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The Influence of Some Meteorological parameters on Solar Radiation in Yola, Adamawa State, Nigeria.

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Abstract

A study was carried out to estimate the global solar radiation in Yola, North Eastern, Nigeria (Latitude 09.14^0N, Longitude 12.28^0E and altitude 186.1 m above sea level) in order to examine the impact of cloud cover, relative humidity, rainfall, minimum and maximum temperature and the daily values of global solar radiation, using different proposed empirical models for a period of 15 years (2001-2015). The values of the measured and the estimated global solar radiation models were tested using the Root Mean Square Error (RMSE), the Mean Bias Error (MBE) and the Mean Percentage Error (MPE) were also calculated. From the results obtained, the equation (Model 4) $\frac{H}{H_o} = 0.52479 + 0.01475(T_{max} - T_{min}) + 0.0001(RH) + 0.003389(RF) + 0.00187(CC)$ outperformed the rest based on statistical analysis. The results obtained show a remarkable agreement between the measured and the predicted values using the model. This model is recommended for designers and engineers of solar energy and other renewable energy devices in this area.

Keywords: Solar Radiation, Empirical Models, Statistical Analysis, Renewable Energy.

Introduction

Due to the developments in the technology, the energy need of people is increased. The sources of the energy are varied according to the technological progress. In the beginning, wood has been used to provide energy, and then coal is replaced instead of wood. Finding oil and natural gases, energy growth has been assured.

Renewable energy is considered to be the most important source to the world for the future. The decrease in the fossil fuels, made an orientation to the renewable energy sources such as sunlight, wind, rain, tides, and geothermal heat. Among the renewable energy resources solar energy is the most actual and usable in the world. It is the energy obtained from the heat and rays of the sun.

Solar Radiation is produced from nuclear fusion that occurs within the sun. The quantity of solar radiation reaching the earth's surface varies dramatically as a function of changing atmospheric conditions as well as the changing position of the sun through the day. Solar radiation data provide information on how much of the sun's energy strikes a surface at a location on earth during a particular time period. The data gives values of energy per unit of area. Readily available solar radiation data is a key to design and simulation of all solar energy applications. Radiation values are either measured with instrumentation or modeled from empirically derived relationships between solar radiation and more readily available atmospheric variables. Often, one of these methods is used to test the validity of the other. Several models have been proposed for generation of global radiation. The random nature of global solar radiation is included in all proposals, but the way of implementing this in a model varies significantly (Ångström, 1924; Erbs et al, 1982; Falayi, and Rabiu, 2005; Falayi, et al, 2011; Trabea and Shaltout., 2000). Meteorological parameters such as cloud cover, relative humidity, rainfall and temperature play an important role in the radiative energy budget of the earth and in the transfer of energy between the surface and the atmosphere. (Bristow and Campbell, 1984; Hargreaves and Samani, 1982) proposed solar radiation estimation using differences between maximum and minimum ambient temperature. Some studies were based on hourly solar radiation prediction using different meteorological parameters. However, the researchers were able to obtain comprehensive results (Zhou et al, 2004; Hassan and Ali 2011; Dimas et al, 2011; Falayi and Rabiu, 2011; Liu et al, 2009; Badescu, 2002; Hamdy, 2007; Falayi and Rabiu, 2012).

When data are measured, strict quality controls are mandatory in order to build a confident database. When data are retrieved from other means, as satellites, their quality has to be determined by convincing parameters. The model accuracy is determined by validation or comparison of modelled data series against measured or other reference data series. Here, it is important to quantify the similarities or the differences between the two series. Usually graphics and correlations are the most commonly used methods for this task. The validation of modelled irradiation values against measurements focuses usually on the root mean square difference (RMS) and the mean bias difference (MB) as shown in the studies of Schillings et al. (2003), and Lefe'vre et al. (2007). Other parameters as the determination coefficient (Lo´pez et al., 2001; Gueymard, 2003), standard deviation (Lo´pez and Batlles, 2004; Kudish et al., 2005) and, in a less number of cases, the variation coefficient, the difference between the mean and the median (Kudish et al., 2005) and the analysis of residuals (Rubio et al., 2005; Gueymard, 2003) are widely used as well.

