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Estimation of mean monthly global solar radiation in Yola - Nigeria using angstrom model

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ABSTRACT

In this study, the estimation of global solar radiation at Yola, Nigeria latitude $9^0$12'N was carried out. The daily sunshine hour were measured for four years (2004 to 2007) using sunshine recorder. The monthly mean values were determined. The Angstrom model was then used to estimate the global solar radiation based on the available climatic parameters of sunshine hour. From the results obtained, the values of the radiation varies from the range of 13.75 $MJm^{-2}day^{-1}$ to 25.16 $MJm^{-2}day^{-1}$ with the mean value of 21.54±0.46 $MJm^{-2}day^{-1}$ in order to be utilized very efficiently in the design and prediction of the performance of solar energy devices. This method was employed since installation of pyranometer is a very costly exercise.

Keywords: Global solar radiation; Angstr□m model; Sunshine hour; Pyranometer.

INTRODUCTION

Apart from water, energy is the other major commodity that furnishes the fundamentals of every human activity for reasonable and good life quality. These two resources are intricately related to each other. In fact, during the early civilizations, waterpower has been employed as the major energy sources. Solar energy is the ancient source, and root material for almost all fossil fuel and renewable types. Special devices have been used for benefiting from the solar energy since immemorial. Energy is a continuous steering power for the social and technological prospective developments. Energy sources are vital and essential ingredients for all human transactions and without them human activities of all kinds will not be progressive at all.

Solar radiation is the energy that comes from the sun which generate huge amount of energy through the process of nuclear fusion. Knowledge of the solar radiation is essential for many applications, including architectural design, solar energy systems, crop growth models and evapotranspiration estimals.

The global solar radiation on horizontal surface at the location of interest is the most critical input parameter employed in the design and prediction of the performance of solar energy device [1]. The best way of knowing the amount of solar radiation at a site is to install a pyranometer at many locations in a given region and look after their day to day maintenance and recording but it is cost effective. With this situation, most researchers within Nigeria use available theoretical values of meteorological data to compute average irradiance of solar radiation for different locations within the country. They lack standard measured data obtained from reliable measuring instrument suitable for their local environment and therefore result to theoretical prediction using different models for the global daily sunshine radiation [2 – 8].

Since the installation of pyranometers at location in our study is very costly exercise, the alternative approach is to correlate the global solar radiation with meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics at which solar data are not available.

Without the sun's radiant energy, the earth would gradually cool, in time becoming ice. [9] 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 consistence basis. It is therefore, necessary to appreciate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperature, cloud cover and geographical locations.

In this work, Angstroms equations was used to estimate the global solar radiation at Yola, Adamawa state, Nigeria based on the available climatic parameters of sunshine hour and the computed values of the extraterrestrial solar radiation and maximum day light duration. Yola has been chosen for this study due to its climatic condition which varies significantly with the season of the year.

Theoretical Background

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. The formula is [10]:

$$\frac{H}{H_0} = a + b\frac{S}{S_o} \tag{1}$$

Where

H = the global solar radiation (MJm^{-2}day^{-1});

H_0 = the extraterrestrial solar radiation on a horizontal surface (MJm^{-2}day^{-});

S = the number of hour measured by the sunshine recorder;

S_0 = the maximum daily sunshine duration (or day length);

a, b = the regression constant to be determined.

For monthly average, this formula holds

$$\frac{\bar{H}}{\bar{H}_0} = a + b\frac{\bar{S}}{\bar{S}_o} \qquad (2)$$

Where

$\bar{H}$ = the monthly average daily global radiation on a horizontal surface;
$\bar{H}_0$ = the monthly average daily extraterrestrial radiation on a horizontal surface;
$\bar{S}$ = the monthly average daily number of hours of bright sunshine;
$\bar{S}_0$ = the monthly average daily maximum number of hours of possible sunshine.
The regression coefficient *a* and *b* have been obtained from the relationship given as [11];

$$\begin{aligned} a &= -0.110 + 0.235\cos\phi + 0.323(S/S_o) \\ b &= 1.449 - 0.553\cos\phi - 0.694(S/S_o) \end{aligned} \qquad (3)$$

