Empirical Models for Correlation of Clearness Index with Cloud Index at Rutba, Iraq State

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ABSTRACT

In this study, the monthly average daily values of global solar radiation and relative sunshine hours global solar radiation on a horizontal surface over a period of five years (2004-2008) using multi-linear polynomial form of the Angstrom-Prescott model have been developed to estimate global solar radiation for Rutba (one of west Iraqi cities) which lies on latitude 30°03'N and longitude 40°28' E. It was found that the five different mathematical correlations models (first order, second order, exponential, powered, and logarithmic) utilizing relative sunshine hours gave the best overall estimate of the total solar radiation in Rutba. The agreement between the measured values (that obtained from the archives of Iraqi meteorological office) and the computed values is remarkable and the models are recommended for use in Rutba.

Keywords - Global solar radiation, Rutba, Solar energy.

1- INTRODUCTION

The sun is a very intense source of energy not only for Iraq but also for the world. When sunlight reaches the Earth, it is distributed unevenly in different regions. Not surprisingly, the areas near the equator receive more solar radiation than anywhere else on earth. 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 other applications. 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]. Several models have been proposed to estimate global solar radiation. Badescu (1999) studied existing relationships between monthly mean clearness index and the number of bright sunshine hours using the data obtained from Romania [2], Trabea and Shaltout (2000) studied the correlation between the measurements of global solar radiation and the meteorological parameters using solar radiation, mean daily maximum temperature, mean daily relative humidity, mean daily sea level pressure, mean daily vapour pressure, and hours of bright sunshine data obtained from different parts of Egypt [3], while Sfetsos and Coonick (2000) used artificial intelligence techniques to forecast hourly global solar radiation[4]. Several investigations (Akpabio *et al*., 2004, Falayi and Rabiu, 2005, Safari and Gasore, 2009) have demonstrated the predictive ability of the Angstrom type model, correlating the global solar radiation to relative sunshine duration in a simple linear regression form [5, 6, and 7]. Menges *et al*.(2006) reviewed and tested available global solar radiation models to compute the monthly average daily global solar radiation on a horizontal surface using the data obtained from Konya, Turkey[8]. In this work we employ the Angstrom type first order polynomial and fifth other equations to estimate the relation between clearness index and cloud index , and then we can estimate the monthly average daily global solar radiation on horizontal surfaces at Rutba city.

2- METHOD OF ANALYSIS

The monthly average daily data for the sunshine duration and global solar radiation were obtained from the archives of Iraqi meteorological office. The geographical location of the city is presented in Table 1. The duration of record is from 2004 to 2008.

***Table 1**: Geographical location of the city*

City	Latitude	Longitude
Rutba	33°03' N	40°28' E

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. The formula is[9]:

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

Where H is the global solar radiation ($MJm^{-2}day^{-1}$), H_o is the extraterrestrial solar radiation on a horizontal surface ($MJm^{-2}day^{-1}$), S is the number of hours measured by the sunshine recorder, S_o is the maximum daily sunshine duration (or day length),and a, b are the regression constant to be determined. For monthly average, this formula holds:

$$\frac{\overline{H}}{\overline{H_o}} = a + b\left(\frac{\overline{S}}{\overline{S_o}}\right) \quad (2)$$

Where $\overline{H}$ is the monthly average daily global radiation on a horizontal surface, $\overline{H_o}$ is the monthly average daily extraterrestrial radiation on a horizontal surface, $\overline{S}$ is the monthly average daily number of hours of bright sunshine, $\overline{S_o}$ is the monthly average daily maximum number of hours of possible sunshine. Where $\left(\frac{\overline{H}}{\overline{H_o}}\right)$ is clearness index, and $\left(\frac{\overline{S}}{\overline{S_o}}\right)$ is cloud index.