In this paper, four different models were used to estimate the global solar radiation using cloud cover, rainfall, relative humidity and temperature difference. This is to identify the most appropriate model for the estimation of global solar radiation as well as an aid in designing and construction of solar energy devices and equipment's in Yola, Adamawa State, Nigeria.

Materials and Methods

The Study Area

Yola, the capital of Adamawa state, comprising of Yola North and Yola South local Government Areas, is located between longitude 12°30' E of the prime meridian and between latitudes 09°20' N of the equator. It is situated in the Benue Valley area of the state with a mean elevation 186ft.

Data source

The measured monthly average daily global solar radiation, sunshine hour, maximum and minimum temperatures, rainfall, cloud cover and relative humidity covering a period of fifteen years (2001 - 2015) for Yola, North – Eastern, Nigeria was obtained from the Nigerian Meteorological Agency (NIMET), Yola International Airport, Adamawa State. The station is a standardized weather station in which climatic data are measured primarily for the purpose of aviation and also used for research purpose.

Data Analysis

Several empirical models exist to evaluate global solar radiation, using available meteorological and geographical parameters such as sunshine duration, difference between the maximum, T_{max}, and the minimum, T_{min} temperatures, Rainfall (RF), Relative Humidity (RH), Cloud Cover (CC) and latitude. In this study, three models were used to estimate monthly mean values of global solar radiation. Mathematical software for computation (Scientific workplace) and Microsoft Office Excel software's was used for the data analysis.

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. The formula is (Duffie and Beckman, 1994; Medugu and Yakubu, 2011):

$$\frac{H_m}{H_o} = \left[a + b\frac{n}{N}\right] \quad 1$$

H_m is daily mean values of global radiation ($MJm^{-2}day^{-1}$), N the daily average value of day length, and 'a' and 'b' values are known as Angstrom constants and they are empirical. H_o is daily mean values of extraterrestrial radiation ($MJm^{-2}day^{-1}$), calculated using Eq. (2) as described by (Duffie and Beckman, 1994; Medugu and Yakubu, 2011):

$$H_o = \frac{24 \times 3,600}{\pi} I_{sc} E_o \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \quad 2$$

$$I_{sc} = \frac{1,367 \times 3,600}{1,000,000} MJm^{-2}day^{-1} \quad 3$$

I_{sc} the solar constant, the units in KWh m^{-2} day^{-1}.

E_o represents the eccentricity correction, and described using Eq. (4) in Eq. (2)

$$E_o = 1 + 0.033\cos\frac{360 n_d}{365} \quad 4$$

n_d is the day number of the year /Julian day (1 Jan, n_d = 1 and 31st December, n_d= 365), φ is the latitude of the site, δ the solar declination and, ω, the mean sunset hour angle for the given month. The solar declination (δ) and the mean sunset hour angle (ω_s) can be calculated as suggested by (Duffie and Beckman, 1991):

$$\delta = 23.45\sin 360\frac{284 + n_d}{265} \quad 5$$

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

For a given day, the maximum possible sunshine duration (monthly values of day length, (N) can be computed by using (Duffie and Beckman, 1991):

$$N = \frac{2}{15}\omega_s \quad 7$$

Models

The models to which the measured data were fitted are as follows:

Model 1

$$\frac{H}{H_o} = a + b(T_{max} - T_{min}) + c(CC) \quad 8$$

Model 2

$$\frac{H}{H_o} = a + b(T_{max} - T_{min}) + c(RH) \quad 9$$

Model 3

$$\frac{H}{H_o} = a + b(T_{max} - T_{min}) + c(RF) \quad 10$$

Model 4

$$\frac{H}{H_o} = a + b(T_{max} - T_{min}) + c(RH) + d(RF) + e(CC) \quad 11$$

Where a, b, c, d and e are empirical constants. The measured data were used in multiple linear regression analysis to obtain the values of empirical constants in Eqs. (8) – (11).

