*IOSR Journal of Applied Physics (IOSR-JAP)*
*e-ISSN: 2278-4861.Volume 9, Issue 5 Ver. IV (Sep. - Oct. 2017), PP 15-23*
*www.iosrjournals.org*

# Measurement and Comparison of Selected Empirical Models for the Estimation of Global Solar Radiation for Usmanu Danfodiyo University, Sokoto, Nigeria.

M. Momoh[1], G. M. Argungu[1], U. M. Zangina[2], A. M. Rabiu[2] and G. Saidu[2]
*[1](Department of Physics/Usmanu Danfodiyo University, Sokoto, Nigeria)*
*[2](Sokoto Energy Research Centre/Usmanu Danfodiyo University, Sokoto. Nigeria)*
**Correspondent Author: garba.musa@udusok.edu.ng*

***Abstract**: An automated weather monitoring station was installed at an open space within the main campus of Usmanu Danfodiyo University, Sokoto (UDUS), where hourly global solar radiation, number of sunshine hours, minimum and maximum temperatures as well as percentage of relative humidity data were monitored for a period of one complete calendar year (June, 2016 to May, 2017). The objective of this study is to compare the performance of selected empirical models commonly used for the estimation of global solar radiation in UDUS with ground based measured global solar radiation data. Five different models were selected and used for the study. The results obtained from the models were compared with the monthly average measured global solar data for the location. The comparism was made using four statistical error analysis namely; mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE) and mean absolute deviation (MAD), in order to identify which of the selected models considered for the estimates best fit the measured data. According to the statistical test, it was observed that model number four and model number one recorded best and least fit for measured data, models number four is the therefore recommended for use for the estimation global solar radiation for UDUS and other locations with similar climatological conditions.*

***Keywords:** Solar Radiation, Renewable Energy, measurement, Statistical test and Estimation.*

---

Date of Submission: 18-08-2017 Date of acceptance: 27-10-2017

---

## I. Introduction

Energy is the fundamental bedrock and a developmental organ of any society, it is also a vital requirements for meaningful progress of a nation. The availability of cheap and abundant supply of sustainable energy is an index for measurement of standard of living of any modern day society. Industrialization and increase in population causes the demand for energy to increase in both developed and developing countries. The developmental progress of any nation can be compared in terms of its per capita consumption of energy i.e. the amount of energy consumed per person per year [11].

Nigeria is richly endowed with both fossil energy resources like crude oil, natural gas, coal, as well as renewable energy resources such as solar, wind, biomass, etc. For many years, in Nigeria conventional energy resources have been the major leading energy sources, which account for over 90% of the total national energy consumption [9]. The total energy outlook of the country has shown that energy demand is very high and increasing geometrically, while the supply remains inadequate, insecure and irregular, these sometimes decrease periodically with time. The main sources of these energy is basically dominated by fossil fuels, which are fast being depleted apart from being environmentally unfriendly [14]. It is however, becoming very obviously that the Nigerian energy requirements like many other developing nation is not likely to be met by fossil fuels alone, future energy demands, need to be augmented by introducing an increasing significant percentage from the alternative fuels, such as that from solar, wind, and biomass [2].

In Nigeria Solar energy is one of the best option among the renewable energy resources for wide distribution of the resources as compared to other renewable energy sources, particularly in the northern part of the country. According to [11] the estimated annual average of daily solar radiation varies from $7kW/m^2/day$ in the northern region to about $3.5kW/m^2/day$ in the coastal regions of the south. Secondly, the technology has reached advanced stage for both Solar Photovoltaic (PV) and Concentrator Solar Power (CSP). In most of the developing countries such as Nigeria, the major challenges associated to the use of renewable energy resources is basically due to lack of ground-based measurement of solar radiation and wind data.

Sokoto in Nigeria, like many other locations lacks facility for the ground-based measurements of solar radiation in many sites desired for solar energy application, whereas meteorological and hydro-logical data are available at many different parts of these regions. Obviously the best way of knowing the amount of global solar radiation at any location of consideration is to install Pyranometer at many locations in the given region and look after their day-to-day maintenance and recording, which is a very expensive venture [12]. The alternative approach is to correlate the global radiation with the meteorological parameters where the data can be collected. The resultant correlation may then be used for locations of similar meteorological characteristics [3]. Thus, developing the empirical model to estimate the global solar radiation using easily available parameters such as sun-shine duration, maximum and minimum temperature, relative humidity, rainfall and geographical location, etc., is an essential assignment for locations like Sokoto.

