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Analysis of temperature based radiation models for Nsukka

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ABSTRACT

Four temperature-based models have been used to analyze global solar radiation for Nsukka. The statistical parameters used for the analysis were the root mean square error (RMSE), the modeling efficiency (ME) and the Coefficient of residual mass (CRM). The analysis of the models shows that the Allen and the Annandela et al., models are adequate for estimating global solar radiation in Nsukka. This implies that the values of the estimated global solar radiation obtained from these models can be used for designing solar systems and for research purposes for Nsukka.

Keywords: Temperature, solar radiation, solar systems, analysis, models

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INTRODUCTION

Knowledge of the global solar radiation is of fundamental importance for all solar energy conversion systems. The solar radiation data is not easily available for every location in many countries. Also many countries cannot afford to pay for the cost of measuring equipment and the techniques involved [1]. Solar radiation data is very essential for locations used in sitting solar energy utilities for optimal design and performance of such installed systems. Where solar radiation data is absent, a regression analysis can be used to correlate solar radiation with other meteorological data like sunshine duration, relative humidity, pressure, temperature, etc. in places where solar radiation data is available [2]. The resulting correlation can then be applied to similar locations with same meteorological and geographical characteristics. Many temperature-based models have been used to estimate global solar radiation [3-10]. The objective of this study is to analyze some temperature-based models for estimating global solar radiation at Nsukka.

MATERIALS AND METHODS

The global solar radiation, temperature, pressure, relative humidity data were obtained from the Centre for Basic Space Science (CBSS) for Nsukka located at Latitude 6.8°N and Longitude 7.4°E at an altitude of 488.0m above sea level [11]. From the data the monthly mean daily solar radiation, the root mean square error (RMSE), the modeling efficiency (ME) and the coefficient of residual mass (CRM) were calculated. The calculated monthly mean daily solar radiation was compared with the estimated values from the models used by determining the RMSE, ME and CRM [10-11].

Model Description

Extraterrestrial solar radiation can be obtained as a function of latitude or calculated using Eqn. (1) [12]:

$$H_{er} = \frac{24 \times 3600}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\phi\cos\delta\sin\omega + \frac{\pi\omega}{180}\sin\phi\sin\delta\right) \quad (1)$$

where H_{er} is the monthly mean daily extraterrestrial radiation (MJm^{-2}), I_{sc} is the solar constant ($1367Wm^{-2}$), n is the mean day of each month, ϕ is the latitude of the location, δ is the declination angle given as

$$\delta = 23.45\sin\left(360\frac{248 + \overline{D}}{365}\right), \quad (2)$$

and ω is the sunset hour angle for a typical day given as

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \quad (3)$$

Hargreaves and Samani Model

Hargreaves and Samani [13] estimated global solar radiation from the difference in the maximum and minimum temperature using

$$H_e = K_r (T_{max} - T_{min})^{0.5} H_{er} \quad (4)$$

where H_e is the solar radiation ($MJm^{-2}d^{-1}$), H_{er} is the extraterrestrial radiation ($MJm^{-2}d^{-1}$), T_{max} is the maximum temperature (°C), T_{min} is the minimum temperature (°C) and K_r is the empirical coefficient which is recommended to be 0.16 for interior regions and 0.19 for coastal regions [14].

Annandela Model

A correction factor for K_r^1 was introduced [15] to account for the effects of reduced atmospheric thickness on solar radiation. The correction is given by

$$K_r^1 = (1 + 0.000027 \times M)K_r \quad (5)$$

where K_r^1 is the corrected K_r and M is the altitude (m) [10, 16].

Allen Model

Allen [17] estimated K_r as a function of elevation to account for the effect of elevation on the volumetric heat capacity of the atmosphere by using

$$K_r = K_{ra}\left(\frac{P}{P_o}\right)^{0.5} \quad (6)$$

where K_{ra} is the empirical coefficient having a value of 0.17 for the interior regions and 0.20 for the coastal regions, P is the mean atmospheric pressure at the site, and P_o is the mean atmospheric pressure at sea level which is 101.3kPa.

Samani Model

Samani [18] developed the empirical relationship between K_r and the difference between air temperature extremes using

$$K_r = 0.00185(T_{\max} - T_{\min})^2 - 0.0433(T_{\max} - T_{\min}) + 0.4023 \quad (7)$$

According to Samani [10], equation (5) can be applied to locations between latitudes 7°N and 50°N.

Bristow – Campbell Model

Bristow and Campbell [19] introduced another method for estimating solar radiation from air temperature using

$$H_e = S_t H_{er} \quad (8)$$

where H_e is the estimated solar radiation, H_{er} is the extraterrestrial solar radiation, S_t is the daily total atmospheric transmittance which is expressed as

$$S_t = S_{t\max}\left[1 - \exp\left(-\beta \Delta T^c\right)\right] \quad (9)$$

$$S_{t\max} = a + b \quad (10)$$

where a and b are expressed as Angstrom coefficients or determined as a function of latitude, L and elevation, h [20] which give more accurate results:

$$a = -3.517x10^{-3} L - 1.492x10^{-6} h + 0.3263 \quad (11)$$

$$b = 5.042x10^{-4} L + 4.845x10^{-5} h + 0.4644, \quad (12)$$

β is a function of mean monthly temperature which is expressed as

$$\beta = 0.036 \exp\left(-0.154 \overline{\Delta} T\right) \quad (13)$$

c is a constant value of 2.4.

