FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 April Special Issue, 2025, pp 280 - 283
DOI: https://doi.org/10.33003/fjs-2025-09(AHBSI)-3410

EVALUATING SOLAR RADIATION POTENTIAL OF NORTH EAST USING ANGSTROM-PRESCOTT MODEL

***[1,2]Ladan, H. M. A, [1,2]Ukasha, A., [3]Buba, A. D. A. and [3]Adelabu, J. S. A.**

[1]Department of Physics, Faculty of Science, Sa'adu Zungur University, Gadau, Nigeria
[2]CEMS Group, SAZU Bauchi State, Nigeria
[3]Department of Physics, Faculty of Science, University of Abuja, Abuja,

*Corresponding authors' email: Ladan@basug.edu.ng; Ladansons@gmail.com
ORCID iD: http://orcid.org/0000-0001-8535-7911

ABSTRACT

In this study, the model for estimating solar energy radiation potential in the north eastern Nigeria using Bauchi (Lat. 10º 18' 48N; Lon 90 50' 36E) as a case study was examined. The data on monthly average temperature, relative humidity, sunshine hours, atmospheric precipitation, hour angle, solar declination, and extra-terrestrial solar radiation were collected and analysed using Angstrom-Prescott model (APM):

$$\frac{H_0}{H} = 1.88 + 0.10\,\frac{S}{S_0} + 0.38\left(\frac{S}{S_0}\right)^2 + 0.112\,CC^2 - 0.125\,(T_{av}) + 0.00193(T_{av})^2$$

The metrological parameters were obtained from Bauchi airport between 2001 and 2010 (10 years). It was observed that the regression equation gives the highest values of R^2 and least values of MBE, RMSE and MPE and provided the best estimate for the monthly mean average temperature, cloud cover (clearness index), and sunshine duration. It indicated a good agreement between the measured and estimated values for Bauchi state. Regression constants a_0, a_1 and R^2 as 1.88, 0.00193 and 80.30 respectively for 2001-2010. The quantity of solar radiation in the study area is useful to engineers, hydrologists, architects and agriculturists in planning and executing projects.

Keywords: Solar Radiation Models, North east, Angstrom-Prescott, MBE, MPE, RMSE

INTRODUCTION

Nigeria with ~200 million people in tropical region has abundant solar energy potential and if properly harnessed can tackle the energy challenge due to overdependence on depleting fossil fuels. Energy from fossil and atomic fuels will be used up with time and contributes to environmental pollution. Solar energy is cheap, clean and available compared with renewable energy sources (Anyanwu and Salami, 2021; Chanchangi et al., 2023; Nwokolo et al., 2023). Estimating the value of global solar radiation (GSR) is vital for many uses such as solar energy systems, architectural design, crop growth models and crop water requirements. Solar radiation (SR) is a driver for many physical, chemical, and biological activities on the earth's surface. Solar energy engineers, architects, agriculturists, and hydrologists often require knowledge of the availability of the solar resource such as long-term average daily global irradiation (Besharat et al., 2013; Heris et al., 2014; Ali et al., 2023).

In areas where no actual measured values are available, an estimation of average daily GSR is done using relevant empirical correlations based on the measured data at those locations. The GSR models in the literature are in four categories, i.e., cloud-based, sunshine-based, temperature-based, and other meteorological parameter based models as model input for the region of interest. In 2013 Besharat et al., used geographical and meteorological data of Yazd city, Iran and results revealed that all models correlations have a good estimation of the monthly average daily GSR on a horizontal surface in Yazd city. The El-Metwally sunshine-based model predicts with a higher accuracy. Heris et al., 2014 tested twenty-four empirical GSR models were evaluated using measured daily SR and actual sunshine hours for the years of 2001-2011 at Tabriz northwest Iran. In 2015, Ladan et al., worked on the models for estimation of solar radiations potential at Abuja, Nigeria using Hargreaves-Samani (HS), Annandale and Samani models. The results indicated the HS and Annandale models were perfectly fitted continuously during summer and increases in winter. Hassan et al., 2016 presented new ambient-temperature-based models for estimating GSR for ten different locations around the coastal areas of Egypt. Recently Ali et al., 2023 evaluated the proficiency of several GSR models at five new locations and determine the most suitable one for GSR prediction using temperature data. The result showed a coefficient of determination (R^2), ranging from 95 to 98% and 91 to 95% for coastal areas.

