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ESTIMATION OF GLOBAL SOLAR RADIATION IN MAIDUGURI, NIGERIA USING ANGSTROM MODEL

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ABSTRACT

In this study, the daily sunshine duration is used to estimate average global solar radiation for Maiduguri, Nigeria. The daily sunshine hour were measured for five years (2004 to 2007) from which the monthly mean values were determined. Angstrom model was then used to estimate the global solar radiation based on the monthly mean sunshine hour. The values of solar radiation for Maiduguri town vary from the range of $16.80403 MJm^{-2}day^{-1}$ to $25.03763\ MJm^{-2}day^{-1}$ under the period of study with the mean value of$23.20437 MJm^{-2}day^{-1}$. This value can be utilized in the design and performance estimation of solar energy systems, which is gaining significant attention in Nigeria in particular and the world at large.

Keywords: solar radiation, angstrom model, sunshine hours.

1. INTRODUCTION

Solar energy occupies one of the most important places among the various possible alternative energy sources. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. Unfortunately, for many developing countries solar radiation measurements are not easily available due to the shortage of measurement equipments. It is therefore important to consider methods of estimating the solar radiation based on the readily available meteorological parameters.

Over the years, many models have been proposed to predict the amount of solar radiation in some cities in Nigeria using various metrological data [1-6].

In this work, the Angstroms model is used to estimate the global solar radiation at Maiduguri, Borno state, Nigeria based on the available climatic parameters of sunshine hour.

2. METHOD OF COMPUTATION

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. The Angstrom formula is given by [3]:

$$\frac{\bar{H}}{\bar{H}_O} = a + b\frac{\bar{S}}{\bar{S}_O} \quad (1)$$

where $\bar{H}\ (MJm^{-2}day^{-1})$ is the monthly mean daily global solar radiation on a horizontal surface, $\bar{S}(Hours)$ is the monthly mean daily bright sunshine hours, $\bar{S}_O(Hours)$is the maximum possible monthly mean daily sunshine hours, $\bar{H}_O(MJm^{-2}day^{-1})$ is the monthly mean extraterrestrial solar radiation on horizontal surface and *a* and *b* are regression constants given by the equations [3]

$$a = -0.110 + 0.235cosL + 0.323\left(\frac{\bar{S}}{\bar{S}_O}\right) \quad (2)$$

$$b = 1.449 - 0.553cosL - 0.694\left(\frac{\bar{S}}{\bar{S}_O}\right) \quad (3)$$

The monthly mean daily extraterrestrial irradiation $\bar{H}_O$ and monthly mean day length $\bar{S}_O$ can be derived from the following formulae:

$$H_O = \frac{24\times3600}{\pi} I_{SC}\left[1 + 0.033cos\left(360\frac{n}{365}\right)\right]\left[sinLsin\delta\left(\frac{2\pi\omega_s}{360}\right) + cosLcos\delta sin\,\omega_s\right] \quad (4)$$

$$\bar{S}_O = \frac{2}{15}cos^{-1}(-tanL\ tan\delta) \quad (5)$$

Where δ is the solar angle of declination and is approximately given as: $\delta = 23.45sin\left(360\frac{284+n}{365}\right)$ (6)

Where *n* is the day of the year from January 1 to December 31. The value $1367 Wm^{-2}$ has been recommended for the solar constant I_{SC} [7].

3. RESULTS AND ANALYSIS

The monthly mean daily data for sunshine hours were obtained from the Nigerian Meteorological Services, Maiduguri, Borno state, Nigeria. The data obtained covered a period of five years (2006 - 2010) for Maiduguri, Nigeria located on latitude 11.8464^oN and longitude13.1603^oE. The relevant meteorological and solar radiation data calculated using equations (1) to (6) presented for the whole period are shown in Tables 1 to 6.

Table-1. Monthly mean values of daily solar radiation and the required meteorological parameters for Maiduguri in the year 2006.

Year 2006							
Month	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***a***	***b***	$\bar{H}_o$	$\bar{H}$
JAN	9.0	12.01623	0.748987	0.361923	0.387969	37.61314	24.54282
FEB	9.0	11.95803	0.752632	0.3631	0.385439	37.6165	24.57088
MAR	9.0	12.02109	0.748684	0.361825	0.388179	37.61136	24.53948
APR	9.0	12.03572	0.747774	0.361531	0.388811	37.61686	24.53649
MAY	7.4	11.99821	0.616759	0.319213	0.479736	37.61538	23.1370
JUN	7.0	11.9686	0.584864	0.308911	0.501871	37.61352	22.65977
JUL	7.0	12.00553	0.583065	0.30833	0.503119	37.61504	22.63225
AUG	7.0	12.01968	0.582378	0.308108	0.503596	37.61287	22.62005
SEP	7.0	12.03817	0.581484	0.307819	0.504216	37.61773	22.60874
OCT	7.0	12.00006	0.58333	0.308416	0.502935	37.61211	22.6347
NOV	7.0	11.96796	0.584895	0.308921	0.501849	37.61786	22.66288
DEC	7.0	12.00358	0.583159	0.30836	0.503054	37.61042	22.63097

Table-2. Monthly mean values of daily solar radiation and the required meteorological parameters for Maiduguri in the year 2007.