Although various models have been developed previously for the estimation of global solar radiation in order to theoretically and empirically model a quite number of different regression coefficients using different regression techniques for different locations in order to compute the components of the global solar radiation by quite a number of different researchers using linear regression techniques for various countries and for different locations, many of them that gave reasonable regression coefficient when compared with ground based measured data, may turn out to give poor regression coefficient at other locations [5, 6]. Since accurate solar energy data is an essential prerequisite for designing, sizing and performance evaluation of any solar energy conversion systems and not easily accessible in many localities of the word particularly in developing countries such as Northern Nigeria, as such radiation data for many locations would have to be rely solemnly on empirical modeling. It is therefore of vital importance to identify even among already developed models the one that best fit measured data at each of the potential location for solar energy conversion.

One of the common and most used model across the globe is the Angstrom-Prescott model which is based on correlation of global solar radiation with sunshine hours. Generally speaking most of the empirical models used for the calculation of solar radiation were usually based on astronomical factors, geographical factors, geometric factors, physical factors and meteorological factors [12]. Other models that can be used includes temperature and relative humidity based models as independent variables for the correlation techniques [4, 10, 13]. In this study, annual solar radiation, meteorological/ hydrological data was used to derive the regression coefficients b, c, d and intersection constant ‘a’ that was used for the linear regression technique for the estimation of the monthly average of daily global solar radiation for UDUS area, where the results obtained was compare with the values of the ground based measured global solar radiation data for the location.

## II. Study Area And Data Acquisition Techniques

An automated data logging devised (data logger) model CR-1000 by Campbell scientific Africa is one of the most widely used data logging system across the globe, because of their wide range of applications. It is designed to be used in a broad range of measurement and control functions rugged enough for even extreme conditions. The CR1000 is a compact, modular line data with a measurement and control module, external power supply, and keyboard display. Their power consumption and packaging are optimized for unattended network applications. UDUS, is selected based on the perennial shortage of electrical power supply in the Campus like many of our Nigerian campuses, however the location is blessed with Solar and wind resources in reasonable quantities which could be utilized to reduce the scarcity of power. The area lies between latitudes $10^0$N and $13^0$58’ N and longitudes $4^0$8’ E and $6^0$54’E [8].

The experimental set-up was installed around the mini market area, very close to the Usmanu Danfodiyo University, Sokoto (UDUS) clinic, picture is attached in appendix A. The latitudes longitude and Altitudes of the geographical location is presented in table 2.1. The Pyrometer was used for the measurement of hourly average of the global solar radiation data, the radiation data is usually integrated over some period of time, such as an hour or daily. In this study, the global radiation on a horizontal surface was measured at an hourly interval for a period of one calendar year. The radiation data were recorded at every 2 seconds and averaged over 5 minutes and stored in the data-logging device. Furthermore, the 5 minutes interval solar radiation data along with other meteorological variables were calculated and stored sequentially in the permanent memory of the data-logger, where monthly data download at the weather stations was performed by the use of ***RS-232*** serial cable on visiting the site on monthly basis.

**Table 2.1. GEOGRAPHICAL LOCATION OF THE STUDY AREA**

| Location | Latitude ($^0$N) | Longitude ($^0$E) | Altitude (m) |
|---|---|---|---|
| Sokoto | 13.01 | 5.27 | 296 |

### 2.2 Theoretical Consideration

As earlier mentioned, the estimation of the monthly average global solar radiation was computed and compared using five linear models: model 1 was based on Angstrom-Prescott Model while model 2, 3. 4 and model 5 were new empirical linear models developed based on monthly average daily sunshine hours, temperatures and relative humidity. The model equations are:

$$Model\ 1: K_T = \frac{\bar{H}_m}{\bar{H}_0} = a_1 + b_1\left(\frac{\bar{n}_d}{\bar{N}_d}\right) \qquad (1)$$

$$Model\ 2: K_T = \frac{\bar{H}_m}{\bar{H}_0} = a_2 + b_2\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + c_2\left(\frac{\bar{\theta}_{ave}}{\bar{\theta}_{max}}\right) \qquad (2)$$