Due to the unavailability of GSR measurements in many parts of the world, several models have been developed. In Nigeria, accurate determination for predicting actual value of SR for a given location are still scarce for a particular location. In this study, the solar radiation in Bauchi State north eastern Nigeria was estimated using Angstrom-Prescott model (APM). The obtained results will be compared with experimental data.

MATERIALS AND METHODS

The Angstrom–Prescott model

The first and the most widely used correlation for estimating monthly average daily global solar radiation was proposed by Angstrom in 1924, who derived a linear relationship between the ratio of average daily global radiation to the corresponding value on a completely clear day $H = H_o$ at a given location and the ratio of average daily sunshine duration to the maximum possible sunshine duration.

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_O}\right) \qquad (1)$$

A basic difficulty with equation 1, lies in the definition of the term H_o. Prescott and the others have modified the method to base it on extra-terrestrial radiation on a horizontal surface rather than on clear day radiation and proposed APM:

$$\frac{H}{H_O} = 0.3326 + 0.3110\left(\frac{S}{S_O}\right) \quad (2)$$

The data such as monthly average sunshine hours (S/S_0), average temperatures (T_{av}), relative humidity (R (%)) and global solar radiation data for Bauchi can be used for the analysis. Some parameters were obtained from Bauchi airport, Nigeria. The data collected covered a period of ten years (2001 – 2010) for Bauchi state latitude 10° 18' 48N, longitude 90 50' 36E, altitude 610m above sea level. The meteorological parameters that are used for solar radiation analysis include T_{av}, R (%), value of measured average daily solar radiation on the horizontal surface (H), CC, and the atmospheric precipitation (Atp). H is the measured monthly mean daily global solar radiation, H_0 is the monthly mean extra-terrestrial solar radiation on horizontal surface, S is the monthly mean daily brightness sunshine hours. S_0 is the maximum possible monthly mean daily sunshine hour or the day length, H/H_0 is the clearness index (cloud cover), S/S_0 is the fraction of sunshine hours 'a' and 'b' are regression constants (Ladan et al., 2015; Hassan et al., 2016; Ali et al., 2023).

The extra-terrestrial solar radiation on horizontal surface is given by Igbal, in 1983 is

$$H_0 = \frac{24}{\pi}(I_{sc})(E_0)\frac{24}{\pi}\left(\frac{\pi}{180}\,\epsilon\,\omega s \sin\varphi \sin\delta + \cos\delta \sin\omega s\right) \quad (3)$$

Where I_{sc} is the solar constant, ϵ_0 is the eccentricity correction factor, φ = latitude; δ = solar declination; ωs = hour angle.

$$R = (\sin\varphi \sin\delta + \cos\varphi \cos\delta \sin W) \quad (4)$$

The deviation between the estimated and measured values was determined using the statistical parameters mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE)

$$MBE = \left[\frac{1}{n}\sum_{n=1}^{N}(H_{cal} - H_{meas})\right] \quad (5)$$

$$RMSE = \left[\frac{1}{n}\sum_{n=1}^{N}(H_{cal} - H_{meas})\right]^2 \quad (6)$$

$$MPE = \sum\left|\frac{H_{cal} - H_{meas}}{H_{meas}}\right| x\,100 \quad (7)$$

When n = 2,3,…N and N is the number of observations, the calculated and measured valued of GSR on the horizontal surface were compared.

Table 1: Mean monthly average temperature, relative humidity, sunshine hours and atmospheric precipitation

Month	T_{av} (^{0}C)	R%	S	Atp
January	29.18	26.2	7.1	0
February	32.74	32.1	8.02	0
March	35.37	37.3	7.71	0
April	35.5	47.4	7.71	47.04
May	34.4	64.2	7.27	53.91
June	32.05	90.3	7.1	124.63
July	29.69	92.8	6.38	318.93
August	29.32	96.4	5.22	307.69
September	30.43	78.1	6.81	335.98
October	31.82	40.4	7.87	25.38
November	31.37	40.2	8.34	0
December	30.61	33.2	7.66	0
Total	382.48	678.6	87.19	1213.56

