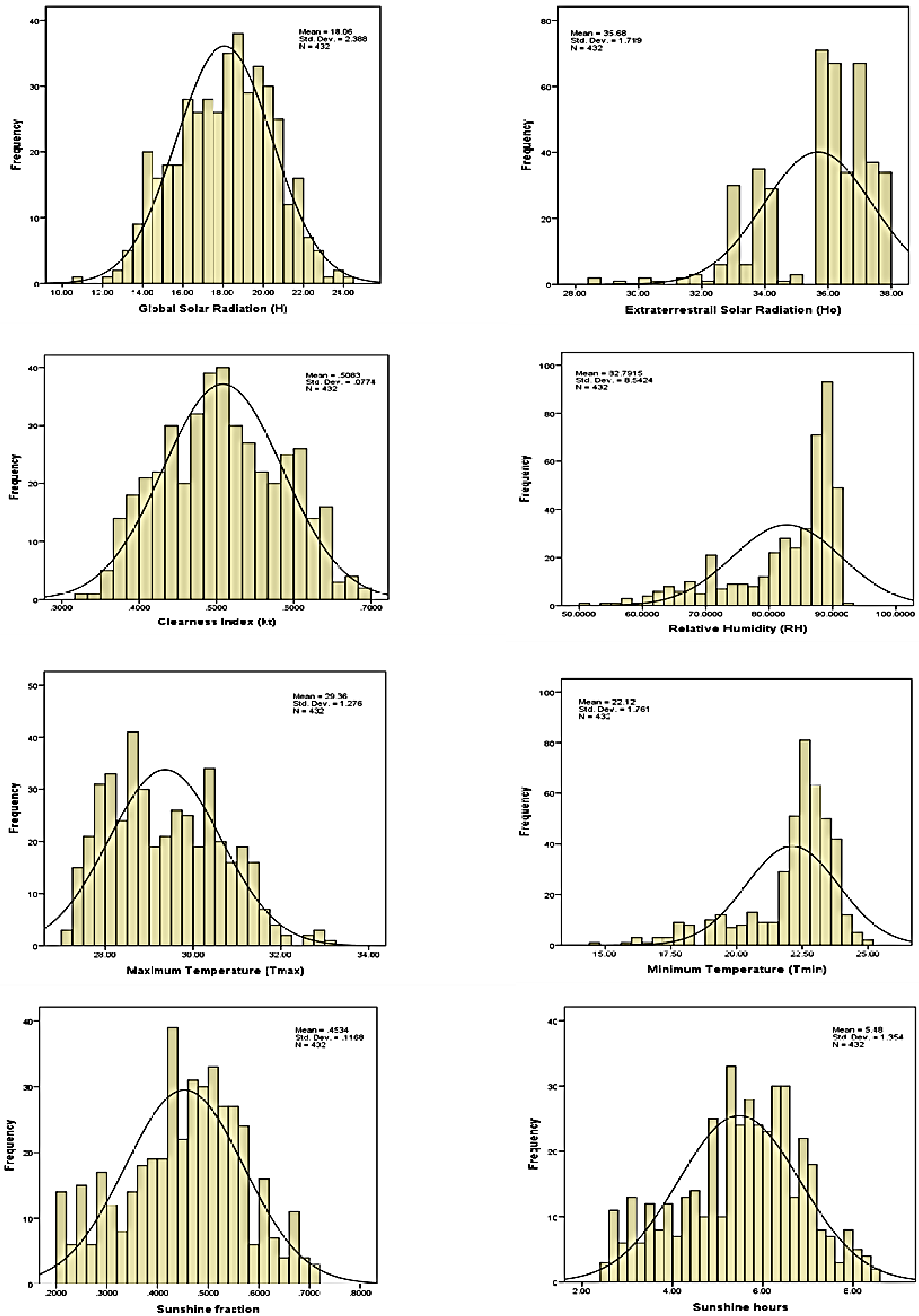

Figure 2. Descriptive statistics for AE-FUNAI

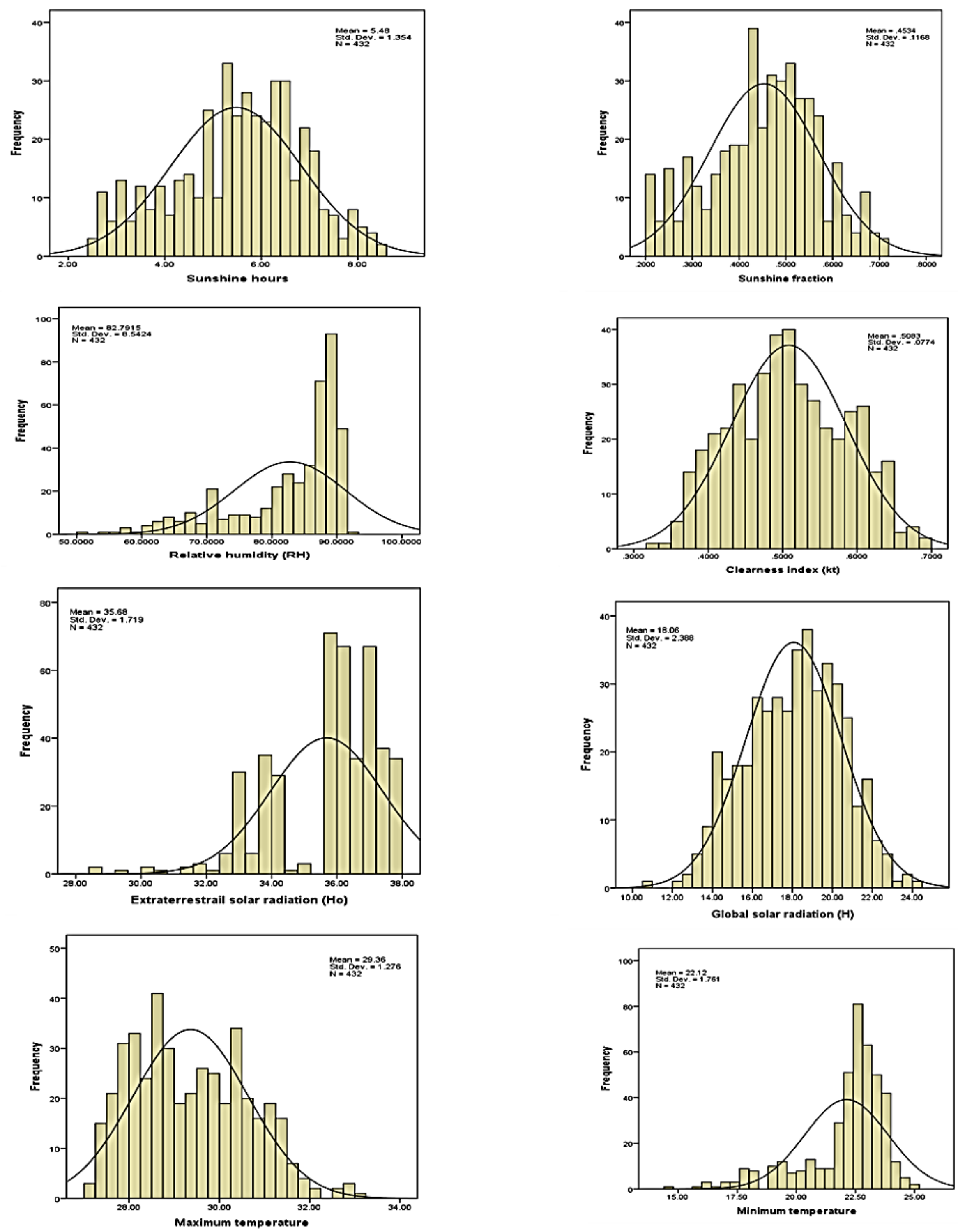

Figure 3. Descriptive statistics for EBSU

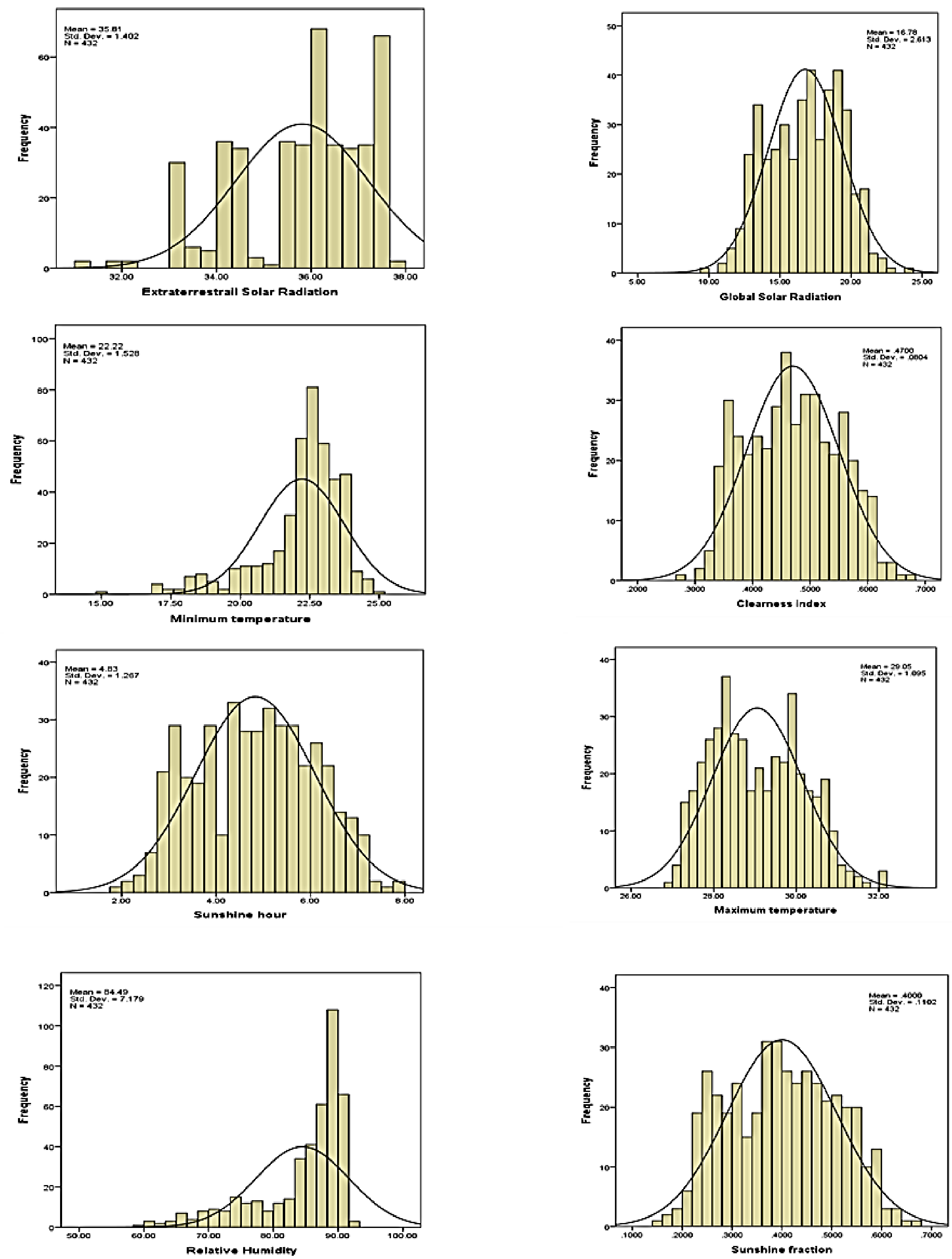

Figure 4. Descriptive statistics for AIFPU

The monthly maxima and minima of the monthly global solar radiation averages occurred in February and August respectively at these three locations as shown in Table 3 and Figure 5. For instance, EBSU recorded 20.71 $MJm^{-2}day^{-1}$ for maximum global solar radiation and 14.34 $MJm^{-2}day^{-1}$ for the minimum, with a corresponding annual average value of 17.94 $MJm^{-2}day^{-1}$. Other details can be found in Table 3. The results validate the results of several authors around the world that meteo-solar parameters such as solar hours, latitude, maximum temperature, relative humidity and other atmospheric parameters influence global solar radiation as reported nationally, Nwokolo and Ogbuluezie, [9]; regional, Nwokolo and Ogbuluezie, [10]; and global review [15].