$$Model\ 3: K_T = \frac{\bar{H}_m}{\bar{H}_0} = a_3 + b_3\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + c_3\left(\frac{\bar{T}_{ave}}{\bar{T}_{max}}\right) \qquad (3)$$

$$Model\ 4: K_T = \frac{\bar{H}_m}{\bar{H}_0} = a_4 + b_4\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + c_4\left(\frac{\bar{\theta}_{ave}}{\bar{\theta}_{max}}\right) + d_4\ in\overline{RH} \qquad (4)$$

$$Model\ 5: K_T = \frac{\bar{H}_m}{\bar{H}_0} = a_5 + b_5\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + c_5\left(\frac{\bar{T}_{ave}}{\bar{T}_{max}}\right) + d_5 in\overline{RH} \qquad (5)$$

Where,

$\bar{H}_0$ *is the monthly mean daily extraterrestrial solar radiation on a horizontal surface,* $MJm^{-2}day^{-1}$

$\bar{H}_m$ *is the measured monthly mean daily solar radiation on a horizontal surface,* $MJm^{-2}day^{-1}$

$\bar{n}_d$ *is the monthly mean daily sunshine hours ;*

$\bar{N}_d$ *is the monthly average maximum possible daily hours of sunshine or the day length ;*

$\bar{\theta}_{av}$ *is the monthly mean of daily average temperature in degree celcius scale;*

$\bar{\theta}_{max}$ *is the monthly mean of daily maximum temperature in degree celcius scale;*

$\bar{\theta}_{min}$ *is the monthly mean of daily minimum temperature in degree celcius scale;*

$\bar{T}_{av}$ *is the monthly mean of daily average temperature in Kelvin scale;*

$\bar{T}_{max}$ *is the monthly mean of daily maximum temperature in Kelvin scale;*

$in\overline{RH}$ *is the natural logarithm of daily average relative humidity;*

$K_T$ *is the clearness index*

## III. Methodology

The study area is based on Sokoto location in the North-Western part of Nigeria with geographical coordinates: Latitude$\Phi = 13.01^oN$; Longitude, $\lambda = 5.27^oE$ and altitude$296m$.The primary data of hourly global solar radiation data on horizontal surface for UDUS was measured for the period of one complete year from June, 2016 to May, 2017 for location. The most widely used Microsoft Office Excel softwares was used for the data analysis. The measured data of hourly solar radiation obtained from measurements was averaged to daily average and subsequently to monthly daily average, maximum and minimum temperatures, sunshine hours and relative humidity were also averaged to monthly average and the result obtained is presented in Table 3.2. The following equations were used in the evaluation of extraterrestrial solar radiation. The data obtained was processed in Microsoft Office Excel to obtain the required form i.e., daily extraterrestrial solar radiation in MJ/m$^2$, daily global radiation in MJ/m$^2$, the ratio of daily mean of maximum and minimum temperature to daily maximum temperature in both degree Celsius and Kelvin scale and natural logarithm of average value of daily relative humidity data of the period of measurements. The equation of least square line was used [7]:

$$a + bx + cy + dz = K_T \qquad (6)$$

Where, $K_T = \frac{H_m}{H_0}$ is dependent variable called clearness index,

a, b, c, d are regression constant and

$x = \left(\frac{n}{N_d}\right), y = \left(\frac{T_{av}}{T_{max}}\right), z = in\ \overline{RH}$, are independent variables and the earlier explained meteorological parameters.

To perform the regression analysis of the least square line, both sides of equation (6) above will have to be multiply by 1, x, y and z successively and summing both sides to obtained the values of regression constants (a, b, c, d and z) for the location.

$$aN + b\sum_{i=1} x + c\sum_{i=1} y + d\sum_{i=1} z = \sum_{i=1} K_T \qquad (7)$$

$$a\sum_{i=1} x + b\sum_{i=1} x^2 + c\sum_{i=1} xy + d\sum_{i=1} xz = \sum_{i=1} K_T x \qquad (8)$$
$$a\sum_{i=1} y + b\sum_{i=1} yx + c\sum_{i=1} y^2 + d\sum_{i=1} yz = \sum_{i=1} K_T y \qquad (9)$$
$$a\sum_{i=1} z + b\sum_{i=1} zx + c\sum_{i=1} xy + d\sum_{i=1} z^2 = \sum_{i=1} K_T z \qquad (10)$$

