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Estimation of Global Solar Radiation Based on Daily Relative Humidity for Bauchi, Bauchi State, Nigeria

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Abstract— *The need to study solar radiation is an interesting aspect in the study of renewable energy. This project presents the model for the estimation of the global solar radiation for Bauchi State, Nigeria based on daily relative humidity values The daily averaged data were averaged into monthly averaged data. And later combined for twelve months. Two (2) years (2021-2022) solar radiation data were obtained from the Nigerian Meteorological Agency (NIMET), Bauchi, Nigeria for the solar radiation estimation using regression analysis. Four empirical models (linear, quadratic, cubic and exponential) were employed to fit the experimental data based on their root mean square error (RMSE) and coefficient of determination (R^2). From the work, the model that gives lowest value of RMSE = 0.096 is exponential model, which means that for Bauchi exponential model is suitable for estimating solar radiation.*

Keywords— *Solar radiation, regression analysis, linear model, quadratic model, cubic model, exponential model, coefficient of determina tion.*

I. Introduction

Solar energy is the principal energy source for the processes such as biological, chemical and physical activities. Accurate knowledge of the solar radiation is important for many application; simulations and modelling, architectural design, solar energy systems. There are many meteorological stations those measure basic meteorological parameters; but not all of them measure the global radiation in the worldwide (Okonkwo and Eze, 2015. Sometimes measurement of solar radiation cannot be available due to the equipment cost, maintenance and calibration requirement in developing countries. There are several empirical models in the literature to estimate the global radiation using various parameters (Chen *et. al.,* 2004)

Energy is the motive force behind sustained technological development of any nation and Nigeria is a blessed with reasonable high quantities of various energy resources. These include the non-renewable such as biomass, solar, wind and hydro energy.

At present, the dominant source used in Nigeria is oil and its derivatives, accounting for over 75% of the energy consumption except in the rural area where biomass in the form of fuel wood dominates (UNIDO, 2003). Energy trend indicates world oil production will reach peak and start a long downward slide some day when the fossil fuel and gas would have exhausted. Nigeria is a blessed with abundant amount of sunshine with an estimated 3000 hours of annual sunshine (Bu and Sambo, 2001)

Global solar radiation is an important parameter necessary for most ecological models and serves as input for different photovoltaic conversion system; hence, it is of economic importance to renewable energy alternative. The solar radiation reaching the earth's surface depends on the climatic condition of the specific site location, and this is essential for accurate prediction and design of a solar energy system (Burari and Sambo, 2001).

Solar radiation is the most evenly distributed energy resources on earth and the most abundant (Aitken, 2010). The amount of energy released by the sun during 1 hour may be sufficient to cover the world's energy need for one year. Part of this radiation can be used directly to produce heat or electricity called photovoltaic solar energy (Jenny Nelson,2003). This mode of production does not require network distribution, because it can generate electricity and can be consumed in places such as villages, detached houses, water pumping refuge .the sun discharges continuously an enormous amount of energy radiant in the solar system (Eduardo Lorenzo, 1994).. Earth intercepts a small portion of this energy radiated into space. An average of 1367 watt square per meter reaches the edge outside of the terrestrial atmosphere (for an average distance for average distance earth sun 150 million kilometers) this quantity is called solar constant. the energy received by earth's surface defend on the thickness of the atmospheric crossing. It is the function of air mass (Harlan, 2008. Some countries such as France have conducted studies to have measurement to encourage generating electricity from solar energy. Therefore, for the design of and development of various solar energy system, the estimation of solar radiation is considered as the most important parameters. However, the availability of the required data, are very scarce and often not readily accessible. The encounter of solar radiation particularly with cloud lead to the variation in intensity of sunshine and the number of sunshine hours at the ground surface: the variation however is not due to cloud only but also to the angle of incidence of the sun's rays with the ground surface and its azimuth (Babatunde,1988)

In many regions, including parts of Nigeria, long-term solar radiation measurements are either unavailable or incomplete due to equipment limitations, maintenance challenges, and data gaps. This lack of reliable solar radiation data limits the effective planning and development of solar energy technologies, which are increasingly important for sustainable energy solutions.

To address this challenge, researchers have developed empirical and analytical models that estimate solar radiation using commonly available meteorological parameters such as temperature, sunshine duration, relative humidity, and cloud cover (Arinze and Obi). Despite the existence of several estimation models, their accuracy often varies with geographic location and climatic conditions (Modi, &Sukhatme,(1979). Therefore, there is a need to evaluate and apply appropriate models for estimating solar radiation in specific regions to ensure reliable data for scientific, environmental, and energy applications.