4.3 Meteo-Solar Classification

4.3.1 Sunshine Fraction

The fraction of monthly sunshine is the ratio of the actual duration of the sun to the maximum possible sunshine duration which varies from one month to another due to the movement of the earth as shown in Table 3. Based on the World Meteorological Organization classification namely: (1) cloudy sky ($0 \leq S/So < 0.3$), (2) sky with scattered clouds ($0.3 \leq S/So < 0.7$) and (3) clear skies ($0.7 \leq S/So \leq 1.0$), sunshine conditions at the three locations (EBSU, AIFPU and AE-FUNAI) are mostly Type 2 sky conditions, except in the months of July to September when this can be viewed as the state of the cloudy sky. These proportions are comparable to the values recorded in the literature in the same warm semi-arid climatic region of Nigeria [18, 24].

4.3.2 Clearness Index

The monthly average clearness index designates the percentage of depletion by the sky of the incoming global solar radiation and therefore indicates both the level of availability of solar radiation and the changes in atmospheric conditions in a given location. The prevailing clearness index ranged between 0.39 - 0.51 for EBSU; 0.36 - 0.49 for AIFPU and 0.40 - 0.51 for AE-FUNAI between the months of April to October in the rainy season and 0.54 - 0.61 for EBSU; 0.50 - 0.58 for AIFPU and 0.55 - 0.62 for AE-FUNAI between the months from January-March to November-December in the dry season with an annual value of 0.51 for EBSU, 0.47 for AIFPU and 0.51 for AE-FUNAI as shown in Table 3. Using the meteorological classification proposed by Iqbal [25] which are: (1) heavily cloudy weather ($k_t \leq 0.4$); (2) partially cloudy weather ($0.4 \leq k_t \leq 0.6$); and (3) clear weather ($k_t \geq 7$), Ebonyi's prevailing weather conditions fall within the partially cloudy weather. These indicate that the notable features of Ebony State are the predominance of partially cloudy weather. It has been observed from Table 3 that global solar radiation increases as the clearness index increases and then increases rapidly as heavy cloudy weather becomes lighter. This reveals that the global solar radiation is optimally controlled by the clearness index except during August in EBSU and AE-FUNAI and July to September for the AIFPU sites when the weather conditions can be considered as heavily cloudy weather in Ebonyi State, Nigeria. Meteorological conditions predominant for the three locations within the maximum intensity of solar radiation which occurred in December-January for EBSU (0.61), 0.58 in December-January for AIFPU and 0.62 in January for AE-FUNAI fall within the partially cloudy weather. Predominant weather conditions for Ebonyi within the minimum intensity of solar radiation occurring in August for EBSU (0.39), AIFPU (0.36) and AE-FUNAI (0.40) fall within heavily overcast weather. It is appropriate to state emphatically that the month in which the minimum clearness index occurs (August) represents the peak cloudiness in which persistent precipitation occurs sandwiched by some days of sunshine, otherwise known as little dry season (LDS) or "August Break" in the local parlance. From Table 3, it can be seen that the EBSU and AE-FUNAI localities recorded respectively 0.39 and 0.40 values in the month of August representing only heavily cloudy weather while the AIFPU recorded values of the clearness index of 0.37, 0.36 and 0.38 in the months of July, August and September respectively in the peak of the months of the rainy season. This indicates that AIFPU's location is more turbid than EBSU and AE-FUNAI due to perhaps, peculiar land-river characteristics, relatively higher cloud cover, relative humidity, prolonged rainy season, and increased absorption of diffuse and near infrared radiation in the spectrum solar radiation, resulting in low global solar radiation received at the site compared to EBSU and AE-FUNAI. In general, it can be concluded that, as the prevailing weather conditions are sampled in parts of EBSU, AIFPU and AE-FUNAI from different parts of Ebonyi State, the skies are mostly clear. This suggests that various photovoltaic solar technologies such as mono-silicon, hybrid silicon, amorphous silicon, cadmium telluride, and poly-silicon can function properly in the State, especially in the EBSU and AE-FUNAI sites.

4.4 Fittings Performance Evaluation

Hybrid regression technique and single parameter were used to estimate monthly average global solar radiation (H) at EBSU, AIFPU and AE-FUNAI representing various institutions of higher education in the Ebonyi State. Consequently, for each institution selected in this study, performance analyses were performed using the adjusted empirical models EM1 -EM6 presented in Table 4. Table 4 presents the regressive functional empirical forms with their respective coefficients, as well as the HS temperature model and the Angstrom-Prescott (AP) sunshine model selected from the literature. The AP model represents the conventional empirical model of the sunshine hour parameter from which at least other linear and non-linear regression techniques are developed using meteo-solar parameters. As a result, HS adopted the AP functional form to develop the temperature model as a power function. It can be seen that the HS model was the first empirical model to calculate the global solar radiation (H) using the temperature parameter, and Angstrom was the first researcher to introduce the linear idea of Kimball [26] in linear functional form correlated with the application of the solar eclipse fraction with H in the clear sky in the convenient functional form that is currently used worldwide as an empirical reference model to estimate H. This technique was instilled to compare the fitted models in this study with the famous HS and AP models because most solar testers often used these models as a reference model to develop other models based on sunshine and temperature parameters for solar systems in order to compare HS and AP coefficients, since models based on temperature and sunshine parameters are the best empirical models available in Nigeria (Nwokolo and Ogbulezie, [20]; India, Makade *et al*. [27]; China, Feng *et al*., [28]; West Africa, Nwokolo and Ogbuluezie, [10], global, Besharat *et al*., [15]). The error metrics for the training and testing data sets of the six regression models are presented in Table 5. Figures 6 - 8 show the relative performance of the three distinct models (AE-FUNAI, EBSU and AIFPU respectively) comparing the observed and estimated global solar radiation for the three selected higher education institutions sites, using models based on individual parameters and on the training and suitability test categories.