The regression coefficient *a* and *b* have been obtained from the relationship given as[10]:

$$a = -0.110 + 0.235\, cos\emptyset + 0.323(S/S_o) \qquad (3a)$$

$$b = 1.449 - 0.553\, cos\emptyset - 0.694(S/S_o) \qquad (3b)$$

The extraterrestrial solar radiation on a horizontal surface can be calculated from the following equation[9]:

$$H_o = \frac{24}{\pi} 3600\, G_{SC} \left[1 + 0.33\, cos\left(360\frac{d}{365}\right)\right] \left[\left(\frac{2\pi\omega_s}{360}\right) sin\emptyset\, sin\delta + cos\emptyset\, cos\delta\, sin\omega_s\right] \qquad (4)$$

The value of the solar constant G_{SC} is (1353 Wm^{-2}) [11].The hour angle w_s for horizontal surface is given as [9]:

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

Declination is calculated as [9,12]:

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

where *d* is the day of the year. In most cases 15th of each month is the day of the month on which the solar declination is calculated [13].

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 [9]

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

In this work, a (first and second) order polynomials, power, logarithmic, and exponential models in addition to the Angstrom-Prescott equation will be developed. The regression constants will be obtained from statistical analysis using EES program.

3- RESULTS AND DISCUSSIONS

The various equations developed for Rutba are:

$H_1 \rightarrow$

$$\frac{\overline{H}}{\overline{H_o}} = 0.454381 + 0.289023\left(\frac{\overline{S}}{\overline{S_o}}\right)$$

$H_2 \rightarrow$

$$\frac{\overline{H}}{\overline{H_o}} 0.0870205 + 1.30837\left(\frac{\overline{S}}{\overline{S_o}}\right) - 0.694\left(\frac{\overline{S}}{\overline{S_o}}\right)^2$$

$H_3 \rightarrow$

$$\frac{\overline{H}}{\overline{H_o}} = 0.483476\, exp(0.436059(\overline{S}/\overline{S_o}))$$

$H_4 \rightarrow$

$$\frac{\overline{H}}{\overline{H_o}} = 0.737134\, (\overline{S}/\overline{S_o})^{0.319216}$$

$H_5 \rightarrow$

$$\frac{\overline{H}}{\overline{H_o}} = 0.73389 + 0.211439\, \ln\left(\frac{\overline{S}}{\overline{S_o}}\right)$$

Figure(1) shows the relationship between clearness index and cloud index vs. months of the year that estimated using a linear model (Angstrom model) equations (2, 3a, and 3b) as a sample of estimation of global solar radiation values over Rutba city. Figures (2-6) explain the relationship between clearness index and cloud index vs. months of the year from estimated equations (H_1 , H_2 , H_3, H_4, and H_5). From these figures we can shows that the estimated equations are reliable for calculated the global solar radiation on a horizontal surface for Rutba city. Figure (7) explain the the monthly global solar radiation vs. months of the year for Rutba city which can be noted the calculated value which dependent on Rutba weather condition and that estimated values. Good agreements are obtained when comparing the clearness measured values that taken from the Iraqi meteorological organization and seismology for Rutba city (which explained in blue color) and calculated values from Angstrom model for months (which explained in red color) as shown in figure (8).

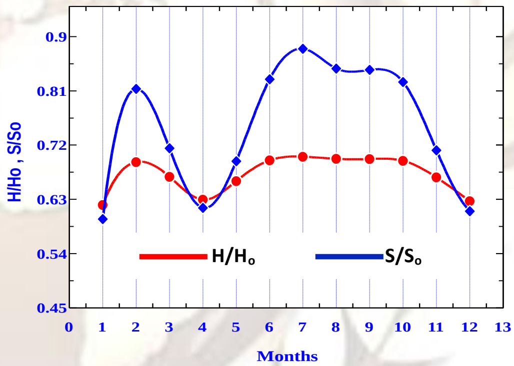

Fig.1: *Variation of S/S_o and H/H_o that calculated for months of the year for Rutba From Eq.(2)*