This work was aimed to accurately provide the model for Estimation of Global Solar Radiation Based on Daily Relative Humidity for Bauchi, Bauchi State, Nigeria

II. Theoretical Backgroung

Solar radiation reaching the Earth's surface, commonly referred to as global solar radiation, consists of direct and diffuse components. It plays a key role in heating the Earth's surface and the lower atmosphere. The amount of solar radiation received at the surface is influenced by atmospheric conditions such as clouds, aerosols, and water vapor.

Solar radiation reaching the Earth's surface is often expressed in relation to extraterrestrial radiation as

$$SR=\frac{H}{H_o} \quad (1)$$

Where H represents the global solar radiation at the Earth's surface and H_o is the extraterrestrial solar radiation and SR is Solar radiation (Duffie & Beckman, 2013)

High solar radiation increases surface temperature and enhances evaporation and evapotranspiration, which subsequently affects the moisture content of the atmosphere (Iqbal, 1983).

The incoming solar radiation at the top of the atmosphere is given by

$$I_o = I_{sc}\left(1+0.033\cos\left(\frac{360n}{365}\right)\right) \quad (2)$$

Where I_o is the extraterrestrial solar radiation, I_{sc} is the solar constant and n is the day of the Year

Relative humidity (RH) is defined as the ratio of the actual water vapor pressure to the saturation vapor pressure at a given temperature

$$RH = \frac{e}{e_s}\times 100 \quad (3)$$

Where RH is the relative humidity, e is the actual water vapour and e_s is the saturated water vapour

The saturated vapour pressure as a function of temperature e_s is given by

$$e_s = 6.112e^{\left(\frac{17.502T}{T+240.97}\right)} \quad (4)$$

Where T is the value of temperature in degree Celsius (°C)
Several empirical models estimate solar radiation using meteorological variables including relative humidity.
A general empirical relationship is

$$SR = a + bRH \quad (5)$$

Where RH is the relative humidity, SR is the Global solar radiation, while a and b are empirical constants

Another commonly used model relates solar radiation to sunshine duration (Angstrom–Prescott model):

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \quad (6)$$

Where H is the measured solar radiation, H_o is the extraterrestrial radiation, S is the actual sunshine hours, S_o is maximum possible sunshine hours
While a and b are empirical coefficients

Water vapor absorbs and scatters solar radiation, reducing the amount reaching the surface. High humidity levels often correspond to increased cloud formation, which decreases incoming solar radiation.

The attenuation of solar radiation in the atmosphere can be expressed as

$$I = I_o e^{-\tau m} \quad (7)$$

Where I is the solar radiation reaching the surface, I_o is the extraterrestrial radiation, τ is the optical depth and m is the air mass

Atmospheric moisture contributes to the optical depth, thereby influencing solar radiation transmission (Liou, 2002).

III. Materials and Method

Materials

To estimate Global solar radiation for Bauchi (latitude of 10.7761° N and longitude 9.9992° E based on relative humidity, data were obtained from Nigerian Metrological Agency (NiMET), Bauchi State Nigeria. The relative humidity daily averaged data were averaged into monthly for a period of 2 years (2021-2022).

Method

Statistical package for social science (IBM SPSS) was used to carry out the analysis to obtain simple regression equation model that estimate the solar radiation from either linear, quadratic, cubic or exponential model.

Statistical Analysis Parameters

In order to evaluate the accuracy of the developed models which Root mean square error (RMSE), was employed. (Muzathiket 2011)
Root Mean Square Error is defined as (Iqbal M., 1982):

$$RMSE = \left\{\sum\left(H_{pred} - H_{meas}\right)^2/n\right\}^{1/2} \quad (8)$$

Where $\overline{H_{pred}}$ and $\overline{H_{meas}}$ is the measured and calculated value and n is the total number of observations. In general a low RMSE is desirable.

Data Analysis

Four regression analyses (linear, quadratic, cubic and exponential) were employed to estimate the prediction of global solar radiation for the Meteorological data for Bauchi State, Nigeria for the period of 2021-2022. The accuracy of the estimated values was tested by calculating RMSE and R^2. The empirical mathematical models used for this work are:

LINEAR: $y = a + bx$ (9a)

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QUADRATIC: $y = a + bx + cx^2$ (9b)
CUBIC: $y = a + bx + cx^2 + dx^3$ (9c)
EXPONENTIAL: $y = ae^{bx}$ (9d)
The constants a, b, c and d are obtained from the regression analysis using IBM SPSS 25 software to fit the measured solar radiation data. Excel software was employed to plot the various graphs.

