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Research Article

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Evaluation of Global Solar Radiation for Mubi, Adamawa State, Nigeria

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Abstract For many developing countries solar radiation measurements are only available for selected stations due to the cost of the measurement equipment and the techniques involved. In this paper Angstrom-Prescott model was used to estimate the global solar radiation based on the monthly mean sunshine hour for Mubi town, Adamawa State. The daily sunshine hour were measured for five years (2009 to 2013) from which the monthly mean values were determined. The values of solar radiation for Mubi town vary from the range of 24.286 ($MJm^{-2}day^{-1}$) to 17.541 ($MJm^{-2}day^{-1}$). Under the period of study, the mean value of 19.974 ($MJm^{-2}day^{-1}$) was obtained. Results suggest that the model can be used for any location in the Northern hemisphere and can be utilized in the design and performance estimation of solar energy systems, which is gaining significant attention in Nigerian particular and the world at large.

Keywords Solar radiation, Angstrom-Prescott model, Sunshine hours, Northern hemisphere, performance estimation.

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 equipment's [1]. In spite of the importance of global solar radiation data, its measurements are not frequently available especially in developing countries [2]. It is therefore important to consider methods of estimating the solar radiation based on the readily available meteorological parameters.

It was observed that the meteorological stations measuring solar radiation data in the developing countries are few [4]. This situation can be solved by using empirical models, which estimate global solar radiation based on the relationships with frequently measured climatic variables.

Angstrom was the first scientist known to suggest a simple linear relationship to estimate global solar radiation [5], later on modified by Prescott [6]. After many studies have been used in estimating incoming solar radiation in Nigeria [4, 7].

In this paper, the Angstroms model is used to estimate the global solar radiation in Mubi, Adamawa State, Nigeria based on the available climatic parameters of sunshine hours, the computed values of the extraterrestrial solar radiation and maximum day light duration.

Mubiis chosen because it has a tropical climate. It is located on latitude 10.26° N and longitude 13.26° E. It has significant rainfall throughout the year. Even the driest month still has a lot of rainfall. Its climate is classified by the Köppen-Geiger system. The average annual temperature is 23.9 °C. In a year, the average rainfall is 1629 mm. The least amount of rainfall occurs in July. The average in this month is 77 mm. Most precipitation falls in November, with an average of 179 mm. The temperatures are highest on average in April, at around 24.4 °C. In July, the average temperature is 23.2 °C. It is the lowest average temperature of the whole year.

Materials and Method

In this work, monthly mean daily data for sunshine hours were obtained for a period of five years (2009 – 2013) from Department of Geography metrological unit situated in Adamawa State University.

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 [8]:

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{S}}{\bar{S}_0} \tag{1}$$

Where $\bar{H}$ is the monthly average global solar radiation (MJm^{-2}day^{-1}), $\bar{S}$ is the monthly average daily bright sunshine hour, $\bar{S}_0$is the maximum possible monthly average daily sunshine hour or the day length, and b are coefficients of Angstrom formula.

Different models use different approaches for estimating the coefficient a and b [9, 10].

$$a = -0.110 + 0.235\cos\theta + 0.323\frac{\bar{S}}{\bar{S}_0} \tag{2}$$

$$\text{b} = 1.449 - 0.553\cos\theta - 0.694\frac{\bar{S}}{\bar{S}_0} \tag{3}$$

$\bar{H}_o$, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_0 = \frac{24\times 360}{\pi} I_{Sc}\left[1 + 0.033\cos\left(360\frac{284+\bar{D}}{365}\right)\right]\left[\left(\frac{2\pi\omega_s}{360}\right)\sin\theta\sin\delta + \cos\delta\sin\omega_s\right] \tag{4}$$

Where $\bar{D}$ is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, $\emptyset$ is the latitude of the location, $\delta$is the declination angle given as:

$$\delta = 23.45\sin\left(360\frac{284+\bar{D}}{365}\right) \tag{5}$$

And ω is the sunset hour angle as

$$\omega_s = \cos^{-1}(-\tan\theta\tan\delta) \tag{6}$$

The maximum possible sunshine duration $\bar{S}_0$is given by

$$\bar{S}_0 = \left(\frac{2}{15}\right)\omega_s \tag{7}$$

In this paper a and b were computed for each month using Equations (2) and (3), respectively. Also the values of $\bar{H}_o$ and $\bar{S}_0$were computed for each month by using Equation (4) and (7), respectively, $\bar{H}$was also obtained using equation (1).

Results and Discussion

The relevant metrological and solar radiation data were calculated using equations (1) to (7) presented for the whole period are shown in Tables 1 to 6.

Graphs 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 and 2 respectively.

