MONTHLY AVERAGE DAILY GLOBAL AND DIFFUSE RADIATION FOR QASSIM, SAUDI ARABIA

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ABSTRACT

Based on solar radiation measurement from 1992 to 1994 at Qassim (26° 12′ N Latitude, 43° 42′ E Longitude and 751 m Altitude), Saudi Arabia, modified-Angstrom type model was obtained for monthly average daily global radiation. The best fit of the empirical model was with a = 0.231 and b = 0.526 for global radiation. Comparison to other similar location models was investigated and found to be in good agreement. For monthly average daily diffuse irradiance, the correlation introduced in 1979 by Collaras-Pereiras and Rabl was found to be acceptable with minimal root mean square of errors reaching 0.993.

Keywords: Solar energy, Radiation, Solar radiation, Diffuse radiation, Global radiation, Location models.

INTRODUCTION

With the increasing interest in solar energy application in various field, knowledge of global, direct and diffuse irradiation is extremely important. In any locality, optimum design of solar systems can be achieved only with reasonably accurate data. To expand the use of measured solar radiation data, empirical models are usually fitted with specific localized constants. Meteorological data provides independent variables for such models. This information can be used on hourly, daily or monthly bases for global, direct or diffuse irradiation prediction.

Angstrom-type regression model is one of the most simple and widely used relation for solar radiation estimation. This study was conducted with data covering years from 1992 to 1994 at Qassim (26° 12′ N Latitude, 43° 42′ E Longitude and 751 m Altitude). Measurement of global and diffuse irradiation on horizontal surface was possible using Eppley Black and White Pyranometer (Model 8-48). Calibration was performed against Eppley Precision Pyranometer (Model PSP). Duration of bright sunshine hours was measured by Campell-Stokes sunshine recorder.

2. MODEL CORRELATION

Since Angstrom (1956) introduced his model for estimating the monthly average global radiation on horizontal surface which then modified to be more applicable, many models have been developed for many locations through out the world. The general form of this model is shown in equation (1).

$$\frac{\bar{H}}{\bar{H}_c} = a' + b'\left(\frac{\bar{n}}{\bar{N}}\right) \qquad (1)$$

where:

$\bar{H}$ the monthly average daily radiation on horizontal surface.

$\bar{H}_c$ the average clear sky daily radiation for the location and month in question.

a′,b′ empirical constants.

$\bar{N}$ monthly average of the maximum possible daily hours of bright sunshine.

This model was later modified by Page (1964) and others to overcome the difficulty of defining $\bar{H}_c$. They used $\bar{H}_o$ instead of $\bar{H}_c$ where $\bar{H}_o$ is the monthly average daily extraterrestrial radiation on horizontal surface. This produced equation (2).

$$\frac{\bar{H}}{\bar{H}_o} = a + b\left(\frac{\bar{n}}{\bar{N}}\right) \tag{2}$$

The ratio $\bar{H}/\bar{H}_o$ is termed as clearness index, $\bar{K}_T$. Using this empirical model, Lof et al. (1966), developed sets of constants a and b for various locations. Kamel et al. (1993) obtained equation (3) for Asyuot (27° 12′ N Latitude), Egypt.

$$\frac{\bar{H}}{\bar{H}_o} = 0.222 + 0.501\left(\frac{\bar{n}}{\bar{N}}\right) \tag{3}$$

Srivastava et al. (1993) presented equation (4) for Lucknow (26° 45′ N Latitude), India.

$$\frac{\bar{H}}{\bar{H}_o} = 0.2006 + 0.5313\left(\frac{\bar{n}}{\bar{N}}\right) \tag{4}$$

In the same manner, diffuse empirical models can be used as indicated by Liu and Jordan (1960).

$$\frac{\bar{H}_d}{\bar{H}} = a + b\bar{K}_T \tag{5}$$

where:

$\bar{H}_d$ the average monthly daily diffuse radiation,

a,b empirical constants.

Collares-Pereira and Rabl (1979) introduced equation (6) as a regression model for diffuse radiation.

$$\frac{\bar{H}_d}{\bar{H}} = 0.775 + 0.00653(\omega_s - 90) - [0.505 + 0.0045(\omega_s - 90)] \cos[115\bar{K}_T - 103] \tag{6}$$

where ω_s is the sunset hour angle of the mean day of the month,

Moreover, different models were developed by Stanhill (1966), Choudhary (1963), Tuller (1976) and many others. Gopmathan (1992) tried nine different models for application at South Africa region and found some disagreement between many of these models.

3. METHODOLOGY

To define model's constants, extraterrestrial radiation H_o and maximum sunshine hours N were computed using equation (7) and (10) respectively according to Duffie and Beckman (1980).

$$H_o = \frac{24(3600)G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360D}{365}\right)\right] \left[\cos\phi\cos\delta\sin\omega_s) + \left(\frac{2\pi\omega_s}{360}\right)\sin\phi\sin\delta\right] \tag{7}$$

where:

G_{sc} the solar constant,

D the day of the year,

ϕ the locale latitude,

δ and ω_s are solar declination and sunset hours angle defined in equation (8) and (9) respectively.

$$\delta = 23.45 \sin\left(\frac{360(284 + D)}{365}\right) \tag{8}$$

$$\omega_s = \cos^{-1}(-\tan\delta\tan\phi) \tag{9}$$

$$N = \frac{2}{15}\cos^{-1}[-\tan\delta\tan\phi] \tag{10}$$

Calculation was carried out for every day of each month, then they were averaged to obtained $\bar{H}_o$. Also, the same process was applied for N to generate $\bar{N}$.