The values of a are respectively 0.318581, 0.24358, 0.7571 and 0.52479 in Eqs. (8) – (11) while the values *b* are 0.03477, 0.0382, 0.00733 and 0.01475 in Eqs. (8) – (11). 0.00001, 0.000598, 0.0013 and 0.0001 are the values of c in Eqs. (8) – (11), while those of *d* and *e* are 0.003389 and 0.00187 in Eqs. (11).

Model Accuracy Evaluation

The performance of the 4 Models was evaluated on the basis of the following statistical error tests: the Mean Percentage Error (MPE), Root Mean Square Error (RMSE) and Mean Bias Error (MBE). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations.

The Mean percentage error is defined as:

$$MPE = \frac{\left[\sum(H_{i,m} - H_{i,c})/H_{i,m}\right]100}{N} \quad 12$$

Where $H_{i,m}$ is the ith measured value, $H_{i,c}$ is the ith calculated value of solar radiation and N is the total number of observations.

The root mean square error is defined as:

$$RMSE = \left(\left[\frac{\sum\{H_{i,c} - H_{i,m}\}^2}{N}\right]\right)^{1/2} \quad 13$$

Mean Bias Error: The mean bias error is defined as:

$$MBE = \frac{\left[\sum\{H_{i,c} - H_{i,m}\}\right]}{N} \quad 14$$

Results and Discussion

Data Presentation

Table 1, 2 and 3 present monthly daily average meteorological data, input parameter for the estimation of monthly average daily global solar radiation and statistical comparison error test for Yola respectively. Fig.1 displays the relationship between the clearness index and relative sunshine duration in yola.

Table 1: Monthly Daily Average Meteorological data for Yola

Months	CC	RH (%)	RF (mm)	T_{max} (°C)	T_{min} (°C)	$\frac{n}{N}$	$H_m (MJm^{-2}day^{-1})$
Jan.	4.79	36.3	0.00	34.8	18.0	0.60	18.5
Feb.	4.81	30.6	0.00	38.2	21.8	0.59	20.1
Mar.	5.19	28.3	0.07	40.55	25.4	0.57	21.1
Apri.	5.49	47.5	29.5	37.4	28.0	0.55	19.8
May	6.04	65.9	78.21	33.7	26.6	0.49	18.2
Jun.	6.07	76.2	137.94	31.7	24.6	0.46	17.2
Jul	6.40	80.3	157.17	30.8	23.9	0.43	15.4
Aug.	6.57	84.3	186.0	31.1	23.6	0.36	14.2
Sept.	6.27	84.4	172.29	33.2	23.4	0.42	16.5
Oct.	5.55	76.1	53.01	36.7	23.6	0.59	18.9
Nov.	5.10	55.5	0.00	37.6	22.6	0.72	20.4
Dec.	4.95	43.2	0.00	35.6	19.6	0.62	19.0

Table 2: Input parameter for the estimation of monthly average daily global solar radiation at Yola.

Months	$\frac{n}{N}$	$H_m (MJm^{-2}day^{-1})$	$H_o (MJm^{-2}day^{-1})$	$K_T = \frac{H_m}{H_o}$
Jan.	0.60	18.5	34.2	0.54
Feb.	0.59	20.1	36.4	0.55
Mar.	0.57	21.1	38.5	0.54
Apri.	0.55	19.8	39.0	0.50
May	0.49	18.2	38.2	0.47
Jun.	0.46	17.2	36.5	0.47
Jul	0.43	15.4	37.9	0.40
Aug.	0.36	14.2	34.2	0.41
Sept.	0.42	16.5	38.3	0.43
Oct.	0.59	18.9	36.0	0.52
Nov.	0.72	20.4	31.6	0.64
Dec.	0.62	19.0	30.4	0.63

Table 3: Validation of the models under different statistical error tests, for the period of 2001-2015

Statistical parameters	**Model 1**	**Model 2**	**Model 3**	**Model 4**
SE (MJm^2)	0.0560	0.0521	0.0510	0.0403
MBE (MJm^2)	2.719	-2.701	-1.002	- 5.471