Correlation between Solar Radiation and Relative Humidity

The correlation between solar radiation and relative humidity can be expressed using a statistical measure known as the correlation coefficient. The correlation coefficient, often denoted as "R," represents the strength and direction of the linear relationship between two variables. It ranges from -1 to +1, where:

$R = +1$ Indicate a perfect positive linear correlation (as one variable increases, the other increases proportionally), $R = -1$ indicate a perfect negative linear correlation (as one variable increases, the other decreases proportionally) and $R \approx 0$ indicate a weak or no linear correlation (there is no clear relationship between the two variables).

To calculate the correlation between solar radiation (SR) and relative humidity (RH), you need a dataset with corresponding values of both variables. If you have a set of n data points (SR_1, RH_1), (SR_2, RH_2) ... (SR_i, RH_i), the correlation coefficient (R) can be computed using the following formula:

$$R = \frac{\Sigma((SR_i - \overline{SR})(RH_i - \overline{RH}))}{\sqrt{\Sigma(SR_i - \overline{SR})^2 \Sigma(RH_i - \overline{RH})^2}} \quad (10)$$

Where: SH_i represent the i-th value of solar radiation, RH_i represents the i-th value of relative Humidity, $\overline{SR}$ is the mean (average) of all solar radiation values, $\overline{RH}$ is the mean (average) of all relative humidity values and Σ represents the sum of the values for the given expression.

IV. Results and Discussion

Results

The results was presented in form of tables and graph for the global solar radiation using Statistical Package for Social Sciences (SPSS) for linear, quadratic, cubic and exponential model on the horizontal surface of Bauchi state and also the maximum value of calculated global solar radiation are observed in the months of March while the minimum value appeared in August, the maximum values of predicted global solar radiation appeared between the months of March, while the minimum value appeared in August, the maximum values of relative humidity appeared in August while the minimum value was observed in March and the regression constants a, b, c and d for linear, quadratic, cubic and exponential are also found using SPSS. The values coefficient of determination R^2, Standard error of estimation ($RMSE$) are also calculated.

TABLE 1: Measured and Predicted Global Solar Radiation for the Linear Model

Months	Measured Solar Radiation ($MJday^{-1}m^{-2}$)	Predicted Solar Radiation ($MJday^{-1} m^{-2}$)
JAN	19.6	22.183
FEB	21.3	22.528
MAR	23.3	22.643
APR	22.4	20.918
MAY	19.7	20.228
JUN	17.4	18.273
JUL	15.4	16.893
AUG	14.9	16.548
SEPT	17.3	16.663
OCT	21.4	18.273
NOV	23.1	20.458
DEC	21.4	21.378

TABLE 2: Measured and Predicted Global Solar Radiation for the Quadratic Model

Months	Measured Solar Radiation ($MJday^{-1} m^{-2}$)	Predicted Solar Radiation ($MJday^{-1} m^{-2}$)
JAN	19.6	21.973
FEB	21.3	21.796
MAR	23.3	21.725
APR	22.4	22.16
MAY	19.7	21.956
JUN	17.4	20.205
JUL	15.4	17.925
AUG	14.9	17.22
SEPT	17.3	17.461
OCT	21.4	20.205
NOV	23.1	22.048
DEC	21.4	22.176

TABLE 3: Measured and Predicted Global Solar Radiation for the Cubic Model

Months	Measured Solar Radiation ($MJday^{-1} m^{-2}$)	Predicted Solar Radiation ($MJday^{-1} m^{-2}$)
JAN	19.6	22.051
FEB	21.3	21.941
MAR	23.3	21.902
APR	22.4	22.262
MAY	19.7	22.191
JUN	17.4	20.882
JUL	15.4	18.613
AUG	14.9	17.830
SEPT	17.3	18.102
OCT	21.4	20.882
NOV	23.1	22.233
DEC	21.4	22.229

TABLE 4: Measured and Predicted Global Solar Radiation for the Exponential Model

Months	Measured Solar Radiation ($MJday^{-1} m^{-2}$)	Predicted Solar Radiation ($MJday^{-1} m^{-2}$)
JAN	19.6	22.367
FEB	21.3	22.774
MAR	23.3	22.911
APR	22.4	20.939
MAY	19.7	20.198
JUN	17.4	18.240
JUL	15.4	16.973
AUG	14.9	16.670
SEPT	17.3	16.770
OCT	21.4	18.240
NOV	23.1	20.442
DEC	21.4	21.447