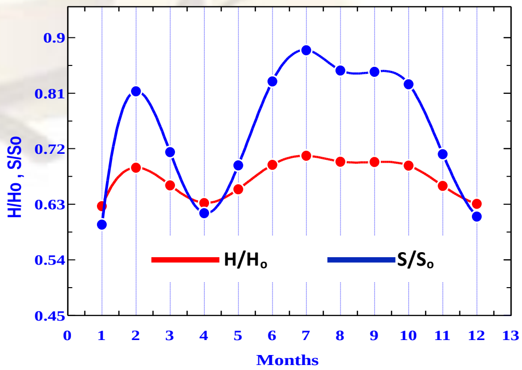

Fig.2: *Variation of S/S_o and H/H_o that estimated for months of the year for Rutba From* (H_1)

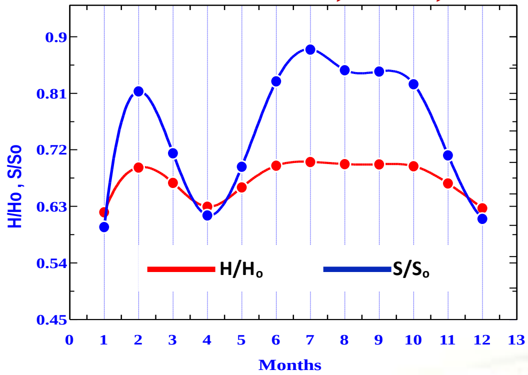

Fig.3: *Variation of* S/S_o *and* H/H_o *that estimated for months of the year for Rutba From* (H_2)

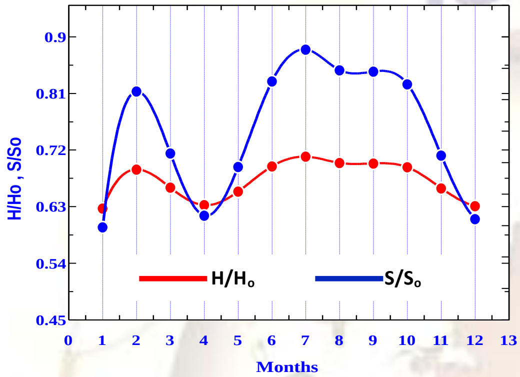

Fig.4: *Variation of* S/S_o *and* H/H_o *that estimated for months of the year for Rutba From* (H_3)

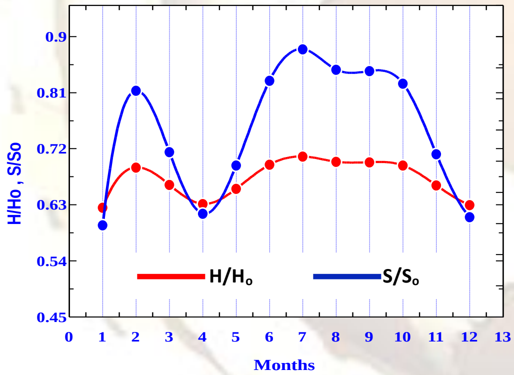

Fig.5: *Variation of* S/S_o *and* H/H_o *that estimated for months of the year for Rutba From* (H_4)

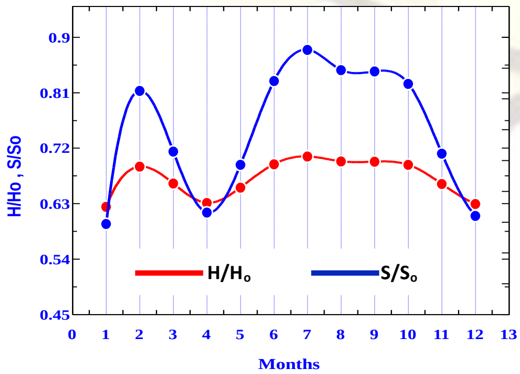

Fig.6: *Variation of* S/S_o *and* H/H_o *that estimated for months of the year for Rutba From* (H_5)

