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Empirical Models for Estimation of Global Solar Radiation in Jos, Plateau State, Nigeria

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Abstract
The monthly mean daily global solar radiation, maximum and minimum temperature, and relative humidity data are used to estimate the global solar radiation for Jos North, Plateau State, Nigeria located on latitude 9°55`N and longitude 8°54`E . Data for a period of three years (2016-2018) was used to generate linear single variable temperature based model, linear single variable relative humidity based model and linear double variable temperature and relative humidity based model. The peak values of the estimated solar radiation are: April (46.02 MJm^{-2}) and August (38.45MJm^{-2}) for the single variable temperature based model, March (47.88 MJm^{-2}) and August (34.14 MJm^{-2}) for the single variable relative humidity based model and March (47.88 MJm^{-2}) and August (34.14 MJm^{-2}) for the double variable temperature-relative humidity based model, based on maximum and minimum values respectively. The estimated solar radiations were tested using the mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) statistical techniques for each model as (0.153, 0.528, 0.029), (0.030, 0.105, 0.006) and (0.028, 0.098, 0.006), for the single variable temperature based model, the single variable relative humidity based model and the double variable temperature-relative humidity based model respectively. The double variable model with the corresponding least values of MBE, RMSE and MPE is suitable for predicting global solar radiation in the area under study.

Keywords: cloudiness index, solar radiation, relative humidity, temperature

INTRODUCTION
The energy transferred from the sun in the form of radiant energy to the earth's surface is called solar radiation. Solar radiation is used in agriculture for crop drying, electricity generation, house heating and water heating. It warms the planet and gives us our everyday wind and weather. Chineke (2007) observed that the network of stations measuring solar radiation data is sparse in many countries. In Nigeria, only few stations have been measuring the daily solar radiation on a consistent basis due to the cost, poor maintenance and calibration required of measuring equipment. It is therefore, necessary to approximate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperatures, cloud cover and geographic location, extraterrestrial radiation, altitude, latitude etc (Taura *et al*, 2017). Most of the solar radiation information comes from the weather station located on the area of study; therefore the estimation of global solar radiation on the earth surface is generally based on mathematical model. Meteorological data

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such as sunshine hour's duration, temperature, precipitation, relative humidity are measured at many locations around the world. Solar radiation is received at the earth surface in an attenuated form, due to the absorption and scattering as its passes through earth atmosphere. Absorption occurs primarily because of the presence of ozone, water vapor, other gases such as CO_2, NO_2, CO, O_2, CH_4 and particulate matter (Sekar, 2012). The component of solar radiation can be broadly classified as direct or beam radiation, diffused radiation, reflected solar radiation, extraterrestrial solar radiation, global or total solar radiation and solar constant. A typical monthly record of global solar radiation is measured by the use of sunshine recorder.

Musa *et al.,* (2012) proposed a sunshine base model using the monthly mean data for sunshine hours obtained from NIMET, Maiduguri, Borno State, Nigeria over a period of five years (2006-2010). Also, Falayi *et al*., (2008) developed forecasting model for the monthly average daily solar radiation using sunshine duration, temperature and relative humidity for a period of five years (1995 – 2000), using data obtained from the Nigerian Meteorological agency Oshodi, Lagos, Nigeria. Muhammad *et al.,* (2014) proposed two models which include temperature based linear model and relative humidity based linear model for estimating monthly global solar radiation on horizontal surface in Kano State Nigeria.

In this research, three models were used in estimating the global solar radiation for Jos North Plateau State, located in the North central part of Nigeria. The combination of the temperature and relative humidity variables provide a better model for estimating solar radiation. The results are useful in the design and installation of solar energy devices in Jos and its environs. It will also help in improving forecasting techniques and for the development of many solar energy devices.

MATERIALS

Secondary data of time series of meteorological variables recorded over Jos was collected from the Agro-meteorological station, Federal College of Forestry Jos, Plateau State, Nigeria. The values of the relative humidity, solar radiation and mean (minimum and maximum) temperature data for three years from 2016 to 2018 were used in carrying out the research. The global solar radiation was measured using Gunn- Bellani radiometer in millimetre which is then converted to the solar intensity unit of $MJm^{-2}day^{-1}$ using a conversion factor: 1mm =1.216 $MJm^{-2}day^{-1}$ (Olomiyesan *et al.,* 2014) and Microsoft Excel 2013 was used to obtained the regression coefficients.