Table 1: Monthly mean values of daily solar radiation and the required meteorological parameters for Mubi Town in the year 2009

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
JAN	6.30	12.55	0.501	0.283	0.546	39.441	22.894
FEB	5.94	7.01	0.847	0.394	0.306	28.437	22.964
MAR	6.75	13.55	0.929	0.292	0.527	39.948	23.644
APR	5.78	12.54	0.460	0.269	0.575	33.844	22.053
MAY	6.11	12.55	0.486	0.278	0.557	39.346	22.585
JUN	4.61	12.54	0.367	0.239	0.639	33.853	19.028
JUL	5.06	12.55	0.403	0.251	0.614	39.344	19.608
AUG	4.58	12.55	0.364	0.238	0.641	37.340	17.541

SEP	6.52	12.54	0.519	0.288	0.534	33.842	19.124
OCT	6.60	12.55	0.525	0.290	0.530	39.868	20.639
NOV	5.59	12.54	0.525	0.290	0.530	33.841	19.229
DEC	5.69	12.55	0.533	0.293	0.524	39.373	19.801

Table 2: Monthly mean values of daily solar radiation and the required meteorological parameters for Mubi North in the year 2010

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
JAN	7.21	12.55	0.574	0.306	0.496	39.341	22.238
FEB	7.10	7.01	1.155	0.494	0.930	27.237	22.848
MAR	9.82	13.55	0.582	0.322	0.462	39.740	23.990
APR	7.32	12.54	0.583	0.312	0.489	33.621	22.806
MAY	8.04	12.55	0.640	0.334	0.450	39.740	21.806
JUN	6.06	12.54	0.480	0.273	0.373	33.880	21.449
JUL	5.73	12.55	0.456	0.262	0.344	39.346	18.338
AUG	6.01	12.55	0.478	0.271	0.363	36.241	17.487
SEP	5.94	12.54	0.473	0.273	0.350	33.864	18.320
OCT	7.59	12.55	0.604	0.316	0.475	39.670	19.019
NOV	7.27	12.54	0.579	0.308	0.492	33.742	20.019
DEC	5.21	12.55	0.494	0.280	0.342	39.546	19.661

Table 3: Monthly mean values of daily solar radiation and the required meteorological parameters for Mubi Town in the year 2011

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
JAN	6.33	12.55	0.504	0.238	0.544	39.621	20.149
FEB	5.876	7.01	0.837	0.392	0.313	28.634	22.158
MAR	7.93	13.55	0.585	0.299	0.611	39.549	23.859
APR	4.94	12.54	0.318	0.229	0.673	33.245	22.991
MAY	5.96	12.55	0.474	0.274	0.565	39.461	21.314
JUN	5.93	12.54	0.472	0.273	0.439	33.950	19.255
JUL	5.35	12.55	0.426	0.258	0.598	39.366	19.171
AUG	5.89	12.55	0.469	0.272	0.569	39.356	17.998
SEP	5.98	12.54	0.476	0.274	0.564	33.561	18.356
OCT	4.50	12.55	0.358	0.236	0.646	39.347	18.380
NOV	5.04	12.54	0.401	0.250	0.616	33.849	19.720
DEC	4.67	12.55	0.372	0.121	0.639	39.318	19.067

Table 4: Monthly mean values of daily solar radiation and the required meteorological parameters for Mubi Town in the year 2012

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
JAN	5.78	12.55	0.460	0.269	0.575	39.341	20.988
FEB	5.62	7.01	0.801	0.379	0.338	27.237	22.047
MAR	6.75	13.55	0.597	0.269	0.56	39.940	23.672
APR	4.41	12.54	0.351	0.234	0.650	33.840	20.539
MAY	4.68	12.55	0.372	0.241	0.636	39.340	19.788
JUN	5.11	12.54	0.407	0.252	0.612	33.850	18.961
JUL	4.74	12.55	0.377	0.242	0.632	39.140	18.893
AUG	4.79	12.55	0.381	0.244	0.630	39.230	17.040
SEP	4.71	12.54	0.375	0.242	0.634	33.840	19.234
OCT	5.25	12.55	0.418	0.256	0.604	39.120	19.603
NOV	5.52	12.54	0.440	0.263	0.589	33.840	18.978
DEC	5.09	12.55	0.405	0.252	0.613	39.132	19.680

Table 5: Monthly mean values of daily solar radiation and the required meteorological parameters for Mubi Town in the year 2013

Month	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
JAN	5.69	12.55	0.453	0.267	0.580	39.344	20.840
FEB	5.11	7.01	0.728	0.356	0.282	28.237	21.626
MAR	6.83	13.56	0.504	0.361	0.662	39.366	24.286
APR	4.95	12.54	0.394	0.248	0.621	33.810	23.572