The above stated equations (7), (8), (9), and (10) was used to evaluate the regression constants a, b, c and d of one year measured data for the location

**TABLE 3.1** EVALUATED REGRESSION CONSTANT FOR THE STUDY LOCATION

| | a | b | c | d |
|---|---|---|---|---|
| Model 1: | 0.0988 | 0.7875 | | |
| Model 2: | -0.725 | 1.0876 | 0.8131 | |
| Model 3: | -5.2831 | 1.1711 | 5.2945 | |
| Model 4: | 0.7517 | 0.371007 | 0.000233 | -0.10309 |
| Model 5 | -1.66929 | 0.621442 | 2.249364 | -0.08213 |

By substituting the evaluated values into the selected models the clearness index and global solar radiation from each model can be estimated, where the following was obtained:

$$Model\ 1: K_T = \frac{\bar{H}_m}{\bar{H}_0} = 0.0988 + 0.7875\left(\frac{\bar{n}_d}{\bar{N}_d}\right)$$

$$Model\ 2: K_T = \frac{\bar{H}_m}{\bar{H}_0} = -0.725 + 1.0876\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + 0.8131\left(\frac{\bar{\theta}_{ave}}{\bar{\theta}_{max}}\right)$$

$$Model\ 3: K_T = \frac{\bar{H}_m}{\bar{H}_0} = -5.2831 + 1.1711\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + 5.2945\left(\frac{\bar{T}_{ave}}{\bar{T}_{max}}\right)$$

$$Model\ 4: K_T = \frac{\bar{H}_m}{\bar{H}_0} = 0.7517 + 0.371007\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + 0.000233\left(\frac{\bar{\theta}_{ave}}{\bar{\theta}_{max}}\right) - 0.10309\ in\overline{RH}$$

$$Model\ 5: K_T = \frac{\bar{H}_m}{\bar{H}_0} = -1.66929 + 0.621442\left(\frac{\bar{n}_d}{\bar{N}_d}\right) + 2.249364\left(\frac{\bar{T}_{ave}}{\bar{T}_{max}}\right) - 0.08213 in\overline{RH}$$

The models were used to predict the values of Global Solar Radiation and the results obtained were presented along with the measured Monthly Mean global solar radiations Value as shown in Table 3.1.

### 3.2 EVALUATION OF EXTRATERRESTRIAL SOLAR RADIATION

Monthly daily Average of extraterrestrial Solar Radiation on horizontal surface is given by Iqbal as cited by (Beckman and Duffie, 1991)

$$\bar{H}_o = I_{sc}\frac{24}{\pi}\left(1 + 0.033\cos\left(\frac{360 d_n}{365}\right)\right)\left(\frac{\pi}{180}w_{ss}\sin\Phi\sin\delta + \cos\delta\cos\Phi\sin w_{ss}\right) \qquad (11)$$

Where,

$\bar{H}_0\ is\ the\ exterrestrial\ solar\ radiation\ on\ horizontal\ surface$

$I_{sc}\ is\ the\ solar\ constant\ given\ by: I_{sc} = \frac{1366.1 \times 3600}{1 \times 10^6}\ MJm^{-2}h^{-1}$

$\omega_{ss}\ is\ the\ sunhour\ angle\ in\ degrees$

$\emptyset\ is\ the\ latitude\ of\ the\ location$

$\delta\ is\ the\ declination$

$d_n\ is\ the\ n^{th}\ day\ of\ the\ year\ i.e. 1 \leq\ d_n \geq 365, (Jan. 1 = 1; Dec. 31 = 365)$

$Solar\ declination\ angle, \delta\ is\ given\ by:$

$$\delta = 23.45 sin\left[\frac{360}{365}(d_n + 284)\right] \qquad (12)$$

Sunset hour angle is given by:

$$\omega_{ss} = \cos^{-1}(-\tan\emptyset\tan\delta)$$

$$= \frac{2}{15}\omega_{ss} \qquad (13)$$

Since 1 hour angle is equal to $15^0$ of the sun travelling the sky, the maximum possible sunshine hours $N_d$ *is obtained as*:

$$N_d = \frac{2}{15}\cos^{-1}(-\tan\emptyset\tan\delta) = \frac{2}{15}\omega_{ss} \qquad (14)$$