The extraterrestrial solar radiation on a horizontal surface can be calculated from the following equation [10]:

$$H_o = \frac{24x3600}{\pi} I_{sc}\left[1 + 0.033\cos\left(360\frac{dn}{365}\right)\right]\left[\left(\frac{2\pi\omega_s}{360}\right)\sin\phi\sin\delta + \cos\phi\cos\delta\sin\omega_s\right] \qquad (4)$$

The value of $1367Wm^{-2}$ has been recommended for solar constant I_{sc} [12].
The hour angle ω_s for horizontal surface is given as [10]:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \qquad (5)$$

Declination is calculated as [13]:

$$\delta = 23.45\sin\left(360\frac{284 + dn}{365}\right) \qquad (6)$$

Where *dn* is the day of the year from January 1 to December 31.

The day length S_o is the number of hours of sunshine or darkness within the 24 hours in a given day. For a horizontal surface it is given by [10]:

$$S_o = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) = \frac{2}{15}\omega_s \qquad (7)$$

(from equation (5)).

MATERIALS AND MEASUREMENT PROCEDURES

Yola is the capital city and administrative center of Adamawa State, Nigeria. Situated latitude 9^0 12'N and longitude$12^0$29'E on the Benue River is geographically favorably located to tap unlimited solar energy, the most dependable renewable energy source.

In this work the daily sunshine hour data were collected for a period of four years (from 2004 – 2007) from the meteorological station of Geography Department at Federal University of Technology, Yola with the aid of a sunshine recorder. The monthly average values were determined for the period the measurements were taken. The monthly mean values of sunshine duration were also determined for the period the measurements were taken. The relevant meteorological and solar radiation data like $\overline{H}$, $\overline{H}_0$, $\bar{S}$, $\bar{S}_0$, ω, a and b calculated from equation (1) to (7) are presented for the whole periods as shown in Tables 1 to 5. Graph of $\overline{H}$ against month and $\bar{S}$ is displayed in Figure 1. In addition, graph of $\overline{H}$ against year is shown in Figure 2.

From Table 5 as well as Figure 2, it is observed that the monthly global solar radiation are not uniform throughout. The peak of radiation being the month of March, April, May and June with 24.38 $MJm^{-2}day^{-1}$, 24.92 $MJm^{-2}day^{-1}$, 24.54 $MJm^{-2}day^{-1}$ and 23.13 $MJm^{-2}day^{-1}$ respectively.

On the other hand, least value of global solar radiation was recorded in January with 16.86 $MJm^{-2}day^{-1}$. This could be explained in terms of peak of could harmattan season. The month of August and September with 20.31 $MJm^{-2}day^{-1}$ and 20.77 $MJm^{-2}day^{-1}$ also has low values of solar radiations; this is also as a result of the peak period of the cloud cover in Yola.

In general, higher value of solar radiation is obtained in dry season than wet season. The value of global solar radiation for yola town over the period of measurement is estimated to be 21.54±0.46 $MJm^{-2}day^{-1}$ using Angstrom equation.

Table 1: Monthly Mean Values of Daily Solar Radiation and the Require Meteorological Parameters for Yola in the Year 2004.

Month	ω (deg.)	$\bar{S}$ (hr)	$\bar{S}_0$(hr)	$\bar{S}/\bar{S}_0$	a	b	$\overline{H}_0$ ($MJm^{-2}day^{-1}$)	$\overline{H}$ ($MJm^{-2}day^{-1}$)
Jan	86.42	3.50	11.52	0.30	0.21	0.72	32.28	13.75
Fed	87.75	6.20	11.70	0.53	0.29	0.54	34.67	19.98
Mar	89.54	10.00	11.94	0.84	0.40	0.31	36.95	24.40
Apr	91.54	10.10	12.21	0.83	0.39	0.33	37.87	25.14
May	93.20	9.15	12.43	0.74	0.35	0.41	37.33	24.39
Jun	94.00	8.00	12.53	0.64	0.31	0.50	36.70	23.12
Jul	93.66	8.30	12.49	0.66	0.32	0.48	36.83	23.45
Aug	92.22	8.10	12.30	0.66	0.33	0.45	37.42	23.46
Sep	90.36	6.00	12.05	0.50	0.29	0.55	37.11	20.97
Oct	88.43	10.00	11.79	0.85	0.40	0.31	35.31	23.42
Nov	86.78	10.00	11.57	0.86	0.39	0.33	32.75	22.07
Dec	85.99	9.00	11.47	0.78	0.36	0.40	31.38	21.09