Mathematical Models and Data Analysis

The linear regression techniques was used to obtain some predictive models classified as temperature based model and relative humidity based model, each as one variable correlation and also the combination of both temperature and relative humidity based model as two variable correlation.

Single variable linear regression temperature based model (Falayi and Rabiu, 2011) is given as in equation (1).

$$\frac{\bar{H}}{\bar{H}_0} = a + b\sqrt{T_{\max} - T_{\min}} \tag{1}$$

The single variable linear regression relative humidity based model (Falayi and Rabiu, 2011) is given as:

$$\frac{\bar{H}}{\bar{H}_0} = a + bRH \quad (2)$$

Double variable linear regression temperature and relative humidity based model (Muhammad and Darma, 2014) is given as:

$$\frac{\bar{H}}{\bar{H}_0} = a + b\sqrt{T_{\max} - T_{\min}} + cRH \quad (3)$$

where $\bar{H}$ is the monthly mean of the daily global radiation on horizontal surface at a location (MJ/m^2day), $\bar{H}_0$ is the monthly mean of the daily extraterrestrial radiation at the same location on a clear day (MJ/m^2day), $T_{\max}$ and $T_{\min}$ are the maximum and minimum monthly mean temperature and RH is the monthly mean relative humidity, a, b *and* c are regression constants obtained from the data analysis. The parameter $\frac{\bar{H}}{\bar{H}_0}$ is the clearness index.

The monthly mean daily extraterrestrial radiation is calculated from equation (4): (Angstrom 1924):

$$\bar{H}_0 = \frac{24 \times 3600}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\left[\cos\varphi\cos\delta\sin\omega_s + \left(\frac{2\pi\omega_s}{360}\right)\sin\varphi\sin\delta\right] \quad (4)$$

where I_{sc} is the solar constant(= 1367w/m^2), φ the latitude of the site, δ the solar declination angle, ω_s the mean sunrise hour angle from the given month and n is the number of days of the year.

The solar declination angle (δ) and mean sunrise hour angle (ω_s) are calculated using equations (5) and (6) respectively.

$$\delta = 23.450\sin\left(360\frac{284+n}{365}\right) \quad (5)$$

$$\omega_s = \cos^{-1}\left(-\tan\varphi\tan\delta\right) \quad (6)$$

The calculation of $\bar{H}_0$ has been simplified and is determined for the particular day in each month on which the extraterrestrial radiation is nearly equal to monthly mean value. The value on which H_0 is equal to $\overline{H_0}$ are as follows: January 17, February 16, March 16, April 15, May 15, June 11, July 17, August 16, September 15, October 15, November 14, and December 10. These dates were used in the calculation of $\overline{H_0}$.

The accuracy of the estimated values were tested by calculating the RMSE (Root Mean square Error), MBE (Mean Bias Error) and MPE (Mean Percentage Error). The RMSE (MJ/$m^2 day$), MBE (MJ/$m^2 day$) and MPE (%) for the three variables defined as follows (Gana and Akpootu, 2013):

$$MBE = \frac{\sum\left(\bar{H}_{pred} - \bar{H}_{meas}\right)}{n} \quad (7)$$

$$RMBE = \left[\frac{\sum\left(\bar{H}_{pred} - \bar{H}_{meas}\right)^2}{n}\right]^{\frac{1}{2}} \quad (8)$$

$$MPE = \frac{\sum\left(\frac{\bar{H}_{pred} - \bar{H}_{meas}}{\bar{H}_{meas}} \times 100\right)}{n} \qquad (9)$$

where $\bar{H}_{pred}$ and $\bar{H}_{meas}$ is the predicted and measured values of the solar radiation and n is the total number of observations. In general a low RMSE is desirable, the positive MBE shows over estimation while a negative MBE indicates under estimation.