Table 3. Monthly and annual diurnal variability of meteo-solar parameters

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	Ebonyi State University (EBSU)												
RH	67.99	70.97	80.57	84.98	87.33	88.63	89.00	89.07	89.75	89.68	83.37	72.14	82.84
Tmin	19.06	21.15	23.28	23.84	23.69	23.01	22.36	22.25	22.53	22.79	22.09	19.36	22.12
Tmax	30.10	31.24	31.04	30.51	29.66	28.66	28.00	27.98	28.02	28.21	29.40	29.53	29.35
Ho	33.46	35.66	37.30	37.50	36.44	35.73	35.95	36.77	37.01	35.92	33.83	32.58	35.46
H	20.44	20.71	20.16	19.28	18.12	16.78	15.08	14.34	15.71	17.36	18.97	19.84	17.94
Kt	0.61	0.58	0.54	0.51	0.50	0.47	0.42	0.39	0.42	0.48	0.56	0.61	0.51
S	5.79	5.85	5.32	5.64	5.57	4.49	3.23	3.08	3.52	4.80	6.28	6.36	4.99
So	11.82	11.93	12.10	12.25	12.38	12.47	12.43	12.32	12.15	12.00	11.85	11.78	12.12
S/So	0.49	0.49	0.44	0.46	0.45	0.36	0.26	0.25	0.29	0.40	0.53	0.54	0.41
	Akanu Ibiam Federal Polytechnic, Unwana (AIFPU)												
RH	71.89	74.90	83.07	86.30	88.09	89.31	89.56	89.50	90.25	90.18	85.44	75.36	84.52
Tmin	19.67	21.58	23.34	23.76	23.59	22.88	22.22	22.07	22.43	22.75	22.36	19.99	22.22
Tmax	29.64	30.63	30.46	30.11	29.41	28.44	27.86	27.90	27.90	28.07	29.02	29.16	29.04
Ho	33.98	35.99	37.38	37.40	36.29	35.50	35.71	36.68	37.11	36.20	34.32	33.17	35.67
H	19.69	19.73	18.75	18.19	16.98	15.25	13.34	13.22	13.94	15.61	17.54	19.10	16.70
Kt	0.58	0.55	0.50	0.49	0.47	0.43	0.37	0.36	0.38	0.43	0.51	0.58	0.47
S	5.56	5.73	5.19	5.50	5.45	4.36	3.11	2.95	3.40	4.56	6.05	6.13	4.83
So	11.82	11.93	12.08	12.23	12.38	12.45	12.43	12.30	12.15	12.00	11.87	11.78	12.12
S/So	0.47	0.48	0.43	0.45	0.44	0.35	0.25	0.24	0.28	0.38	0.51	0.52	0.40
	Alex Ekwueme Federal University Ndufu Alike Ikwo (AE-FUNAI)												
RH	67.91	69.97	80.70	84.91	86.33	89.63	89.57	89.05	89.70	89.64	83.40	72.18	82.75
Tmin	19.08	21.13	23.24	23.86	23.67	23.03	22.34	22.27	22.55	22.76	22.07	19.40	22.12
Tmax	30.15	31.20	31.01	30.53	29.65	28.64	28.01	27.97	28.04	28.23	29.42	29.51	29.37
Ho	33.67	35.81	37.47	37.64	36.69	35.89	36.10	36.92	37.17	36.06	34.07	32.83	35.86
H	20.82	21.19	20.51	19.33	18.17	16.87	15.40	14.69	15.76	17.23	18.97	20.07	18.25
Kt	0.62	0.59	0.55	0.51	0.50	0.47	0.43	0.40	0.42	0.48	0.56	0.61	0.51
S	5.79	5.85	5.32	5.64	5.57	4.49	3.23	3.08	3.52	4.80	6.28	6.36	4.99
So	11.82	11.93	12.10	12.25	12.38	12.47	12.43	12.32	12.15	12.00	11.85	11.78	12.12
S/So	0.49	0.49	0.44	0.46	0.45	0.36	0.26	0.25	0.29	0.40	0.53	0.54	0.41

Figure 5. Monthly diurnal variability of meteo-solar parameters for EBSU, AIFPU & AE-FUNAI

H represents the monthly mean daily global solar radiation (MJm^{-2}/day^{-1}), H_o represents monthly mean daily extraterrestrial solar radiation (MJm^{-2}/day^{-1}), k_t is a dimensionless parameter known as monthly mean daily clearness index, S/S_o is a dimensionless parameter known as the monthly mean daily sunshine fraction, S is the monthly mean sunshine hours, S_o is the monthly mean maximum sunshine hours, RH is the monthly mean relative humidity (%), T_{min} is the monthly mean minimum temperature (^oC), T_{max} is the monthly mean maximum temperature (^oC).

From Table 5, it can be understood that the six regression models used in the different locations accurately estimated the observed average global solar radiation based on the error metric evaluations. The EM6 model classified as a hybrid model based on parameters with input of sunshine fraction shows variation between maximum and minimum temperature, maximum sunshine hours and relative humidity shows better performance in terms of training and test error measures compared to EM1 - EM5 using the difference between maximum and minimum temperature (EM1 and EM2), fraction of sunshine duration (EM3), variation between maximum and minimum temperature and maximum parameters of sunshine (EM4) and relative humidity (EM5) in EBSU, AIFPU and AE-FUNAI. To universally apply the applicability of the AP solar model (EM8) and HS temperature model (EM7) to the HS type models (EM1) and AP (EM3) developed by this study as presented in Table 4, error metrics are presented in Table 5. It may be noted that EM1 and EM3 developed in EBSU, AIFPU and AE-FUNAI performed better than the original AP (EM8) model and the HS model (EM7). This could be attributed to the geographical and climatic factors used to obtain the coefficients of the model EM8 (AP) and the model EM7 (HS). North American meteo-solar parameter is completely different from three meteo-solar parameters used in this study. To test the applicability of the universally applied AP (EM8) sunshine model and the HS (EM7) temperature model to the best performing hybrid (EM6) in the three locations, the metrics indicate that rates of applied error EM6 was better than EM7 (HS) and EM8 (AP) as presented in Table 5. This could be attributed to the geographic and climatic factors used to obtain the coefficients of the EM8 (AP) model and the EM7 (HS) model. North American meteo-solar parameter is completely different from three solar-meteorological parameters in the locations used in this study.