Table 2: Monthly Mean Values of Daily Solar Radiation and the Require Meteorological Parameters for Yola in the Year 2005.

Month	ω (deg.)	$\bar{S}$ (hr)	$\bar{S}_0$(hr)	$\bar{S}/\bar{S}_0$	a	b	$\bar{H}_0$ (MJm^{-2}day^{-1})	$\bar{H}$ (MJm^{-2}day^{-1})
Jan	86.42	5.40	11.52	0.47	0.26	0.61	32.28	17.65
Fed	87.75	8.30	11.70	0.71	0.35	0.42	34.67	22.47
Mar	89.54	10.20	11.94	0.85	0.40	0.31	36.95	24.52
Apr	91.54	9.70	12.21	0.79	0.38	0.36	37.87	25..16
May	93.20	10.00	12.43	0.80	0.37	0.37	37.33	24.86
Jun	94.00	7.50	12.53	0.56	0.29	0.55	36.70	21.95
Jul	93.66	8.00	12.49	0.64	0.32	0.49	36.86	23.34
Aug	92.22	6.50	12.30	0.53	0.29	0.54	37.42	21.56
Sep	90.36	4.80	12.05	0.40	0.25	0.62	37.11	18.48
Oct	88.43	7.60	11.79	0.64	0.33	0.46	35.31	22.05
Nov	86.78	10.10	11.57	0.87	0.39	0.32	32.75	21.89
Dec	85.99	11.00	11.47	0.96	0.42	0.28	31.38	21.61

Table 3: Monthly Mean Values of Daily Solar Radiation and the Require Meteorological Parameters for Yola in the Year 2006.

Month	ω (deg.)	$\bar{S}$ (hr)	$\bar{S}_0$ (hr)	$\bar{S}$ $\bar{S}_0$	a	b	$\bar{H}_0$(MJm^{-2}day^{-1})	$\bar{H}$ (MJm^{-2}day^{-1})
Jan	86.42	4.60	11.52	0.40	0.24	0.66	32.28	16.27
Fed	87.75	7.40	11.70	0.63	0.32	0.47	34.67	21.36
Mar	89.54	9.50	11.94	0.80	0.38	0.34	36.95	24.09
Apr	91.54	8.60	12.21	0.70	0.35	0.42	37.87	24.39
May	93.20	10.10	12.43	0.81	0.37	0.36	37.33	24.70
Jun	94.00	8.20	12.53	0.65	0.32	0.49	36.70	23.43
Jul	93.66	7.80	12.49	0.62	0.31	0.50	36.83	22.83
Aug	92.22	4.70	12.30	0.38	0.24	0.65	37.42	18.22
Sep	90.36	5.90	12.05	0.49	0.28	0.56	37.11	20.57
Oct	88.43	8.80	11.59	0.75	0.36	0.38	35.31	22.77
Nov	86.78	10.10	11.57	0.87	0.39	0.32	32.75	21.89
Dec	85.99	9.84	11.47	0.86	0.38	0.34	31.38	21.10

Table 4: Monthly Mean Values of Daily Solar Radiation and the Require Meteorological Parameters for Yola in the Year 2007.