Table 2: The monthly mean of the hour angle, solar declination, relative humidity, extra-terrestrial solar radiation and sunshine duration

Month	Ws	D	R	H_0	S_0
Jan	84.656	-20.202	0.852	33.003	11.228
Feb	87.478	-16.354	0.913	35.104	11.664
Mar	89.334	-12.624	0.967	35.536	11.911
Apr	94.181	12.500	0.989	37.215	12.557
May	93.710	19.235	0.985	36.273	12.495
Jun	94.547	23.209	0.972	36.607	12.606
Jul	94.018	20.759	0.981	34.540	12.536
Aug	92.388	12.620	0.965	35.420	12.318
Sep	90.223	1.195	0.986	35.572	12.030
Oct	88.020	-10.713	0.931	34.347	11.736
Nov	86.302	-20.055	0.898	32.384	11.507
Dec	84.282	23.704	0.894	32.181	11.229
Total	1079.14	33.274	11.333	432.947	143.877

Table 3: Monthly measured and calculated values for H/H_0 (MJ/m^2/day)

Month	Measured	Calculated	Difference	(difference)^2	Diff /meas.
Jan	0.427840	0.435322	-0.006837	0.000056	0.0174878
Feb	0.442685	0.478436	0.008388	0.0012781	0.0807595
Mar	0.477825	0.470988	-0.001858	0.0000467	-0.0143086
Apr	0.464866	0.473254	-0.001698	0.0000704	0.0180439
May	0.454884	0.453026	0.002564	0.0000035	-0.0040846
Jun	0.411943	0.41025	-0.000324	0.0000029	-0.0041098
Jul	0.384771	0.381335	-0.004338	0.0000066	0.0066637
Aug	0.375201	0.374877	-0.000324	0.000001	-0.0008635

Sep	0.409030	0.404692	-0.004338	0.0.000188	-0.0106056
Oct	0.468163	0.475212	0.007049	0.0000497	0.0150567
Nov	0.501482	0.497835	-0.003647	0.0000133	-0.0072724
Dec	0.518008	0.475473	-0.042535	0.0018092	-0.0821126
Total	5.336698	5.3367	0.000002	0.03355	0.014655

Table 4: Mean Bias Error; Mean Percentage Error, and the Root Means Square Error the APM

MONTH	MBE	RMSE	MPE	% MBE
Jan	0.007482	0.074821	0.017488	0.75
Feb	0.017576	0.017576	0.039703	1.80
Mar	-0.002279	-0.002279	-0.004769	-0.23
Apr	0.000210	0.000210	0.004511	0.02
May	-0.000372	-0.000372	-0.000817	-0.04
Jun	-0.000282	-0.000282	-0.000685	-0.03
Jul	0.000366	0.000366	0.000105	0.04
Aug	-0.000041	-0.000041	0.001178	-0.004
Sep	-0.000482	-0.000482	0.001178	-0.005
Oct	0.0000705	0.0000704	0.000151	0.007
Nov	-0.0033156	-0.003316	0.006612	-0.003
Dec	-0.0035445	-0.003545	-0.006842	-0.004
Total	∑ 0.022938	0.151460	5.660	2.301

Table 5: Regression constants β for the APM

β	A_0	A_1	A_2	A_3	A_4	A_5	A_6	R^2
	1.88	1.10	0.38	0.112	-0.0077	0.125	0.00193	80.30

RESULTS AND DISCUSSION

The APM provided the best estimate for the monthly values in preparation for the correlation of mean average temperature, cloud cover (clearness index), and sunshine duration for Bauchi in table below. Comparing the results, the regression equation indicated a good result using modified the Angstrom equation. It is reflected in the values of the GSR estimated and the measured values sing MBE, RMSE and MPE gives 0.022938, 0.151460 and MPE = 5.60% respectively. It gives the highest value of correlation coefficient and coefficient of determination. Regression constants a_0, a_1 and R^2 are 1.88, 0.00193 and 80.30 respectively for the period 2001-2010 under consideration. It showed an improvement on the ten (10) years data on daily solar radiation, maximum and minimum temperatures from 2001 to 2010 obtained from NIMET and compared to Hargreaves – Samani, Annandale and Samani models.