Study area

Jos north is found in the Northern part of Plateau State which is situated on the coordinates latitude 9°55`N and longitude 8°54`E. Plateau State in general is the twelfth largest state in Nigeria, and is roughly located in the center of the country. It is geographically unique in Nigeria because its boundaries are totally surrounded by the Jos Plateau. The capital of the state is Jos. Plateau State shares borders with Bauchi to the north east, Kaduna State to the north west, Nasarawa State to the south west, and Taraba to the south east. The state is named after the picturesque Jos plateau, (a mountainous area) in the north of the state with captivating rock formation and bore rocks are scattered across the grass land which cover the plateau. The altitude ranges around 1200m (4000ft) to a peak of 1,829m above sea level in the share hill range near Jos. Climatically, the area is in the tropical zone, with an average temperature between 18°C to 22°C. Harmattan wind causes the coldest weather between December and February, the warmest temperature usually occurs in the dry season months of March and April. The mean annual rain fall varies from 131.75cm (52in) in the southern part to 146cm (57in) on the Plateau. The highest rainfall is recorded during wet season months of July and August. (Wikipedia, 2019).

RESULTS AND DISCUSSION

The three modified Angstrom Prescott models were used to estimate the global solar radiation based on the monthly mean minimum and maximum temperature, relative humidity as one variable for each model and the combination of maximum and minimum temperature with relative humidity as two variables. Regression coefficients a, b and c were obtained as (1.086, 0.042), (1.637, -0.007) and (1.329, 0.092, -0.007), for the three models respectively. The maximum and minimum predicted global solar radiation for the temperature based, relative humidity based and temperature-relative humidity based models are obtained as September (46.32 MJm^{-2}), December (36.84 MJm^{-2}), April (46.02 MJm^{-2}), August (38.45MJm^{-2}) and March (47.88 MJm^{-2}), August (34.14 MJm^{-2}). In order to validate the results, three statistical methods (MBE, RMSE, MPE) and the respective results were obtained as: (0.153, 0.528, 0.029), (0.030, 0.105, 0.006) and (0.028, 0.098 and 0.006) .

Mean results obtained for One Variable Temperature Based Model

Figure 1.0, show the mean average results of the three years for the one variable linear temperature-based model. It indicate that the maximum global solar radiation in Jos were measured in the month of (September), This may be due to dry season, while the minimum global solar radiation were measured in the month of (December), This may be due to the heavy rain fall in the area.

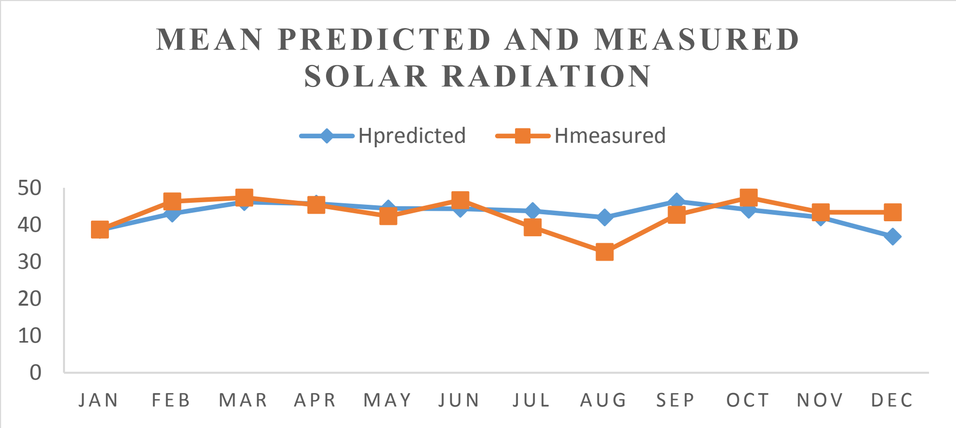

Figure 1.0: Mean average (measured and predicted) monthly global solar radiation for one variables temperature based model.

Fig. 1.0 shows that both the measured and the predicted value were equal in the months of January and April. The months: February, March, June and October have predicted values slightly lower than the measured values, and those of May, July, August and September are above the measured values. This may be due to the variation in the measurement of the atmospheric values. The estimated and predicted values of the monthly global solar radiation have partial correlation.