Table 4. Developed models in this study together with frequently employed models for estimating global solar radiation using various meteorological parameters in AIFPU, AE-FUNAI and EBSU in Nigeria

S/N	Algebraic Equation	Parameter	Station/Country	Study	Model #
1	$\frac{H}{H_o} = 0.181703(\Delta T)^{0.5}$	Temperature	AIFPU, Nigeria	Present	EM1
2	$\frac{H}{H_o} = -0.058 + 0.204(\Delta T)^{0.5}$	Temperature	AIFPU, Nigeria	Present	EM2
3	$\frac{H}{H_o} = 0.264 + 0.464\left(\frac{S}{S_o}\right)$	Sunshine	AIFPU, Nigeria	Present	EM3
4	$\frac{H}{H_o} = 0.238 + 0.415\left(\frac{\Delta T}{S_o}\right)$	Hybrid	AIFPU, Nigeria	Present	EM4
5	$\frac{H}{H_o} = 1.234 - 0.899\left(\frac{RH}{100}\right)$	Relative humidity	AIFPU, Nigeria	Present	EM5
6	$\frac{H}{H_o} = -0.249 + 0.709\left(\frac{S}{S_o}\right) -0.509\left(\frac{S}{S_o}\right)^2 +0.357(\Delta T)^{0.5} - 0.470\left(\frac{\Delta T}{S_o}\right) -0.177\left(\frac{RH}{100}\right)$	Hybrid	AIFPU, Nigeria	Present	EM6
1	$\frac{H}{H_o} = 0.19059(\Delta T)^{0.5}$	Temperature	FUNAI, Nigeria	Present	EM1
2	$\frac{H}{H_o} = 0.070 + 0.164(\Delta T)^{0.5}$	Temperature	FUNAI, Nigeria	Present	EM2
3	$\frac{H}{H_o} = 0.299 + 0.464\left(\frac{S}{S_o}\right)$	Sunshine	FUNAI, Nigeria	Present	EM3
4	$\frac{H}{H_o} = 0.311 + 0.326\left(\frac{\Delta T}{S_o}\right)$	Hybrid	FUNAI, Nigeria	Present	EM4
5	$\frac{H}{H_o} = 1.118 - 0.739\left(\frac{RH}{100}\right)$	Relative humidity	FUNAI, Nigeria	Present	EM5

6	$\frac{H}{H_o} = -0.275 + 0.814\left(\frac{S}{S_o}\right) - 0.643\left(\frac{S}{S_o}\right)^2 + 0.218(\Delta T)^{0.5} - 0.360\left(\frac{\Delta T}{S_o}\right) - 0.435\left(\frac{RH}{100}\right)$	Hybrid	FUNAI, Nigeria	Present	EM6
1	$\frac{H}{H_o} = 0.191588(\Delta T)^{0.5}$	Temperature	EBSU, Nigeria	Present	EM1
2	$\frac{H}{H_o} = 0.053 + 0.172(\Delta T)^{0.5}$	Temperature	EBSU, Nigeria	Present	EM2
3	$\frac{H}{H_o} = 0.298 + 0.469\left(\frac{S}{S_o}\right)$	Sunshine	EBSU, Nigeria	Present	EM3
4	$\frac{H}{H_o} = 0.306 + 0.340\left(\frac{\Delta T}{S_o}\right)$	Hybrid	EBSU, Nigeria	Present	EM4
5	$\frac{H}{H_o} = 1.127 - 0.744\left(\frac{RH}{100}\right)$	Relative humidity	EBSU, Nigeria	Present	EM5
6	$\frac{H}{H_o} = -0.301 + 0.707\left(\frac{S}{S_o}\right) - 0.529\left(\frac{S}{S_o}\right)^2 + 0.207(\Delta T)^{0.5} - 0.081\left(\frac{\Delta T}{S_o}\right) + 0.124\left(\frac{RH}{100}\right)$	Hybrid	EBSU, Nigeria	Present	EM6

Frequently employed models from Literature

1	$\frac{H}{H_o} = 0.17(\Delta T)^{0.5}$	Temperature	North America	Hargreave-Samani	EM7
2	$\frac{H}{H_o} = 0.25 + 0.54\left(\frac{S}{S_o}\right)$	Sunshine	North America	Angstrom-Prescott	EM8

Table 5. Statistical metrics of empirical models developed for EBSU, AIFPU and AE-FUNAI, Nigeria