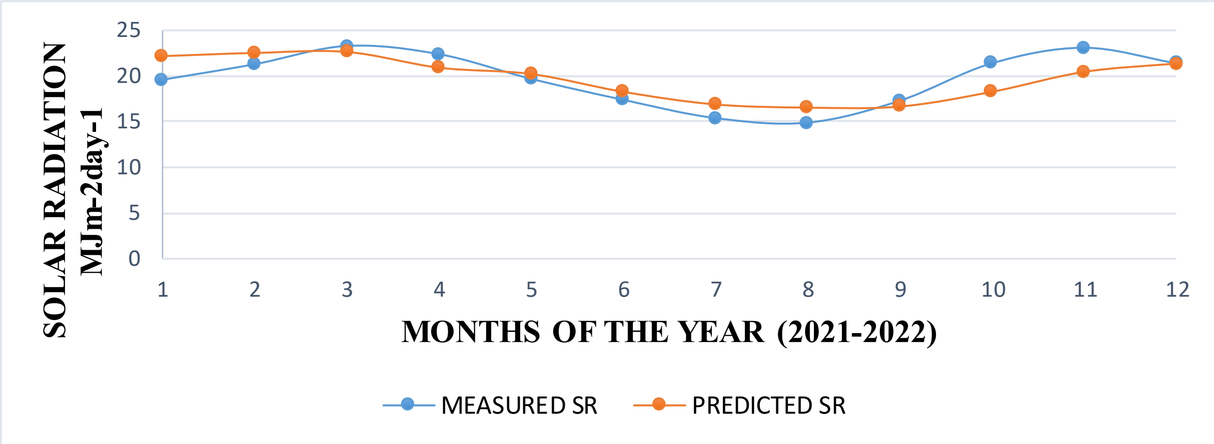

Figure 1: Graph for measured and predicted global solar radiation for the linear model

$SR = 26.093 - 0.115RH$, $R^2 = 0.634$, $RMSE = 1.8427$

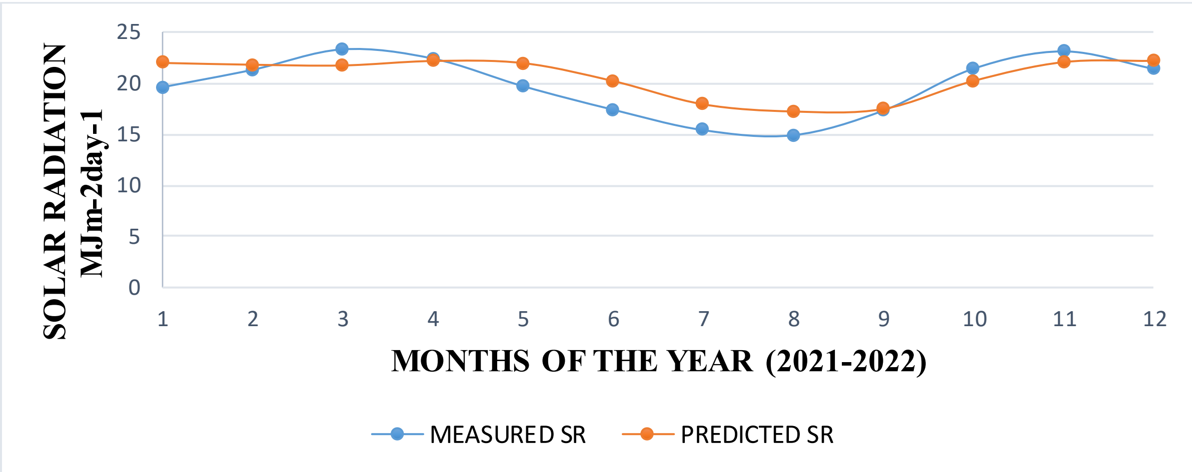

Figure 2: Graph for measured and predicted global solar radiation for the quadratic model