**3.3 Recommended Monthly Average Days and Meteorological Variables.**

The monthly average days as cited in [6] are as shown in Table 3.2

**TABLE 3.2: MONTHLY AVERAGE DAYS AND THEIR CORRESPONDIND DAY NUMBER**

| **Month** | **N** | **Average Day** | **Day Number, $d_n$** |
|---|---|---|---|
| Jan | i | 17 | 17 |
| Feb | 31+i | 16 | 47 |
| Mar | 59+i | 16 | 75 |
| Apr | 90+i | 15 | 105 |
| May | 120+i | 15 | 135 |
| Jun | 151+i | 11 | 162 |
| Jul | 181+i | 17 | 198 |
| Aug | 212+i | 16 | 228 |
| Sep | 243+i | 15 | 258 |
| Oct | 273+i | 15 | 288 |
| Nov | 304+i | 14 | 318 |
| Dec | 334+i | 10 | 344 |

The monthly average days are used for calculation of declination angle used for the analysis as presented in table 3.3

**TABLE 3.3: MEASURED MONTHLY AVERAGE SOLAR RADIATION AND OTHER METEOROLOGICAL VARIABLES AT THE LOCATION**

| Month | Solar Radiation $\overline{H}_m$, (MJ /m$^2$.day) | Sunshine Hours $\overline{n}_d$, (hours) | Temp max $\overline{\theta}_{max}$ (°C ) | Temp min $\overline{\theta}_{min}$, (°C ) | Rel. - humidity $\overline{RH}$, (%) |
|---|---|---|---|---|---|
| Jan | 21.47 | 8.00 | 31.83 | 17.10 | 22.73 |
| Feb | 23.51 | 8.42 | 35.97 | 19.58 | 18.74 |
| Mar | 24.88 | 7.86 | 40.80 | 23.60 | 18.33 |
| Apr | 24.38 | 7.78 | 44.10 | 27.08 | 31.85 |
| May | 22.43 | 7.30 | 43.85 | 27.29 | 48.76 |
| Jun | 20.99 | 7.98 | 42.59 | 25.56 | 58.27 |
| Jul | 19.36 | 7.26 | 40.78 | 23.82 | 71.37 |
| Aug | 18.75 | 6.44 | 40.70 | 22.85 | 78.10 |
| Sep | 19.81 | 7.64 | 43.78 | 23.24 | 72.85 |
| Oct | 21.53 | 8.90 | 48.23 | 23.23 | 51.70 |
| Nov | 22.07 | 9.00 | 49.81 | 20.28 | 26.74 |
| Dec | 21.25 | 8.86 | 50.15 | 17.66 | 24.69 |

## STATISTICAL ANALYSIS

- Accuracy of the estimated values can be tested by comparing with the measured values for the selected models using statistical techniques for the models based on the definition devised by Iqbal (1983) and cited by [6] which is as below: In order to gain an insight into the accuracy and performance evaluation of the selected models, some statistical tests parameters were used.
- Mean Bias Error (MBE) provides information on the long term performance of the models. They are given by:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(\bar{H}_{i\,meas} - \bar{H}_{i\,calc})$$

A positive value indicates the average amount of under estimation in the calculated values while a negative value indicates the average amount of over estimation. A drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation

- Mean Absolute Deviation (MAD)

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|\bar{H}_{i\,meas} - \bar{H}_{i\,calc}|$$

- Mean Percentage Error (MPE) the value is expressed as percentage. It is given by:

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{(\bar{H}_{i\,meas} - \bar{H}_{i\,calc})}{\bar{H}_{i\,meas}} \times 100\%\right)$$

- Root Mean Square Error (RMSE) provides information on the short term performance of the correlations by allowing a term by term comparison of the actual deviation between the calculated value and the measured value. The smaller the value of the RMSE, the better the models performance. It is given by:

$$RMSE = \left\{\frac{1}{n}\sum_{i=1}^{n}(\bar{H}_{i\,meas} - \bar{H}_{i\,calc})^2\right\}^{1/2}$$

**Where,**

$\bar{H}_{i\,meas}$ **is t**he measured value of the solar radiation

$\bar{H}_{i\,cal}$ is the calculated value (model estimate) of the solar radiation

$n$ is the total number of data pairs of the observations

## IV. Results And Discussions

The results obtained from the analysis is presented in tables and figures as shown below, table 4.1 presented the monthly average measured global solar radiation and estimated values obtained from the five selected models as can be seen from both measurement and estimation in the study area the highest global solar radiation on horizontal surface was observed in the months of February, March and April, with the month of March recorded maximum values and month of August recorded least values, even though the results from the models prescribed months April for model 1 and 2 as having the highest average global solar radiation, and month of February in the case of model 3. But in all the models and measured results the month of August show least values of the global solar radiation.