Data Analysis

The estimated solar radiation values using the models were compared with the observed values. The root mean square error (RMSE), modeling efficiency (ME) and coefficient of residual mass (CRM) were indicators used in analyzing the accuracy of the estimated values produced:

$$RMSE = \frac{\sum_{i=1}^{n}\left(H_{e,i} - H_{o,i}\right)^{2/n}}{H_o} \times \frac{100}{1} \quad (14)$$

$$ME = \frac{\sum_{i=1}^{n}\left(H_{o,i} - \overline{H}_o\right)^2 - \sum_{i=1}^{n}\left(H_{e,i} - H_{o,i}\right)^2}{\sum_{i=1}^{n}\left(H_{o,i} - \overline{H}_o\right)^2} \quad (15)$$

$$CRM = \frac{\sum_{i=1}^{n} H_{o,i} - \sum_{i=1}^{n} H_e}{\sum_{i=1}^{n} x_{o,i}} \quad (16)$$

where H_e is the estimated value, $H_{o,i}$ are the observed values and H_o is the average of the observed values and n is the number of observations. The RMSE expressed in percentages is used to compare the models and lower values indicate better performance. The ME gives a unit value when the estimated and observed values are equal. Values close to zero indicate poor performance and negative values show that the estimated values are worse than the observed values. When the CRM value is zero, it means perfect estimation. A positive CRM value indicates an under-estimation of the observed value while a negative value indicates over-estimation of the observed value [20, 21].

RESULTS AND DISCUSSION

The modeled and measured/observed monthly values of the solar radiation in Nsukka [11] are presented in Table 1 and the results obtained from the models that relate the observed solar radiation to the estimated solar radiation are summarized in Table 2.

Table 1: Estimated and Observed Radiation for Nsukka

Month	Estimated Radiation ($MJm^{-2}d^{-1}$)				Observed Radiation ($MJm^{-2}d^{-1}$)
	Samani	Bristow-Campbell	Annandela	Allen	
Jan	25.77	25.6505	21.99854	22.3774	17.59494
Feb	23.4334	26.44175	22.37189	22.8124	25.88425
Mar	28.7636	28.63026	24.55405	25.0072	26.56939
Apr	22.5371	26.47802	22.37266	22.7994	26.4672
May	23.0838	26.90553	22.73431	23.1679	26.16805
Jun	19.1254	23.77308	20.72444	21.1581	22.5648
Jul	18.1507	21.78584	19.73423	20.1593	19.21104
Aug	18.1009	19.51161	19.12842	19.5523	18.21647
Sept	18.9042	22.94559	20.56728	21.023	18.91872
Oct	20.3538	25.09904	21.35612	21.8293	21.1457
Nov	21.0217	24.7276	20.89387	21.3053	20.99808
Dec	26.0334	25.12914	21.64222	19.002	17.09327
Average	**22.1065**	**24.7565**	**21.5065**	**21.6828**	**21.736**

From Table 1, the Allen model gives the best estimation for solar radiation values in Nsukka followed by the Annandela model. The modeled and measured/observed monthly values of the solar radiation in Nsukka [11] are shown in Figs 1 – 4.

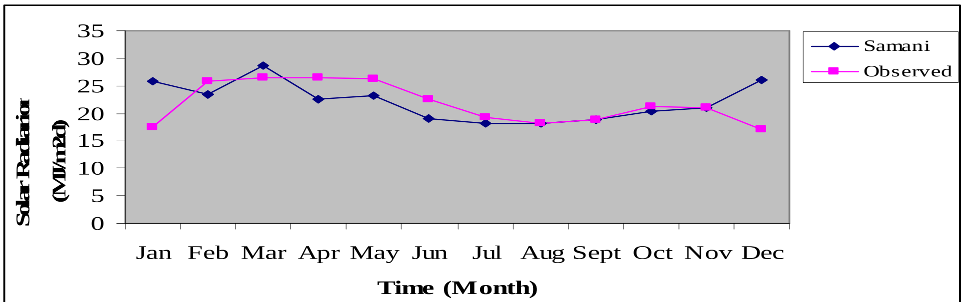

Fig.1: Comparison of Samani Model and Observed Solar Radiation

Fig. 1 shows a lot of disparities between the Samani model and the observed solar radiation in Nsukka especially at the beginning and at the end of the year.