$SR = 16.805 - 0.254RH - 0.003RH^2$, $R^2 = 0.726 RMSE = 1.679$

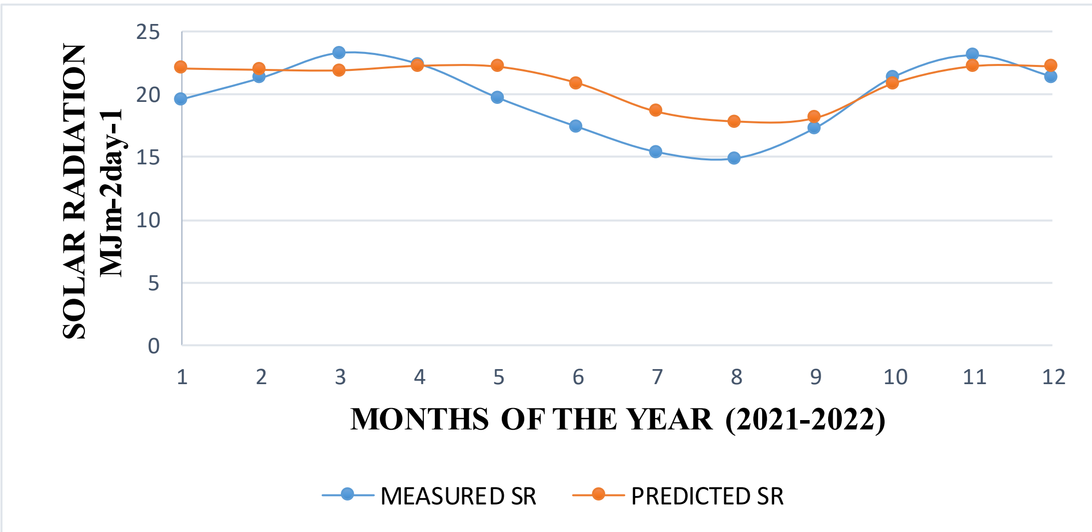

Figure 3: graph for calculated and predicted global solar radiation for the cubic model

$SR = 20.897 + 0.0*RH + 0.002*RH^2 - 0.00002946*RH^3$, $R^2 = 0.730 RMSE = 1.668$

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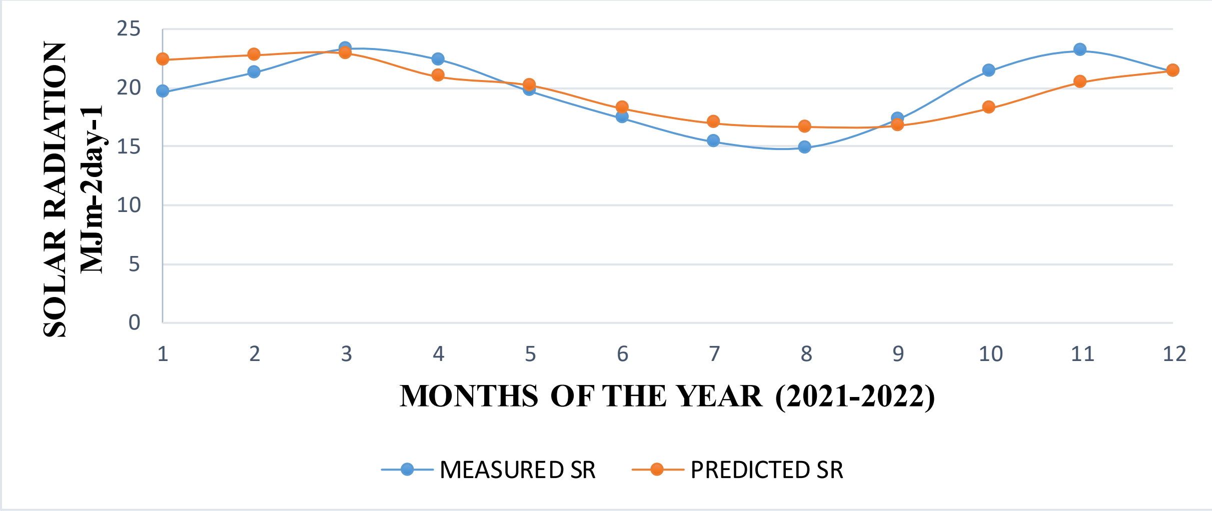

Figure 4: graph for measured and predicted global solar radiation for the exponential model

$SR = 27.429*e^{(-0.006*RH)}$, $R^2 = 0.645$ RMSE = 0.096

Discussion

From the regression analysis of the data, the four models show positive correlation with the measured solar radiation data. The cubic model has the highest coefficient of determination of 73.0% and the smallest of 63.4% for the linear. Further the smallest root mean square error of estimation of 0.096 was obtained for the exponential and highest of 1.8427 for the linear model. Going by this, we can say that the exponential model is most suitable for the prediction of daily solar radiation for Bauchi State, Nigeria based on relative humidity.