MAY	6.15	12.55	0.490	0.279	0.554	38.548	20.555
JUN	5.39	12.54	0.429	0.259	0.596	33.850	19.422
JUL	4.74	12.55	0.377	0.242	0.532	38.539	19.262
AUG	4.84	12.55	0.385	0.245	0.427	36.412	18.310
SEP	4.95	12.54	0.394	0.248	0.521	33.946	18.338
OCT	5.11	12.55	0.407	0.252	0.512	39.735	19.349
NOV	5.33	12.54	0.425	0.258	0.599	33.549	19.441
DEC	4.23	12.55	0.337	0.230	0.550	39.348	19.839

Table 6: Annually mean global solar radiation and other meteorological parameters for Mubi Town from 2009 to 2013

Year	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
2009	5.952500	12.075	0.504917	0.283750	0.543583	36.45733	20.0910
2010	6.941667	12.095	0.594917	0.312583	0.463833	36.45733	20.3930
2011	5.616333	12.285	0.471583	0.259667	0.556417	36.45817	19.9515
2012	5.120833	12.075	0.437083	0.261917	0.589417	36.41567	19.7102
2013	5.193333	12.085	0.440250	0.270417	0.536333	36.45733	20.0275

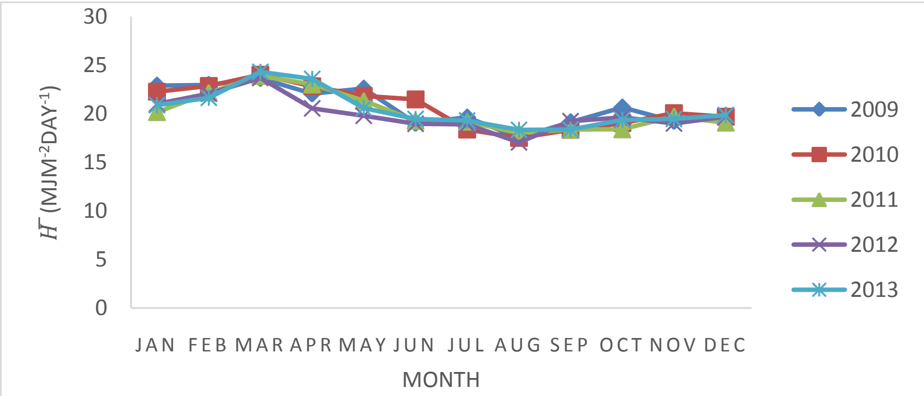
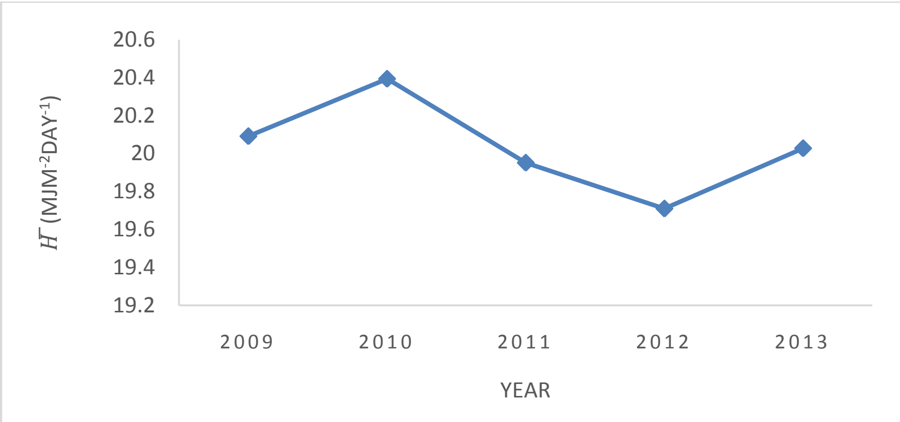


Figure 1: The graphy of Monthly Mean Global Solar Radiation for 2009, 2010, 2011, 2012 and 2013 against Months



Figures 2: Annually mean global solar radiation against year for Mubi Town from 2009-2013

From Table 1-6 as well as Figure 1-2, 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 January, February, March and April with values of 20.988JM^{-2}day^{-1}, 22.964, JM^{-2}day^{-1}, 24.286JM^{-2}day^{-1} and 23.72JM^{-2}day^{-1}

On the other hand, the months of June, July, August and September recorded least amount of solar radiation average values of 19.225JM^{-2}day^{-1}, 18.893JM^{-2}day^{-1}, 17.541JM^{-2}day^{-1} and 19.349JM^{-2}day^{-1} respectively.

This is as a result of the peak period of the cloud cover in Mubi 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 Mubi town over the period of study is estimated to be 20.03464 ($MJm^{-2}day^{-1}$) using the Angstrom model.

Conclusion

In the absence and scarcity of trust worthy solar radiation data, the need for empirical model to predict and estimate solar radiation seems inevitable. In this paper, the results clearly indicates the significance of using empirical models for estimating global radiation on horizontal surfaces reaching the earth for a particular geographical location. The Angstrom model used in this study can also be applied to other cities to predict global solar radiation. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria and Mubi North in particular and the world at large.

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