The measured and predicted values of solar radiation obtained from model for Bauchi showed similar characteristics (Figure 1). It means the model can be used to predict the solar radiation in the areas with similar climatic factors.

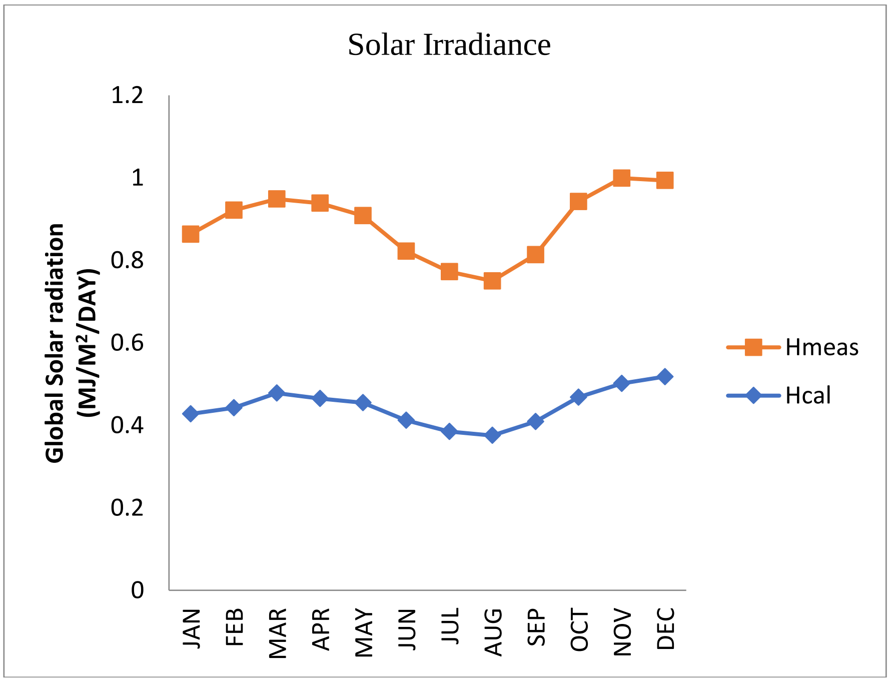

Figure 1: Variation of the average calculated global solar radiation for Bauchi Town

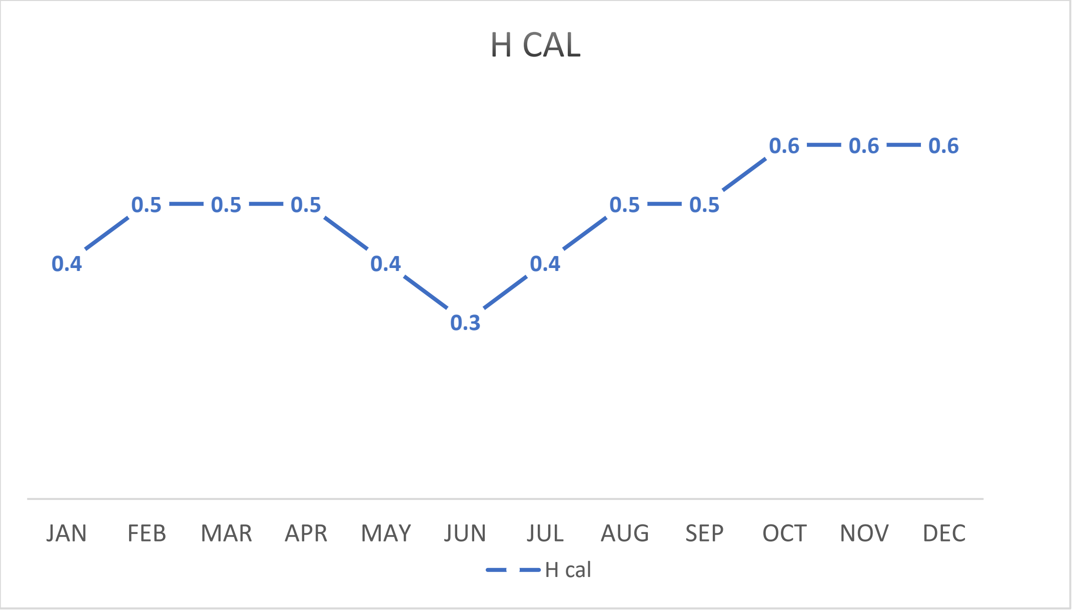

Figure 2: Variation of the average calculated global solar radiation for Bauchi town