Year 2007							
Month	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***A***	***b***	$\bar{H}_o$	$\bar{H}$
JAN	9.0	12.01623	0.748987	0.361923	0.387969	37.61314	24.54282
FEB	9.0	11.95803	0.752632	0.3631	0.385439	37.6165	24.57088
MAR	9.0	12.02109	0.748684	0.361825	0.388179	37.61136	24.53948
APR	9.0	12.03572	0.747774	0.361531	0.388811	37.61686	24.53649
MAY	7.4	11.99821	0.616759	0.319213	0.479736	37.61538	23.137
JUN	7.0	11.9686	0.584864	0.308911	0.501871	37.61352	22.65977
JUL	7.0	12.00553	0.583065	0.30833	0.503119	37.61504	22.63225
AUG	7.0	12.01968	0.582378	0.308108	0.503596	37.61287	22.62005
SEP	7.0	12.03817	0.581484	0.307819	0.504216	37.61773	22.60874
OCT	7.0	12.00006	0.58333	0.308416	0.502935	37.61211	22.6347
NOV	7.0	11.96796	0.584895	0.308921	0.501849	37.61786	22.66288
DEC	8.5	12.00358	0.708122	0.348723	0.416329	37.61042	24.20364

Table-3. Monthly mean Values of daily solar radiation and the required meteorological parameters for Maiduguri in the year 2008.

Year 2008							
Month	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***a***	***b***	$\bar{H}_o$	$\bar{H}$
JAN	9.7	12.01623	0.807242	0.380739	0.347541	37.61314	24.87312
FEB	9.2	11.95959	0.769257	0.36847	0.373902	37.61545	24.67937
MAR	9.4	12.00484	0.783018	0.372915	0.364352	37.61217	24.75665
APR	7.8	12.04259	0.647701	0.329207	0.458262	37.61677	23.549
MAY	7.4	12.01561	0.615866	0.318924	0.480356	37.61526	23.12431
JUN	7.8	11.97901	0.651139	0.330318	0.455876	37.61277	23.58908
JUL	7.6	11.98992	0.633866	0.324739	0.467863	37.61669	23.37129
AUG	5.6	12.0029	0.466554	0.270697	0.583978	37.61259	20.42943
SEP	6.8	12.04111	0.564732	0.302408	0.515842	37.61839	22.33483
OCT	8.9	12.01733	0.740597	0.359213	0.393792	37.61189	24.47984
NOV	10.5	11.98208	0.876309	0.403048	0.299608	37.61682	25.03763
DEC	9.5	11.5971	0.81917	0.384592	0.339262	36.39732	24.11342

Table-4. Monthly mean values of daily solar radiation and the required meteorological parameters for Maiduguri in the year 2009.

Year 2009							
Month	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***a***	***b***	$\bar{H}_o$	$\bar{H}$
JAN	9.3	12.01623	0.773953	0.369987	0.370643	37.61314	24.70607
FEB	8.7	11.95803	0.727545	0.354997	0.40285	37.6165	24.37881
MAR	8.5	12.02109	0.707091	0.34839	0.417045	37.61136	24.1946
APR	7.8	12.03572	0.648071	0.329327	0.458005	37.61686	23.55367
MAY	6.8	11.99821	0.566751	0.303061	0.514441	37.61538	22.36688
JUN	6.5	11.9686	0.543088	0.295417	0.530863	37.61352	21.95586
JUL	7.4	12.00553	0.616383	0.319091	0.479997	37.61504	23.13148
AUG	6.8	12.01968	0.565739	0.302734	0.515143	37.61287	22.34845
SEP	8.3	12.03817	0.689474	0.3427	0.429272	37.61773	24.02536
OCT	8.3	12.00006	0.691663	0.343407	0.427752	37.61211	24.0442
NOV	8.3	11.96796	0.693518	0.344006	0.426464	37.61786	24.06667
DEC	4.9	12.00358	0.408212	0.251852	0.624467	37.61042	19.05972

Table-5. Monthly mean values of daily solar radiation and the required meteorological parameters for Maiduguri in the Year 2009.

Year 2010							
Month	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***a***	***b***	$\bar{H}_o$	$\bar{H}$
JAN	9.5	12.01623	0.790597	0.375363	0.359092	37.61314	24.79683
FEB	8.9	11.95803	0.74427	0.360399	0.391243	37.6165	24.51051
MAR	8.9	12.02109	0.740365	0.359138	0.393953	37.61136	24.47773
APR	7.2	12.03572	0.598219	0.313225	0.492602	37.61686	22.86762
MAY	3.9	11.99821	0.325048	0.224991	0.682183	37.61538	16.80403
JUN	6.4	11.9686	0.534733	0.292719	0.536662	37.61352	21.80415
JUL	5.0	12.00553	0.416475	0.254521	0.618733	37.61504	19.26672
AUG	5.0	12.01968	0.415984	0.254363	0.619073	37.61287	19.25356
SEP	5.0	12.03817	0.415346	0.254157	0.619516	37.61773	19.24034
OCT	5.0	12.00006	0.416665	0.254583	0.618601	37.61211	19.26988
NOV	5.0	11.96796	0.417782	0.254944	0.617825	37.61786	19.30022
DEC	5.0	12.00358	0.416542	0.254543	0.618686	37.61042	19.26601

Table-6. Annually mean global solar radiation and other meteorological parameters for Maiduguri from 2006 to 2010.