MPE (MJm^2)	0.6301	0.6315	0.3502	0.2543

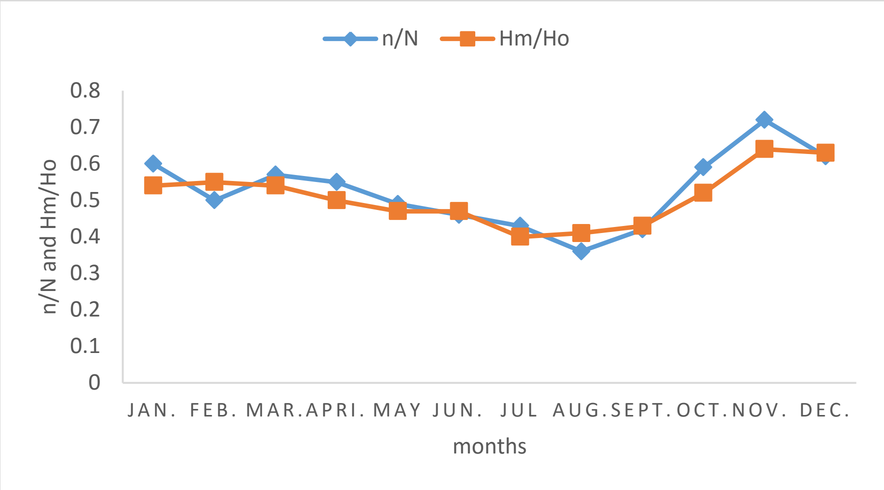

Figure 1: shows the relationship between the clearness index and relative sunshine duration in yola.

As can be seen in Table 2 and Fig 1, the value of clearness Index, K_T (= 0.41) correspond to the lowest value of $\frac{n}{N}$ (= 0.36) and H_m (= 14.2 $MJm^{-2}day^{-1}$) in the month of August indicate poor sky conditions. These conditions correspond to the wet or rainy season (June – September) observed in Yola during which is much cloud cover.

The accuracy of the predicted data is tested and model performance was evaluated using the Root Mean Square Error (RMSE), the Mean Bias Error (MBE) and Mean Percentage Error (MPE). For the present analysis, the RMSE was found to be lowest for Model 4 with the value of 0.0403 as shown in Table 3. The MBE values obtained from the Models is positive in one case and negative in others, which show that these Models vary between under and over estimate of global solar radiation. However, Model 4 has the lowest under estimation with a value of - 5.471, which is expected and acceptable. A low value of MPE is expected, so Model 4 was observed to have an MPE value of 0.2543. Based on statistical tests used in this study, the proposed Model 4 has the best accuracy based on the measured data at Yola station, with the MPE, MBE and RMSE vary from one model to another model. Hence, Model 4 is recommended to be used to estimate monthly mean daily global solar radiation for Yola town.

Conclusion

The global solar radiation can be estimated adequately using different proposed models with the aid of daily recorded meteorological variables of temperature difference, relative humidity, cloud cover and rainfall. In order to obtain some accurate solar radiation estimations, it requires accurate mathematical modeling of all the climatological parameters. From Fig. 1, there is high proportion of cloudy days, relative to low solar energy with low temperature during wet season while low cloudy day with high solar energy and high temperature during dry season across the latitude. The accuracy of the predicted data is tested and model performance was evaluated using the Root Mean Square Error (RMSE), the Mean Bias Error (MBE) and Mean Percentage Error (MPE). From the result obtained, It was observed that the lower the RMSE, MPE and MPE the more accurate the equation. This indicates that Model 4 is most suitable for the estimation of monthly average daily global radiation based on statistical analysis.

References

Ångström, A., (1924). Solar and terrestrial radiation. *Quart J Roy Meteorol Soc*., 50 (210):121–125. 5

Badescu, V., (2002). A new kind of cloudy sky model to compute instantaneous values of diffuse and global solar irradiance. *Theory Appl Climatology*, 72 (1–2): 127–36.

Bristow, K. L, and Campbell G.S., (1984). On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agric Forest Meteorology*; 31(2):159–66.