				Training					Testing				
Study	**Country**	**Method**	**Model No**	**MBE**	**MPE**	**RMSE**	**RRMSE**	**R^2**	**MBE**	**MPE**	**RMSE**	**RRMSE**	**R^2**
Present	EBSU, Nigeria	Empirical	EM1	-0.0022	-0.0227	0.1540	0.9979	0.4159	-0.0001	-0.0021	0.0635	1.1727	0.6503
Present	EBSU, Nigeria	Empirical	EM2	-0.0027	-0.0263	0.1498	0.9821	0.4109	-0.0002	-0.0031	0.0618	1.1571	0.6427
Present	EBSU, Nigeria	Empirical	EM3	0.0015	0.0044	0.1212	0.7357	0.5864	0.0017	0.0069	0.0853	1.4733	0.3534
Present	EBSU, Nigeria	Empirical	EM4	-0.0022	-0.0239	0.1493	0.9773	0.4058	-0.0001	-0.0024	0.0634	1.1818	0.6277
Present	EBSU, Nigeria	Empirical	EM5	-0.0038	-0.0334	0.1577	1.0320	0.3578	0.0000	-0.0023	0.0664	1.2282	0.5946
Present	EBSU, Nigeria	Empirical	EM6	0.0000	-0.0011	0.0457	0.8372	0.7979	-0.0015	-0.0135	0.1074	0.6758	0.6989
HS	North America	Empirical	EM7	0.0163	0.0842	0.2026	1.2169	0.4159	0.0063	0.0329	0.1207	2.1053	0.6503
AP	North America	Empirical	EM8	-0.0037	-0.0280	0.1311	0.8242	0.5575	-0.0001	-0.0034	0.0855	1.5116	0.3285
Present	AIFPU, Nigeria	Empirical	EM1	0.0001	-0.0031	0.0713	1.4559	0.6238	-0.0029	-0.0364	1.5307	11.3552	0.4675
Present	AIFPU, Nigeria	Empirical	EM2	0.0001	-0.0026	0.0707	1.4323	0.6297	-0.0026	-0.0328	1.5235	11.2107	0.4754
Present	AIFPU, Nigeria	Empirical	EM3	-0.0001	-0.0048	0.0908	1.7495	0.3452	-0.0059	-0.0489	1.5181	10.6077	0.5561
Present	AIFPU, Nigeria	Empirical	EM4	-0.0001	-0.0036	0.0723	1.4636	0.6191	-0.0032	-0.0367	1.5040	11.1184	0.4831
Present	AIFPU, Nigeria	Empirical	EM5	-0.0001	-0.0036	0.0718	1.4419	0.6235	-0.0053	-0.0494	1.5730	11.6136	0.4835
Present	AIFPU, Nigeria	Empirical	EM6	0.0001	-0.0013	0.0521	1.0362	0.7890	-0.0029	-0.0255	1.0533	7.4179	0.7739
HS	North America	Empirical	EM7	0.0034	0.0170	0.0946	1.7915	0.6238	0.0069	0.0256	1.7333	11.9041	0.4675
AP	North America	Empirical	EM8	-0.0023	-0.0179	0.1027	2.0297	0.3551	-0.0126	-0.0885	1.7852	12.6083	0.5728
Present	AE-FUNAI, Nigeria	Empirical	EM1	-0.0035	-0.0297	1.4369	9.3590	0.5735	-0.0001	-0.0028	0.7296	13.5724	0.4567
Present	AE-FUNAI, Nigeria	Empirical	EM2	-0.0032	-0.0296	1.4027	9.2546	0.5631	-0.0001	-0.0032	0.6954	13.1496	0.4473
Present	AE-FUNAI, Nigeria	Empirical	EM3	0.0015	0.0044	1.2116	7.3568	0.5854	0.0012	0.0037	0.8960	15.7531	0.3228

Present	AE-FUNAI, Nigeria	Empirical	EM4	-0.0024	-0.0254	1.3956	9.2324	0.5500	0.0003	-0.0010	0.7198	13.4796	0.4208
Present	AE-FUNAI, Nigeria	Empirical	EM5	-0.0025	-0.0259	1.5621	10.1624	0.5693	0.0000	-0.0026	0.6933	12.9603	0.3578
Present	AE-FUNAI, Nigeria	Empirical	EM6	-0.0031	-0.0219	1.1031	6.8804	0.7447	-0.0002	-0.0026	0.5370	9.9125	0.6876
HS	North America	Empirical	EM7	0.0143	0.0732	1.8343	11.0012	0.5735	0.0059	0.0307	1.1758	20.6347	0.4564
AP	North America	Empirical	EM8	-0.0021	-0.0191	1.2639	7.9053	0.5537	0.0000	-0.0038	0.8995	16.1253	0.2992

5. Conclusion and Recommendations

5.1 Conclusion

The present study found that the locally simulated empirical model performed better for global solar radiation on a monthly and annual time scale in AE-FUNAI, EBSU and AIFPU due to the performance evaluation metrics obtained in the error metric evaluation in Table 5. Based on these, the models proposed for AE-FUNAI, EBSU and AIFPU (model numbers EM6 in Table 4) can be judged as an efficient empirical approach to estimate H. Therefore, the simulated models could be largely applied to the monthly forecast of global solar radiation in AE-FUNAI, EBSU and AIFPU as follows:

For AE-FUNAI,

$$\frac{H}{H_o} = -0.275 + 0.814\left(\frac{S}{S_o}\right) - 0.643\left(\frac{S}{S_o}\right)^2 + 0.218(\Delta T)^{0.5} - 0.360\left(\frac{\Delta T}{S_o}\right) - 0.435\left(\frac{RH}{100}\right) \quad 11$$

For EBSU,

$$\frac{H}{H_o} = -0.301 + 0.707\left(\frac{S}{S_o}\right) - 0.529\left(\frac{S}{S_o}\right)^2 + 0.207(\Delta T)^{0.5} - 0.081\left(\frac{\Delta T}{S_o}\right) + 0.124\left(\frac{RH}{100}\right) \quad 12$$

For AIFPU,

$$\frac{H}{H_o} = -0.249 + 0.709\left(\frac{S}{S_o}\right) - 0.509\left(\frac{S}{S_o}\right)^2 + 0.357(\Delta T)^{0.5} - 0.470\left(\frac{\Delta T}{S_o}\right) - 0.177\left(\frac{RH}{100}\right) \quad 13$$

However, these models are open to adjustment and calibration, since numerous meteorological parameters can be incorporated into the empirical model. However, the proposed numerical models (equations 11, 12 and 13) can be used to estimate H in any part of Ebonyi State with similar climatic conditions as AE-FUNAI, EBSU and AIFPU respectively, since it has the mathematical capabilities and the necessary coefficients to function as a statistical model sufficiently and efficiently. Equations 11, 12 and 13 are the model numbers EM6 for each of the stations: AE-FUNAI, EBSU and AIFPU respectively as vividly presented in Table 4. They are the best performing hybrid models as demonstrated by the statistical key performance metrics presented in Table 5 for each of the model numbers EM6 of the individual stations. These results are further corroborated by the plots in Figure 4, Figure 5 and Figure 6 for AE-EUNAI, EBSU and AIFPU respectively.