Annually							
Year	$\bar{S}$	$\bar{S}_o$	$\bar{S}/\bar{S}_o$	***a***	***b***	$\bar{H}_o$	$\bar{H}$
2006	7.700	12.00274	0.64152	0.327211	0.462551	37.6144	23.46939
2007	7.825	12.00274	0.651935	0.330575	0.455324	37.6144	23.59987
2008	8.350	11.97069	0.697537	0.345304	0.423676	37.51327	24.03977
2009	7.633	12.00274	0.635966	0.325417	0.466406	37.6144	23.39748
2010	6.233	12.00274	0.519326	0.287742	0.547354	37.6144	21.51533

Graph of the mean monthly global solar radiation $\bar{H}\ (MJm^{-2}day^{-1})$against month, annual mean global solar radiation against year and the monthly mean sunshine hours $\bar{S}(hr)$ against month are displayed in Figures 1, 2 and 3, respectively

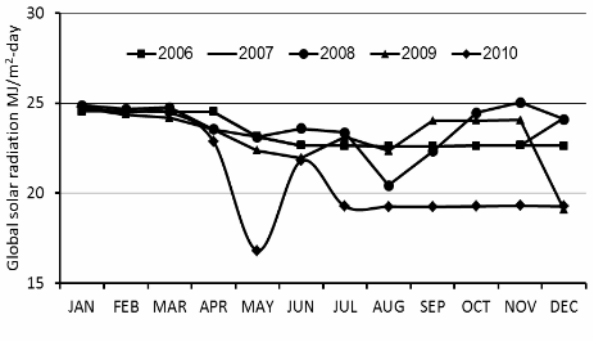

Figure-1. Monthly mean global solar radiation for 2006, 2007, 2008, 2009 and 2010.

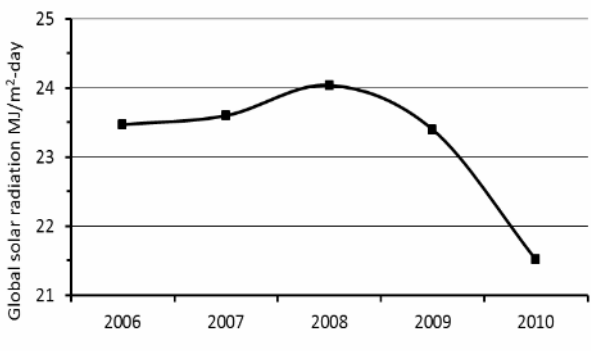

Figure-2. Annually mean global solar radiation against year for Maiduguri from 2006 to 2010.

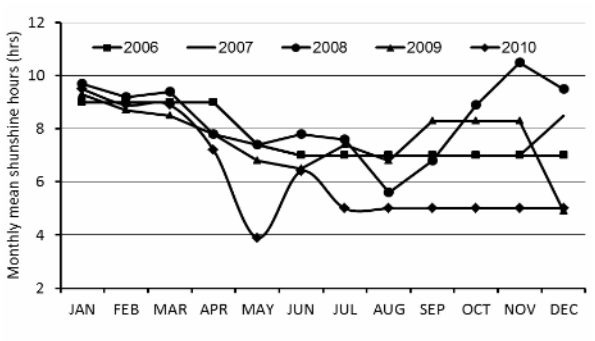

Figure-3. Monthly mean sunshine hours against month for Maiduguri from 2006 to 2010.

From Table-6 as well as Figure-2, it is observed that the monthly global solar radiation is not uniform throughout the period of study. Peak radiation is observed in the months of February, March and April with values of 24.54209 $Mjm^{-2}day^{-1}$, 24.57340 $Mjm^{-2}day^{-1}$and 24.05078$Mjm^{-2}day^{-1}$, respectively.

On the other hand, the months of June, July and August recorded least amount of solar radiation average values of 21.80415 $Mjm^{-2}day^{-1}$, 19.26672 $Mjm^{-2}day^{-1}$ and 19.25356 $Mjm^{-2}day^{-1}$, respectively. This is as a result of the peak period of the cloud cover in Maiduguri due to the rainy season. In general, higher value of solar radiation is obtained in dry season than wet season. The value of global solar radiation for Maiduguri town over the period of study is estimated to be 23.20437 $Mjm^{-2}day^{-1}$ using the Angstrom model.

4. CONCLUSIONS

The results of this research clearly indicate the main significance of developing empirical models for estimating global radiation on horizontal surfaces reaching the earth for a particular geographical location. The Angstrom model can also be applied to other cities to predict global solar radiation. The global solar radiation intensity predicted in this research can be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria in particular and the world at large.

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