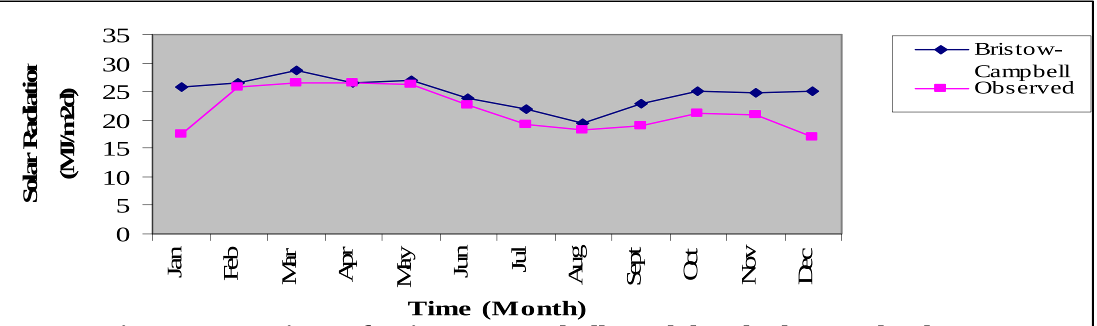

Fig.2: Comparison of Bristow-Campbell Model and Observed Solar Radiation

Fig. 2 also shows some disparities between the Bristow-Campbell model and the observed solar radiation in Nsukka at the beginning and at the end of the year.

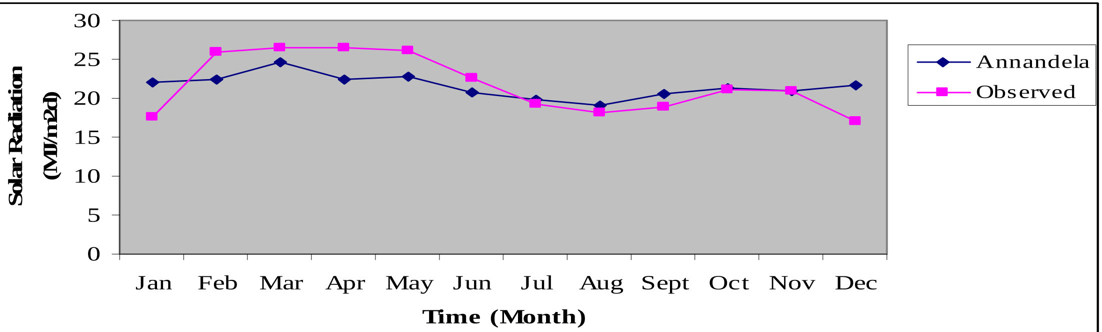

Fig.3: Comparison of Annandela Model and Observed Solar Radiation

Fig. 3 shows a lot of similarities between the Annandela model and the observed solar radiation in Nsukka with minor disparities.

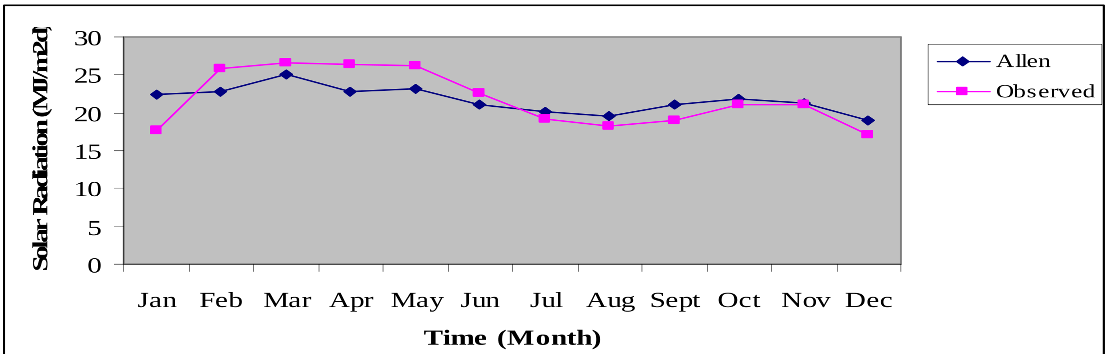

Fig.4: Comparison of Allen Model and Observed Solar Radiation

Fig. 4 shows a very close relationship and the best similarity between the Allen model and the observed solar radiation in Nsukka. The results obtained from the models that relate the observed solar radiation to the estimated solar radiation [11] are summarized in Table 2.

Table 2: Summary of the Models Analyzed

Model	RSME	ME	CRM
Samani	18.5997	-0.31122	-0.01705
Bristow-Campbell	18.3109	-0.27082	-0.13896
Annandela	12.7597	0.382912	0.010558
Allen	11.1511	0.528696	0.002448

From Table 2, the analysis shows that the Allen model [17] gives the best estimation because its RMSE value is the lowest, its ME is close to unity and its CRM is approximately zero. The Annandela et al. model [15] gives good values from the RMSE, ME and CRM results. The Samani model [16] shows poor performance from the RMSE, ME and CRM values. The Bristow-Campbell model [18] gives very poor values for estimating solar radiation in Nsukka as compared with the other models.

CONCLUSION

Four temperature-based global solar radiation models have been analyzed for Nsukka. The analysis of the models shows that the Allen and the Annandela *et al.* models are adequate for estimating global solar radiation in Nsukka. This is because the observed data closely agrees with the estimated data. This implies that the values of the estimated global solar radiation obtained from these models can be used for designing solar systems and for research purposes in Nsukka.

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