Dimas, F.A.R., Syed I. H. G. and Mohd. S. A., (2011). Hourly Solar radiation estimation using ambient temperature and relative humidity data. *International Journal of Environmental Science and Development*, Vol. 2, No. 3.

Duffie, J.A and Beckman, W.A., (1994). *Solar Engineering of Thermal Processes*. John Willey, New York, U.S.A. 2nd pp 234 – 367.

Erbs, D.G, Klein S.A, and Duffie J.A., (1982). Estimation of the diffuse radiation fraction for hourly, daily and monthly average global radiation. *Sol Energy*, 28:293–302.

Falayi, E.O. and Rabiu A.B., (2005). Modelling global solar radiation using sunshine duration data. *Nigeria J. Phys*., 17S: 181-186.

Falayi, E.O., Adepitan, J.O. and Rabiu. A..B. (2008). Empirical models for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria. *International Journal of Physical Sciences* 3(9):210-216.

Falayi, E.O., Rabiu, A.B. and Teliat, R.O. (2011). Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. *Advances in Applied Science Research*, 2 (4):480-490.

Falayi, E.O. and Rabiu, A.B. (2011). Estimation of global solar radiation using cloud cover and surface temperature in some selected cities in Nigeria. *Archives of Physics Research*, 2(3):99-109.

Falayi, E.O. and Rabiu, A.B. (2012). Solar radiation and information for renewable energy application. Published by In Tech, Solar radiation Edited by Elisha. Babatunde. Page 111-130.

Gueymard, C., (2003). Direct solar transmittance and irradiance predictions with broadband models. Part II: validation with high-quality measurements. *Solar Energy* 74, 381–395.

Hamdy, K. E. (2007). Experimental and theoretical investigation of diffuse solar radiation: Data and models Hargreaves, G.H and Samani , Z.A.(1982). Estimating potential evapotranspiration. *J Irrig. Drain Div*, 108 (3):225–30.

quality tested for Egyptian sites. *Energy*, 32, 73–82.

Hassan, A.N H. and Ali, H A. (2011). Time series regression model for prediction of monthly and daily average global solar radiation Al Ain City-UAE. *Proceedings of the global conference warming*, 11-14, Lisbon, Portugal.

Kudish, A.I., Lyubansky, V., Evseev, E.G., Ianetz, A., (2005). Intercomparison of the solar UVB, UVA and global radiation clearness and UV indices for Beer Sheva and Neve Zohar (dead sea), *Israel. Energy* 30, 1623–1641.

Lefe`vre, M., Wald, L., Diabate´, L., (2007). Using reduced data sets ISCCPB2 from the Meteosat satellites to assess surface solar irradiance. *Solar Energy* 81, 240–253.

Liu X.Y, Mei X.R, Li Y.Z, Wang Q.S, Jensen J.R, Zhang Y.Q and Porter J.R. 2009 Evaluation of temperature-based global solar radiation models in China. Agric Forest Meteorology; 149 (9):1433–46.

Lo´pez, G., Rubio, M.A., Martı´nez, M., Batlles, F.J., (2001). Estimation of hourly global photosynthetically active radiation using artificial neural network models. *Agricultural and Forest Meteorology* 107, 279–291.

Lo´pez, G., Batlles, F.J., (2004). Estimate of the atmospheric turbidity from three broad-band solar radiation algorithms. *A comparative study.Annales Geophysicae* 22, 2657–2668.

Rubio, M.A., Lo´ pez, G., Tovar, J., Pozo, D., Batlles, F.J., (2005). The use of satellite measurements to estimate photosynthetically active radiation. *Physics and Chemistry of the Earth* 30, 159–164.

Schillings, C., Meyer, R., Mannstein, H., (2003). Validation of a method for deriving high resolution direct normal irradiance from satellite data and application for the Arabian Peninsula. *Solar Energy* 76, 485 – 497.

Trabea, A.A. and M.A. Shaltout. (2000). Correlation of global solar-radiation with Zhou J., Wu Y. and Yan G., (2004). Estimation of daily diffuse solar radiation in China. *Renewable Energy* 29, 1537–1548.

meteorological parameters over Egypt. Renew. *Energy*, 21: 297-308.