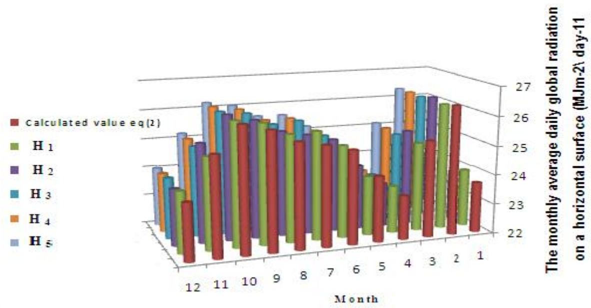

Fig.7: The monthly average daily global radiation on a horizontal surface vs. month

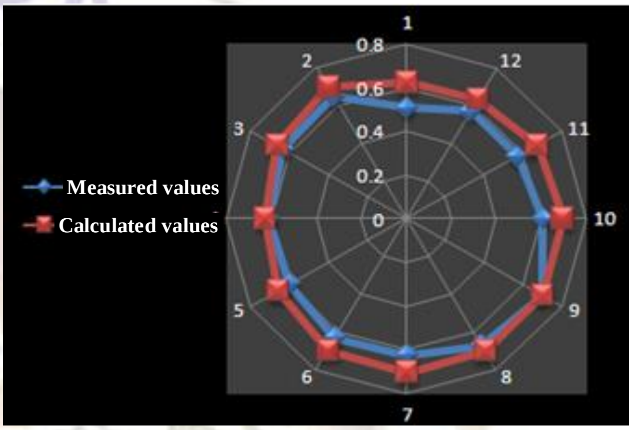

Fig. 8: The clearness index for measured values and calculated values vs. month for Rutba city

4- Conclusion

The results of this study, clearly indicate the primary importance of developing empirical approaches for formulating the global solar radiation on horizontal surface reaching the earth at Rutba , Iraq state. Good agreement between calculated and measured values of the clearness index from the above results and considerations, then we can using the estimated equations with high accuracy to estimate the global radiation on horizontal surfaces at the selected city.

References

[1] M. Hussain, L. Rahman, and M. M. Rahman, Renewable Energy, 18 (1999), pp. 263-275.

[2] V. Badescu, Correlations to estimate monthly mean daily solar global irradiation: Application to Romania. Energy, 24 (1999), 883-893.

[3] A. A. Trabea, and M. A. Shaltout, Correlation of global solar-radiation with meteorological parameters over Egypt. Renew. Energ., 21 (2000), 297-308.

[4] A. Sfetsos, and A. H. Coonick, Univariate and multivariate forecasting of hourly solar radiation with artificial intelligence techniques. Solar Energ., 68 (2000), 169-178.

[5] L. E Akpabio, S.O. Udo and S.E. Etuk, Empirical correlation of global solar radiation with meteorological data for Onne, Nigeria. Turk. J. Phys., 28 (2004), 301-307.
[6] E. O. Falayi, and A. B. Rabiu, Modelling global solar radiation using sunshine duration data. Nigeria J. Phys., 17S (2005), 181-186.
[7] B. Safari, and J. Gasore, Estimation of global solar radiation on horizontal surface in Rwanda using empirical model. Asian J. Sci. Res., 2 (2009), 68-75.
[8] H. O. Menges, C. Ertekin and M. H. Sonmete, Evaluation of global solar radiation models for Konya, Turkey. Energ. Convers. Manage., 47 (2006), 3149-3173.
[9] J. A. Duffie, and W. A. Beckman, Solar Engineering of Thermal Processes. John Willey, New York, U.S.A. 2nd (1994), pp 234 – 367.
[10] R. F Tiwari, and T. H. Sangeeta, Solar Energy. 24 (1997), pp. 89 – 95.
[11] C. Frolich, and R. W. Brusca, Solar Physics, 74 (1981), 209.
[12] P. I. Cooper, Solar Energy, 12 (1969), 333.
[13] J. Almorox, and C. Hontoria, Global solar radiation estimation using sunshine duration is Spain, Energy conversion and Management, 45 (2004), 1529-1535.

Bibliography

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