**TABLE 4.1:** MONTHLY MEAN DAILY MEASURED AND ESTIMATED VALUES OF GLOBAL SOLAR RADIATION (MJ/m$^2$/day).

| | Measured | Estimated | | | | |
|---|---|---|---|---|---|---|
| Month | ($H_m$) | Mod1 | Mod2 | Mod3 | Mod4 | Mod5 |
| Jan | 21.47 | 19.99 | 20.39 | 21.69 | 21.11 | 21.61 |
| Feb | 23.51 | 22.45 | 23.20 | 24.16 | 24.08 | 24.48 |
| Mar | 24.88 | 22.45 | 23.02 | 23.19 | 25.31 | 25.04 |
| Apr | 24.38 | 22.70 | 23.55 | 23.21 | 23.95 | 23.9 |
| May | 22.43 | 21.18 | 21.55 | 21.04 | 21.6 | 21.45 |
| Jun | 20.99 | 22.38 | 22.93 | 22.75 | 21.38 | 21.73 |
| Jul | 19.36 | 20.79 | 20.48 | 20.37 | 19.83 | 19.84 |
| Aug | 18.75 | 19.19 | 17.92 | 17.70 | 18.73 | 18.18 |
| Sep | 19.81 | 21.96 | 21.54 | 21.36 | 20.02 | 20.16 |
| Oct | 21.53 | 23.84 | 24.08 | 23.79 | 21.44 | 21.91 |
| Nov | 22.07 | 22.43 | 21.97 | 21.6 | 21.97 | 21.73 |
| Dec | 21.25 | 21.22 | 20.12 | 19.71 | 21.06 | 20.46 |

The statistical indicators mentioned were used to examine the performance of the models of solar radiation estimation. In general, low values of root mean square error (RMSE), mean bias (MBE) and mean percentage error (MPE) was desirable. While RSME test provides information on the short-term performance whereas MBE and MPE test provide information on the long-term performance. The positive MBE points out the overestimation and negative MBE shows the underestimation [12]. The parameters were calculated in all the models and the result is as shown in Table 4.2.

**TABLE 4.2:** STATISTICAL ERRORS INDICATORS OF THE MODELS

| Parameters | Mod1 | Mod2 | Mod3 | Mod4 | Mod5 |
|---|---|---|---|---|---|
| **MBE** | -0.0133 | -0.0267 | -0.0117 | -0.0042 | -0.005 |
| MAD | 0.1111 | 0.0997 | 0.1025 | 0.0284 | 0.0443 |
| MPE | -0.4864 | -0.3546 | -0.2456 | -0.0405 | -0.0268 |
| RMSE | 1.55232 | 1.3746 | 1.3525 | 0.4067 | 0.5977 |

## 4.3 COMPARISM OF THE MEASURED VALUES WITH VALUES FROM THE MODELS

All the models show negative values of MBE and MPE which implies average amount of over estimation among all the models. In terms of absolute error Model No 4 is the best, then followed by Model No 5 since the least values of MAD are observed in those models. Similarly, as can be seen from the table 5: Model 4 shows best fit from the statistical error test followed by model 5, then model 3 and model 2. Where, model 1 the angstrom periscope model that depends on only number of hours of sunshine recorded least fit for measured data