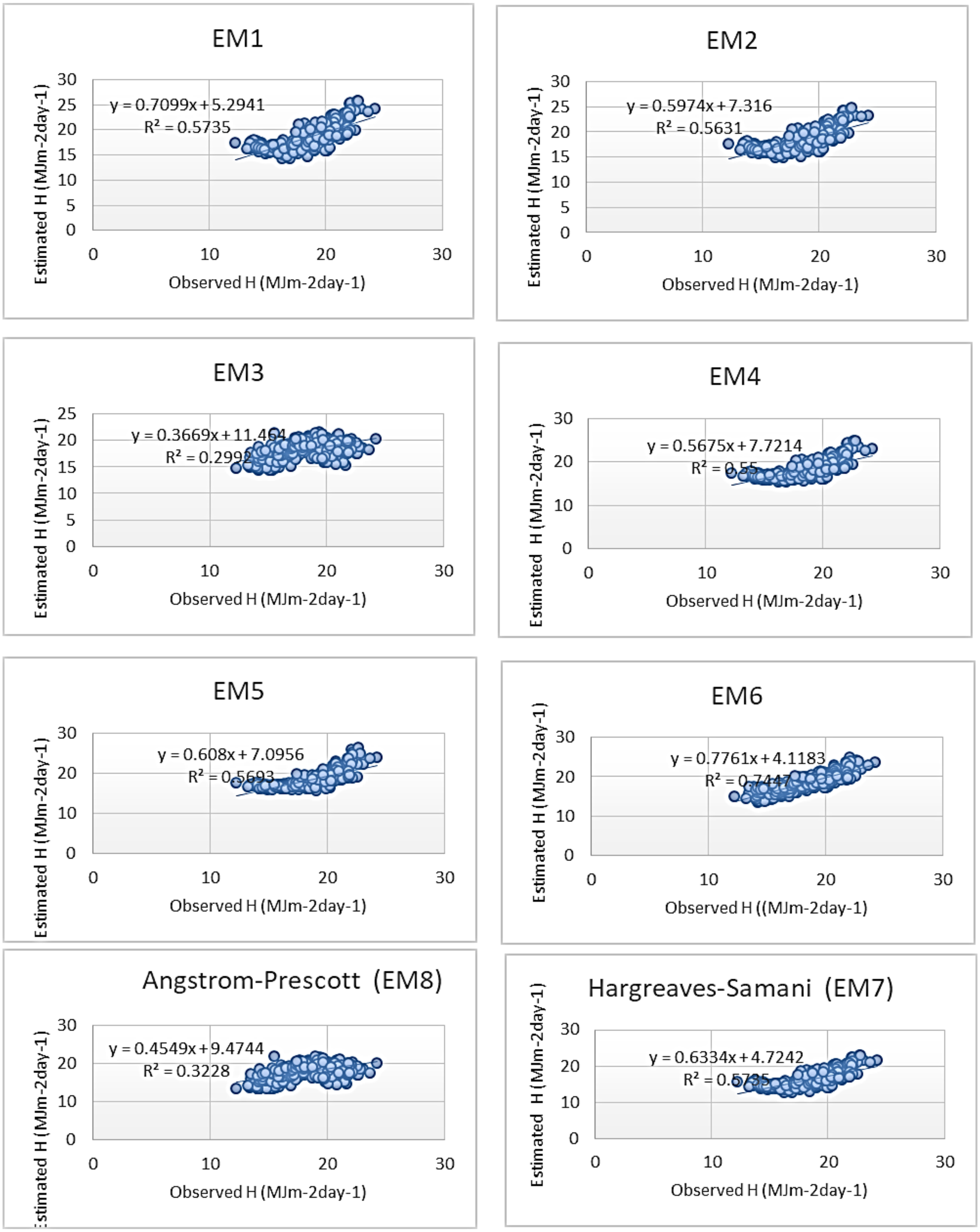

Figure 6. Comparison between observed and estimated for AE-FUNAI

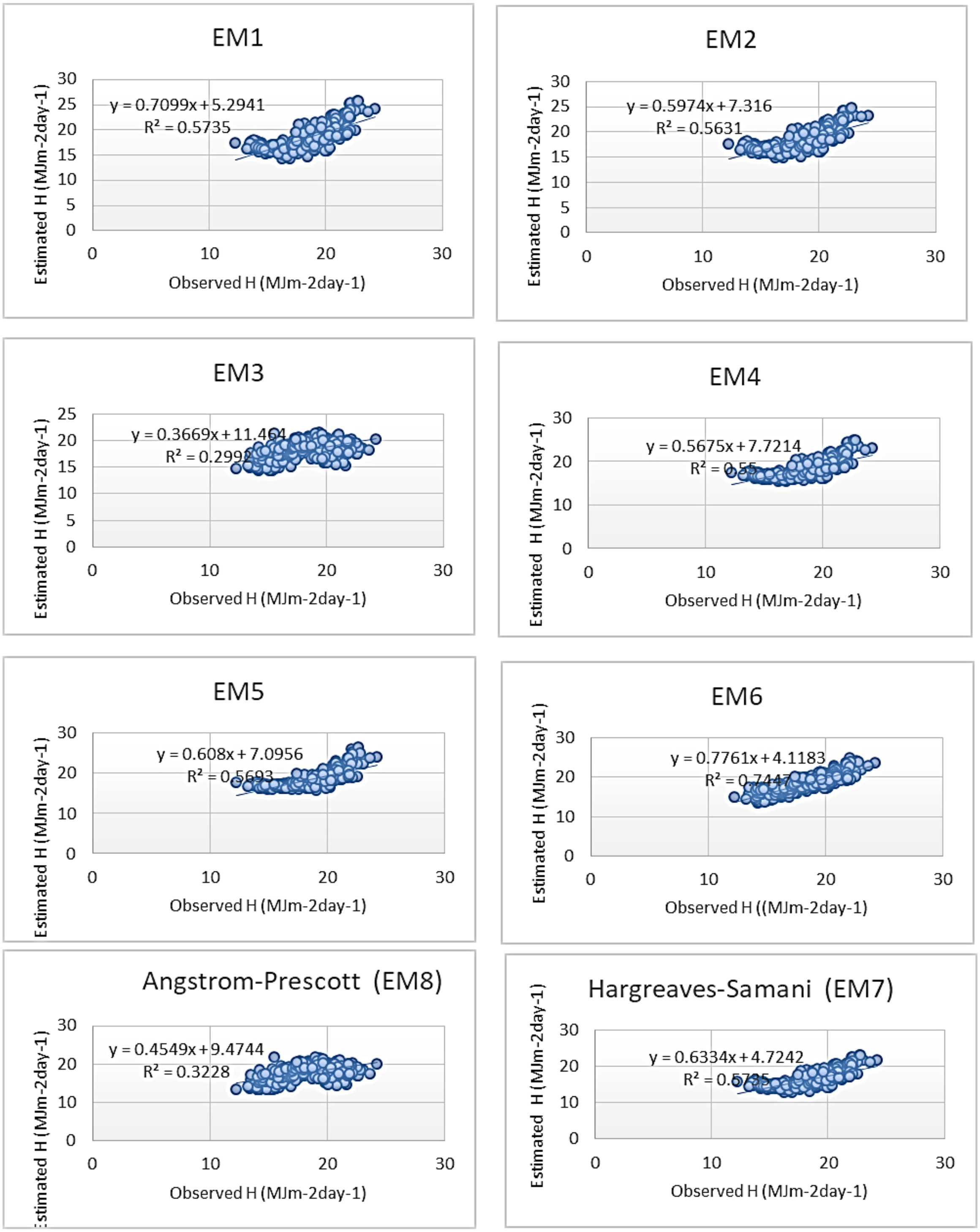

Figure 7. Comparison between observed and estimated for EBSU

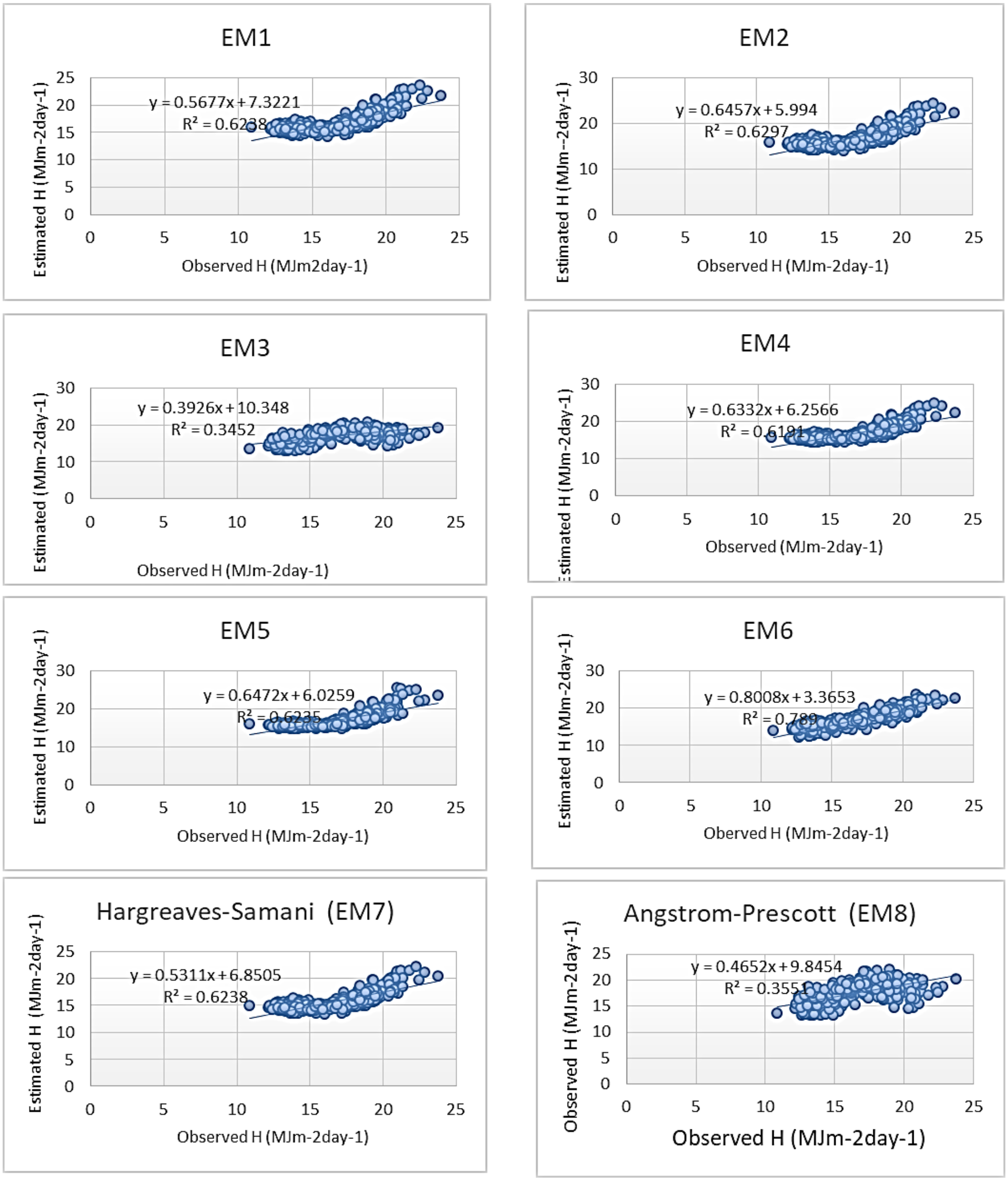

Figure 8. Comparison between observed and estimated for AIFPU

5.2 Recommendations

The researcher recommends routine calibration of the various computational models developed in this study (equations 11 - 13). This is because the historical data used to calibrate the models directly ignores the ever-changing climate over time, which may achieve the good performance of the calibrated models in the calibration years, but as the dataset stretches, the instability of the calibrated models can be seen. The researcher also recommends that the stimulated model coefficients for the evaluation of global solar radiation be regularly calibrated for the remaining municipal towns and remote villages in order to obtain a local coefficient applicable throughout the state of Ebonyi in order to facilitate the evaluation of the global solar radiation data easily without a network of instrumentation that would otherwise be needed.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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