Mean average results obtained for one variable relative humidity-based model

Figure 2.0, show the mean average results of the three years for the one variable linear relative humidity-based model.

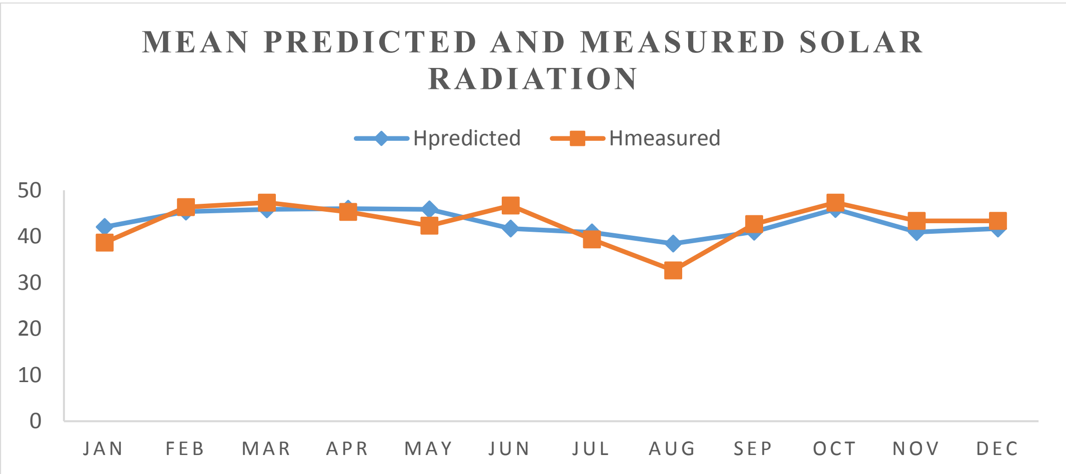

Figure 2.0: Measured and predicted monthly global solar radiation for mean one variable relative humidity based model.

Fig. 2.0 indicates that the maximum global solar radiation in Jos, was measured in the month of October. This may be due to the dry season, while the minimum global solar radiation was measured in the month of August which experiences heavy rain fall. The graph showed that both the measured and the predicted value were almost equal in the months of February, April and July. March, June, September, October, November and December had predicted values which are under the measured values unlike January, May and August with predicted values above the measured values. There is partial correlation between the measured and predicted values of the monthly global solar radiation.

Mean average results obtained for two variable temperature and relative humidity-based model.

Figure 3.0, show the mean average results of the three years for the double variable linear temperature-relative humidity-based model.

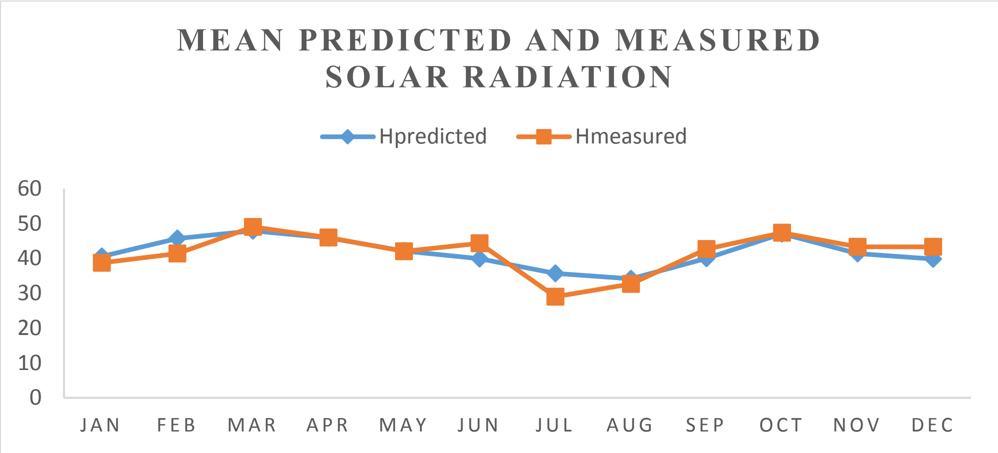

Figure 3.0: Comparison between measured and predicted monthly global solar radiation for average double variable temperature-relative humidity based model.