Based on the above results, we can deduce that there's an inverse relationship between solar radiation and relative humidity. This means that as relative humidity increases, solar radiation decreases. This can water vapor in the atmosphere absorbs some of the sun's rays, which reduces the amount of radiation that reaches the earth's surface.

The relationship between solar radiation and relative is not the only factor that affects the amount of solar radiation that reaches the earth's surface. Other factors such as cloud cover, altitude and latitude can also have a significant impact.

Furthermore, the accuracy of the estimation also affects the results. A well validated model will produce more accurate results than a model that has not been proper tested.

The research finding is in line with Babatunde *et al*. (2010) whose findings revealed a significant positive correlation between relative humidity and solar radiation, with a regression coefficient (*a*) of 0.68 and (*b*) of 0.31. The study provided valuable insights into the potential use of relative humidity data for solar radiation estimation in Bauchi State. The findings by Ojo and Abdullahi (2018) who used data from multiple meteorological stations and applied machine learning algorithms to develop a predictive model for solar radiation estimation which indicated that relative humidity was a crucial parameter in accurately estimating solar radiation in the region also is in line with our findings.

V. CONCLUSION

From the regression analysis for estimating of solar radiation for Bauchi State, Nigeria based on relative humidity, the model that gives the lowest value of the error of estimation (*RMSE* = 0.096) with the coefficient of determination ($R^2 = 0.645$) is the exponential model given by

$$SR = 27.429*e^{(-0.006*RH}$$

This means that for Bauchi exponential model is suitable for estimating solar radiation.

REFERENCES

[1]. Aitken, D. W. (2010). Transitioning to a renewable energy society. ,Pp 54-79
[2]. Arinze and Obi (1983). A global climatological model for solar radiation. *Applied energy,* Pp 57-89.
[3]. Babatunde, A., Adams, J., & Yusuf, S. (2010). Estimation of solar radiation in Bauchi State, Nigeria, based on relative humidity. *Journal of Renewable Energy,* 35(5), Pp 1125-1132.
[4]. Burari, F.W, Sambo,AS., (2001). A global climatological model for solar radiation. *Applied Energy* 5(7), Pp 132-145.
[5]. Chen K., Chin J.L., David .F.F., Tsai H (2004). Global Solar radiation and sunshine duration. *Solar Energy*,46(5), Pp 877-911.
[6]. Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes* (4th ed.). Wiley.
[7]. Eduardo Lorenzo. (1994). Solar Electricity: Engineering of Photovoltaic Systems. *PROGENSA* ISBN 316-848650550 Pp 154-156
[8]. Harlan J.D (2008). HELIOCAL: Software for Calculating Solar Position Parameters. *Journal of Renewable Energy,* 112, Pp 52-75.
[9]. Iqbal.M. (1983). An introduction to Solar Radiation in Department of Mechanical Engineering University of British Coloubia , California Journal of power and energy engineering, 1(3) Pp15-25
[10]. Jenny Nelson. (2003). The Physics of Solar Cells. *Imperial College Press*. ISBN 978-1-86094-840-237 Pp 124-132
[11]. Liou, K. N. (2002). *An introduction to atmospheric radiation* (2nd ed.). Academic Press.
[12]. Modi, V., &Sukhatme, S. P. (1979). Estimation of daily total and diffuse insolation in India from weather data. *Solar Energy*, 22(407) Pp 311-321.
[13]. Muzathiket, I. A.(2011). Estimating solar radiation using relative humidity in Nigeria. *Journal of Renewable Energy*, 15(3), 245-254. doi:10.1016/j.renene.2010.09.015
[14]. Ojo, T., Abdullahi, I. (2018). Machine learning-based estimation of solar radiation in Bauchi State, Nigeria, using relative humidity data. *Journal of Renewable Energy*, 55(9),Pp 1234-1246.

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[15]. Okonkwo, C., &Eze, C. (2015). Estimating solar radiation in Nigeria using relative humidity data. *Solar Energy Research*, 45(7), Pp 876-887.

[16]. United Nations Industrial Development Organization. UNIDO (2003). *Utilization of biomass for energy production: A global analysis of potential and its implications*. Vienna, Austria: United Nations Industrial Development Organization.