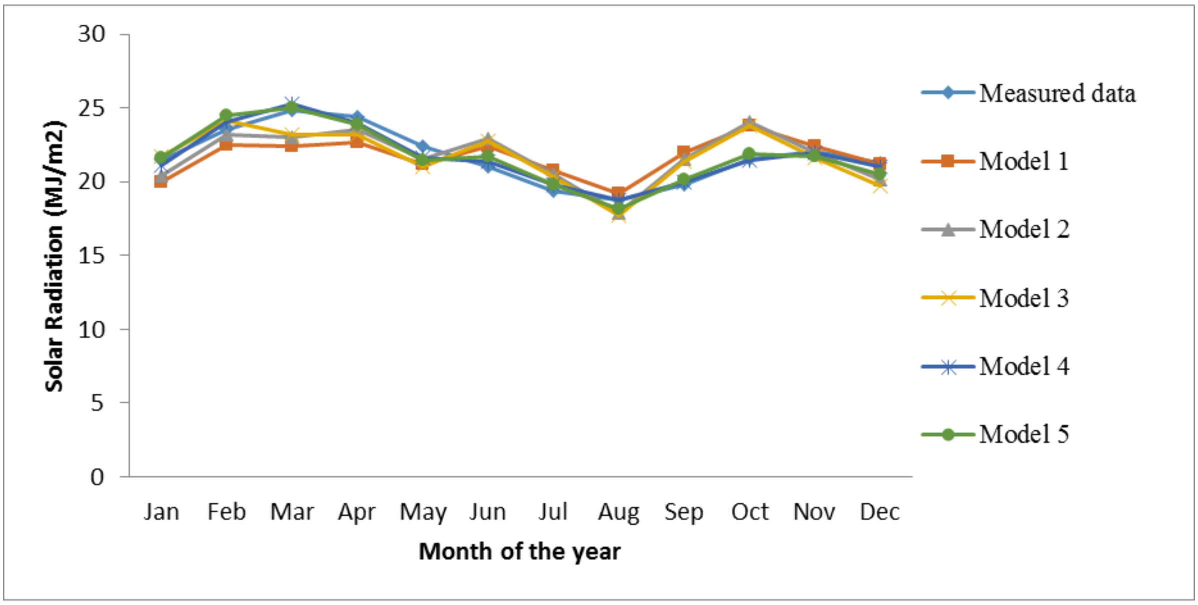

**Figure 4.1**: comparism between the measured values and values obtained from the models

The measured variables were used to evaluate the regression constants for all the selected models, and hence used to estimate the monthly mean daily solar radiation at the location of Usmanu Danfodiyo University, Sokoto as presented in Table 1. Table 2 presents the average days of the months and their corresponding day number, which was used for the calculation of declination angle that was used for the evaluation of monthly mean daily extraterrestrial solar radiation. Table 3 presents the calculated extraterrestrial solar radiation, clearness index, fraction of sunshine duration, ratio of average to maximum temperature and natural logarithm of average humidity.

Similarly high values of sunshine hours were observed in the month of June (95.69) basically because of higher declination angle (23.09) and the least values of (84.32) for similar reason due to low declination angle (-23.05). The clearness index/fraction of sunshine hours was observed to least in the month of August and highest in month of December. The least values in the month of August could be because of higher humidity due to peak period of rainfall.

Table 4 presents the measured and estimated monthly mean daily global solar radiation from the selected models solar global radiation, it can be seen from the table that month of August observed the lowest radiation both from measurement and estimation indicating the overcast/cloud covered skies and more aerosols and in month of March values of (24.88, 22.45, 23.02, 23.19, 25.31 and 25.04 MJ/ $m^2\cdot$day) were observed for the measured and estimated from model 1, 2, 3, 4 and model 5 respectively, suggesting the more clear skies with fewer aerosols, which is the maximum values except for case of model 2 and model 3 where the maximum values of 23.20 and 24.16 MJ/ $m^2\cdot$day were observed in the month of February.

These values were estimated by using the Angstrom-Prescott model as model1 that used only sunshine hour's records and the remaining models that used average and maximum values of temperatures in Kelvin and degree Celsius as well as natural logarithms of the relative humidity in addition to fraction of the sunshine hours.

The statistical analysis of the results has shown very close agreement of the measured and estimated values for all the five selected models. The least values of root mean square error (RMSE), mean absolute deviation (MAD) mean bias error (MBE) and mean percentage error (MPE) indicate the best linear regression relations to estimate global solar radiation using model 4 at UDUS and the regression relation to estimate solar radiation is by using the model 1, which uses only fraction of sunshine hours.

## V. Conclusion

Major finding from the linear regression analysis of the global solar radiation using sunshine hours durations, average and maximum temperatures and relative humidity data through least square technique are as following;

- Among the five selected models considered for this analysis, model number four showed best fit with the measured data from lowest values of MBE, MAD, MPE and RMSE observed
- Model 1 (Angstrom-Prescott model) is the simplest among the three models (require only sunshine hours but statistically is the least in terms of performance and efficiency.
- Statistically, all the five models show some level of accuracy in terms of performance in all the parameters when compared with measured data.
- From the results model number four can be recommend as the best model for the estimation of monthly mean daily solar radiation for UDUS and other locations of similar geographical/climatological characteristics and also can be used to estimate the missing daily/monthly mean daily solar radiation at such locations with existing weather station.