CONCLUSION

The APM is applied to Bauchi state and can be used for estimating the monthly average solar radiation on horizontal surface for any areas within the north eastern region. The values estimated by APM and the measured values tested using MBE, RMSE and MPE = 5.6% recorded 0.022938; 0.151460; and 5.6% respectively. It will assist in predicting the SR in areas within the same geographical regions where equipment and staff are not readily available. This technique adopted was more accurate, since factors such as cloudiness, humidity, latitude, elevation, topography, access to river or ocean influences are not considered. This multi-linear regression process predicted the relationship between GSR with sunshine duration, mean average temperature, and cloud cover as the meteorological parameters produced better results. It is recommended that APM is the suitable for Bauchi GSR measurement as it indicated a good agreement between the measured and estimated values.

REFERENCES

Aksoy, B. (1997), Estimated monthly average global radiation for Turkey and its comparison with observations, renewable energy global radiation for turkey and its comparison with observations, renewable energy, 10:625-633

Ali M.A; Elsayed A.; Elkabani I; Youssef M.E; Hassan G.E (2023) Evaluation and performance comparison of different models for global solar radiation forecasting: a case study on five cities, Environment, Development and Sustainability. https://doi.org/10.1007/s10668-023-04307-5

Angstrom A. (1924) Solar and terrestrial radiation. Quarterly Jnl. of Ro. Met. Soc; 50:121-5.

Anyanwu, J. C.; Salami, A. O. (2021). The impact of COVID-19 on African economies: An introduction. African Development Review, 33 (Suppl. 1), S1–S16. https://doi.org/10.1111/1467-8268.12531

Burari, F.W., Sambo, A.S, and Mshelia, E.D. (2001): Estimation of global solar radiation in Bauchi. Nigerian Journey of renewable energy. 9:34-36.

Chanchangi N,Y; Adu F; Ghosh A; Sundaram S.; Mallick T.K (2023) Nigeria's energy review: Focusing on solar energy potential and penetration Environment, Development and Sustainability (2023) 25:5755–5796 https://doi.org/10.1007/s10668-022-02308-4

Eruola, A., Oyedepo, O., & Afolabi, T. (2019). Renewable energy potentials in Nigeria for national development: A review. Renewable Energy, 133, 1353-1365.

Fariba Besharat, Ali A. Dehghan, Ahmad R. Faghih (2013) Empirical models for estimating global solar radiation: A review and case study, Renewable and Sustainable Energy Reviews 21 (2013) 798-821.

Hassan, G. E., Youssef, M. E., Mohamed, Z. E., Ali, M. A., & Hanafy, A. A. (2016). New Temperature-based Models for Predicting Global Solar Radiation. Applied Energy, 179, 437–450. https://doi.org/10.1016/j.apenergy.2016.07.006

Heris M.A; Vahid Najafi; Hasan Bahadori; Ali Ashraf Sadraddini (2014) Evaluation and calibration of sunshine based solar radiation models for Tabriz, Iran International Journal of Biosciences, Vol. 4, No. 12, p. 27-34 http://dx.doi.org/10.12692/ijb/4.12.27-34

Ladan H.M.A; Buba A.D.A and Adelabu J.S.A (2015) Models for estimating solar radiation at Abuja Nigeria, M.Sc. dissertation, Department of Physics, Faculty of Science, University of Abuja, Nigeria phyfosuofA-14/08484017/09/2014 UniAbuja www.researchgate.net/profile/Muhammed-Ladan

Nwokolo, S.C., Meyer, E.L., Ahia, C.C. (2023). Credible Pathways to Catching Up with Climate Goals in Nigeria. *Climate*, *11*(9), 196. https://doi.org/10.3390/cli11090196

Supit I, Van Kappel RR. (1988) A simple method to estimate global radiation. Solar Energy; 63:147-60.