Month	ω (deg.)	$\bar{S}$ (hr)	$\bar{S}_0$(hr)	$\bar{S}$ /$\bar{S}_0$	a	b	$\bar{H}_0$(MJm^{-2}day^{-1})	$\bar{H}$ (MJm^{-2}day^{-1})
Jan	86.75	6.90	11.52	0.60	0.30	0.52	32.28	19.76
Fed	87.75	8.00	11.70	0.68	0.34	0.44	34.67	22.16
Mar	89.54	10.10	11.94	0.85	0.40	0.31	36.95	24.52
Apr	91.54	9.82	12.21	0.80	0.38	0.35	37.87	24.99
May	93.20	8.76	12.43	0.70	0.34	0.44	37.33	24.19
Jun	94.00	9.20	12.53	0.73	0.34	0.43	36.70	24.00
Jul	93.20	5.93	12.49	0.47	0.26	0.61	36.83	20.13
Aug	92.66	4.50	12.30	0.37	0.24	0.65	37.42	17.98
Sep	90.36	7.45	12.05	0.62	0.33	0.47	37.11	23.06
Oct	88.43	6.98	11.79	0.59	0.31	0.49	35.31	21.15
Nov	86.78	10.00	11.57	0.86	0.39	0.33	32.75	22.07
Dec	85.99	10.40	11.47	0.91	0.40	0.31	31.38	21.40

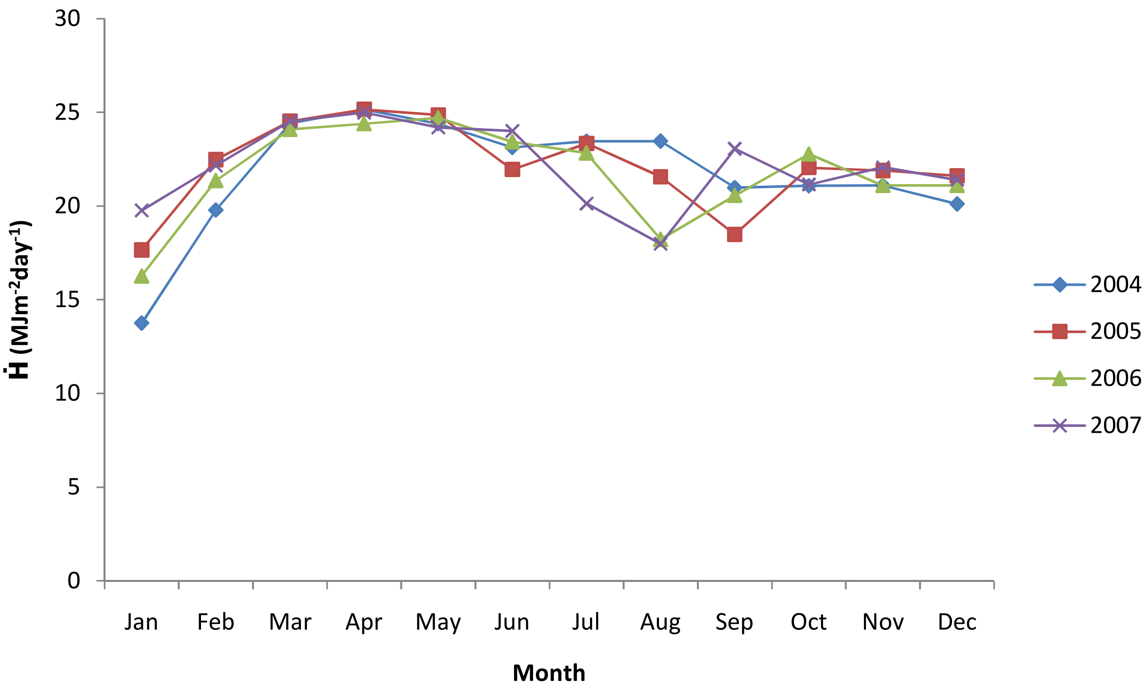

Figure 1: The Graph of Monthly Mean Global Solar Radiation for 2004, 2005, 2006 and 2007 against Months.