## Acknowledgements

The Authors express sincere gratitude and appreciations to the Tetfund and Usmanu Danfodiyo University, Sokoto for providing funds and necessary assistance in the form of logistics for the execution of this research work.

## References

[1] Abdulsalam, D., Mbamali, I., Mamman, M. and Saleh, Y. M. (2012) An Assessment of Solar Radiation patterns for sustainable implementation of Solar Home Systems in Nigeria, American International Journal of Contemporary Research 2(6), pp. 238-243

[2] Argungu, G. M., Aliyu, M. and Ugwuoke, P. E. (2005) Wind Energy Resources in Nigeria for Power Generation, Nigerian Journal of Renewable Energy, Vol. (13), 1&2, Pp 65-68

[3] Augustine, C. and Nnabuchi, M. N. (2009) "Relationship between Global Solar Radiation and Sunshine Hours for Calabar, Port-Harcourt and Enugu, Nigeria". International Journal of Physical Sciences, Vol. 4 (4) pp 182-188.

[4] Chiemeka, I. U. (2008) "Estimation of Solar Radiation at Uturu, Nigeria". Int. J. Physical Science, Vol. 3 (5) pp 126-130.

[5] Dehghan, A. A., Besharat, F. and Faghig, A. R., (2013) "Empirical Models for Estimating Global Solar Radiation: A Review and Case Study". Renewable and Sustainable Energy Review, Vol. 21 pp 798-821 doi: 10.1016/j.rser.2012.12.043..

[6] Duffie, J. A., and Beckman, W. A. (2013) "Solar Engineering of Thermal Processes, 4th Edition", AJohn Willey & Sons inc., Hoboken, New Jersey, U.S.A

[7] Ekpe, E. J. and Nnabuchi, M. N. (2012) "Solar Radiation in Onitsha: A Correlation with Average Temperature," Scholarity Journals of Biotechnology, Vol. 1, No. 5, pp. 101-107.

[8] Ekpoh, I.J., and Nsa, E. (2011) Extreme Climatic Variability in Northwestern Nigeria: An Analysis of Rainfall and Parterns, Journal of Geography and Geology, 3 (1) PP 17-22

[9] Fagbile, L. (1990) Estimation of Total Solar Radiation in Nigeria Using Meteorological Data, Nigerian Journal of Renewable Energy Research, 18, pp. 1-10

[10] Falayi, E. O. and Rabiu, A. B. (2008) "Prediction of Clearness Index for some Nigerian Stations using Temperature Data". J. Sc. & Tech., Vol. 28 (2) pp 94-101.

[11] Innocent, A.J., Jacob, O.B., Chibuzo, G.C., James, I., Odeh, O. (2015) Estimation of Global Solar Radiation in Gusau, Nigeria, International Journal of Research in Engineering and Technology, ISSN pp 2347-4599.

[12] Krishna R. Adhikari1, Binod K. Bhattarai1, Shekhar Gurung **(**2013**)** **"**Estimation of Global Solar Radiation for Four Selected Sites in Nepal Using Sunshine Hours, Temperature and Relative Humidity", Journal of Power and Energy Engineering 1, 1-9.

[13] Okonkwo, G. N. and Nwokoye, A. O. C. (2014) "Estimating Global Solar Radiation from Temperature Data in Minna Location". European Scientific Journal, Vol. 10 (15) pp 254-264.

[14] Ohunakin, O. S., Adaramola, M. S., and Oyewola, O. M. (2011) Wind energy evaluation for electricity generation using WECS in seven selected locations in Nigeria, Journal of Applied energy 88, 3197-3206.

## *APPENDIX 1*

**Figure A:** Picture of the weather station installed at mini market of UDUS, Main Campus, December, 2016.

M. Momoh. “Measurement and Comparison of Selected Empirical Models for the Estimation of Global Solar Radiation for Usmanu Danfodiyo University, Sokoto, Nigeria.” IOSR Journal of Applied Physics (IOSR-JAP) , vol. 9, no. 5, 2017, pp. 15–23.