In this case, the maximum global solar radiation in Jos was measured in the dry season month of March and the minimum global solar radiation was measured in the rainy season month of August. Fig. 3.0 showed that both the measured and the predicted values correspond in April, May and October. June, September November and December had predicted values slightly below the measured values, and January, February, July and August had higher values than the measured values. There is also partial correlation between the measured and predicted values of the monthly global solar radiation.

Tables 1.0, 2.0 and 3.0 compares various meteorological parameters within the three models.

Table 1.0: Mean average modified Angstrom models (Temp, RH and TMP-RH) for Jos station.

MODEL 1	MODEL 2	MODEL 3
One variable Temperature model	One variable Relative humidity	Two variable Temperature & Relative humidity
$\frac{\bar{H}}{H_0}$ =1.076+0.042$\sqrt{(Tmax - Tmin)}$	$\frac{\bar{H}}{H_0}$ =1.637−0.007RH	$\frac{\bar{H}}{H_0}$ =1.329+0.092$\sqrt{(Tmax - Tmin)} - 0.007RH$

Table 2.0: Mean average regression constants and statistical test of variable models in Table1.0.

MODEL	Variable model	a	b	c	$MBE(MJm^{-2})$	$RMS\ (MJm^{-}$	MPE %	SE	R^2
1	One variable Temperature	1.07557	0.04176	_	0.152504	0.528290	0.029529	0.171038	0.214196
2	One variable Relative humidity	1.63660	-0.0071	_	0.030354	0.105150	0.005837	0.157996	0.348336
3	Two variable Temp. &RH	1.32851	0.0921	-0.0067	0.028306	0.098057	0.005649	0.111020	0.676525

Table: 3.0 Mean average estimated global solar radiation for Jos using the two variable based model.

MONTH	Estimated GSR for Jos MJ/m^2day^{-1}	Measured GSR for Jos MJ/m^2day^{-1}
JANUARY	40.5492685	38.6666667
FEBRUARY	45.6517632	41.333333
MARCH	47.8786078	49.000000
APRIL	45.8930959	46.000000
MAY	42.1488368	42.000000
JUNE	39.9058307	44.333333
JULY	35.6339502	29.00000
AUGUST	34.1422821	32.666667
SEPTEMBER	39.9928624	42.666667
OCTOBER	47.0332825	47.333333
NOVEMBER	41.3696802	43.333333
DECEMBER	39.8068857	43.333333

Muhammad *et al.,* (2014), estimating monthly global solar radiation on horizontal surface in Kano state Nigeria obtained the regression constants a and b as (0.2577, - 1.0167) and (0.8317, -0.0043) respectively. Similar, to the present study, August had the lowest global solar radiation, probably due to heavy rainfall. The month of highest global solar radiation however differs, March in Jos and February in Kano.

Abdullahi *et al*., (2014). The results of monthly average daily values of global solar radiation and sunshine hour for five stations of the North-Eastern Nigeria and the clearness index have some similarities. However, the results of Augustine and Nnabuchi (2010) for some selected cities in the Eastern and Southern zone of Nigeria differ with the results obtained for Jos North, Plateau State.

CONCLUSION

The results obtained in this research work clearly predict the estimated global solar radiation in Jos North, Plateau State Nigeria. The single variable temperature based model gave the values April (46.02 MJm^{-2}) and August (38.45MJm^{-2}), and the single variable relative humidity based model gave these results: March (47.88 MJm^{-2}) and August (34.14 MJm^{-2}). The double variable temperature-relative humidity-based model gave the highest solar radiation values in March (47.88 MJm^{-2}) and the lowest in August (34.14 MJm^{-2}). The double variable temperature-relative humidity-based model was selected to give better result due to it is low value of MBE, RMSE and MPE of 0.028306624, 0.098057021 and 0.005649974. The models can also be applied to other cities of similar or the same geographical location as Jos North, Plateau State to predict the global solar radiation.

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