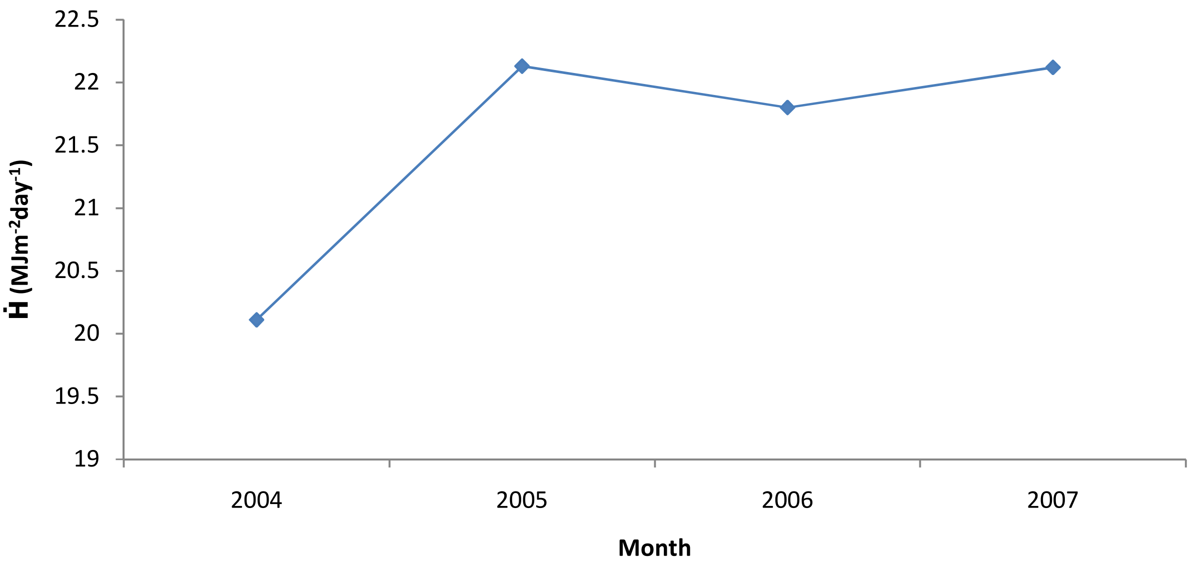

Figure 2: The Graph of Annually Mean Global Solar Radiation against Year for Yola from 2004 to 2007

Table 5: Annually Mean Global Solar Radiation and other Meteorological Parameters for Yola from 2004 to 2007

Year	$\bar{S}$ (hr)	$\bar{S}_0$ (hr)	$\bar{S}/\bar{S}_0$	a	b	$\bar{H}_0$ ($MJm^{-2}day^{-1}$)	$\bar{H}$ ($MJm^{-2}day^{-1}$)
2004	8.20	12.00	0.68	0.34	0.44	35.55	20.11
2005	8.26	12.00	0.69	0.34	0.44	35.55	22.13
2006	7.96	12.00	0.66	0.33	0.46	35.55	21.80
2007	8.17	12.00	0.68	0.34	0.45	35.55	22.12
Mean	8.15	12.00	0.68	0.34	0.45	35.55	21.54

CONCLUSION

Energy is a continuous steering power for the social and technological prospective development. Renewable energy is consider as the key source for the future as it is the vital and essential ingredients for all human transactions and without them human activities of all kind will not be progressive at all.

The result of this work, clearly indicate the primary importance of developing empirical approaches for formulating the global solar radiation on horizontal surface reaching the earth at different climatologically condition in Yola – Nigeria. Equations 1 – 7 are used with high accuracy to estimate the global solar radiation on horizontal surface at Yola using common meteorological parameter.

From the above results and considerations, the maximum values of global solar radiation appears in March, April and May with 24.38 $MJm^{-2}day^{-1}$, 24.92 $MJm^{-2}day^{-1}$ and 24.54 $MJm^{-2}day^{-1}$, respectively during dry season while minimum values of 20.31$MJm^{-2}day^{-1}$ and 20.77 $MJm^{-2}day^{-1}$ were observed in August and September, respectively during wet season.

It can now be concluded that the mean global solar radiation for the period is 21.54±0.46 $MJm^{-2}day^{-1}$.

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