Two procedures were used to evaluate each model. These two methods included root mean square of errors (RMSE) as defined in equation (11) and the mean relative percentage of errors (MPE) defined in equation (12).

$$RMSE = \left[\frac{\sum(\bar{H}_{ical} - \bar{H}_{imeas})^2}{n}\right]^{0.5} \tag{11}$$

$$MPE = \left[\frac{\sum(\bar{H}_{imeas} - \bar{H}_{ical})/\bar{H}_{imeas})}{n}\right] x100 \tag{12}$$

where:

$\bar{H}_{i\,cal}$ the i-th calculated value,

$\bar{H}_{i\,meas}$ the i-th measured value,

n total number of observations.

4. RESULTS AND DISCUSSIONS

General yearly pattern of solar radiation at Qassim is summarized in Figure (1). This shows the monthly average daily extraterrestrial radiation, the monthly average daily global radiation and the monthly average daily diffuse radiation. Figure (2) shows the yearly pattern of the monthly average sunshine hours for Qassim. This included the maximum possible and recorded sunshine hours. These figures show general apparent pattern for all recorded years. In spit of the increase in $\bar{N}$ from February to May in Figure (2), the recorded $\bar{n}$ decreased and the same result can be seen for global radiation in Figure (1). This can be understood by considering the increase in cloud presence and rain season between February and May at Qassim. From May to June, sharp increase in sunshine hours and global radiation is shown. During this period, sky is usually very clear after the rain season. After. July, dust presence in the atmosphere reduces sunshine hours and global radiation. Diffuse component of solar radiation peaked between April and May with the increase in cloud presence.

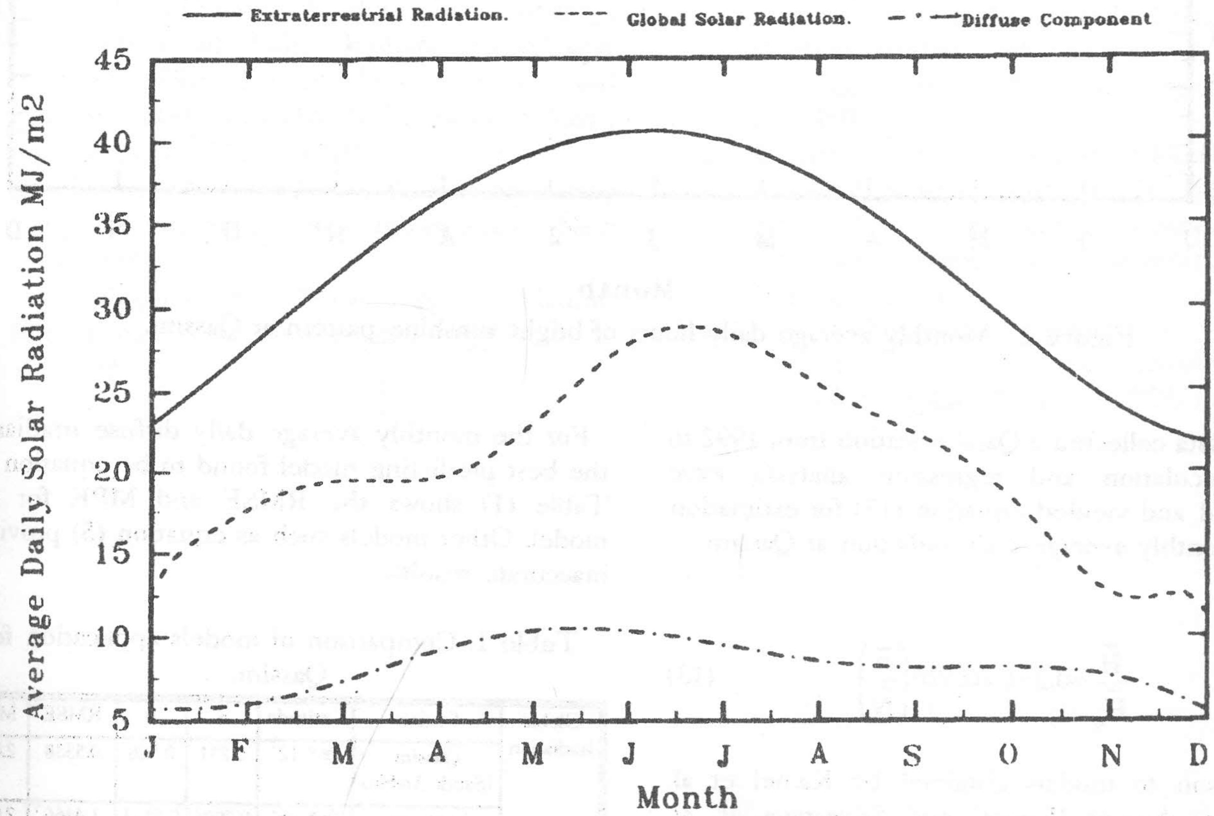

Figure 1. Monthly average daily solar radiation patterns for Qassim.

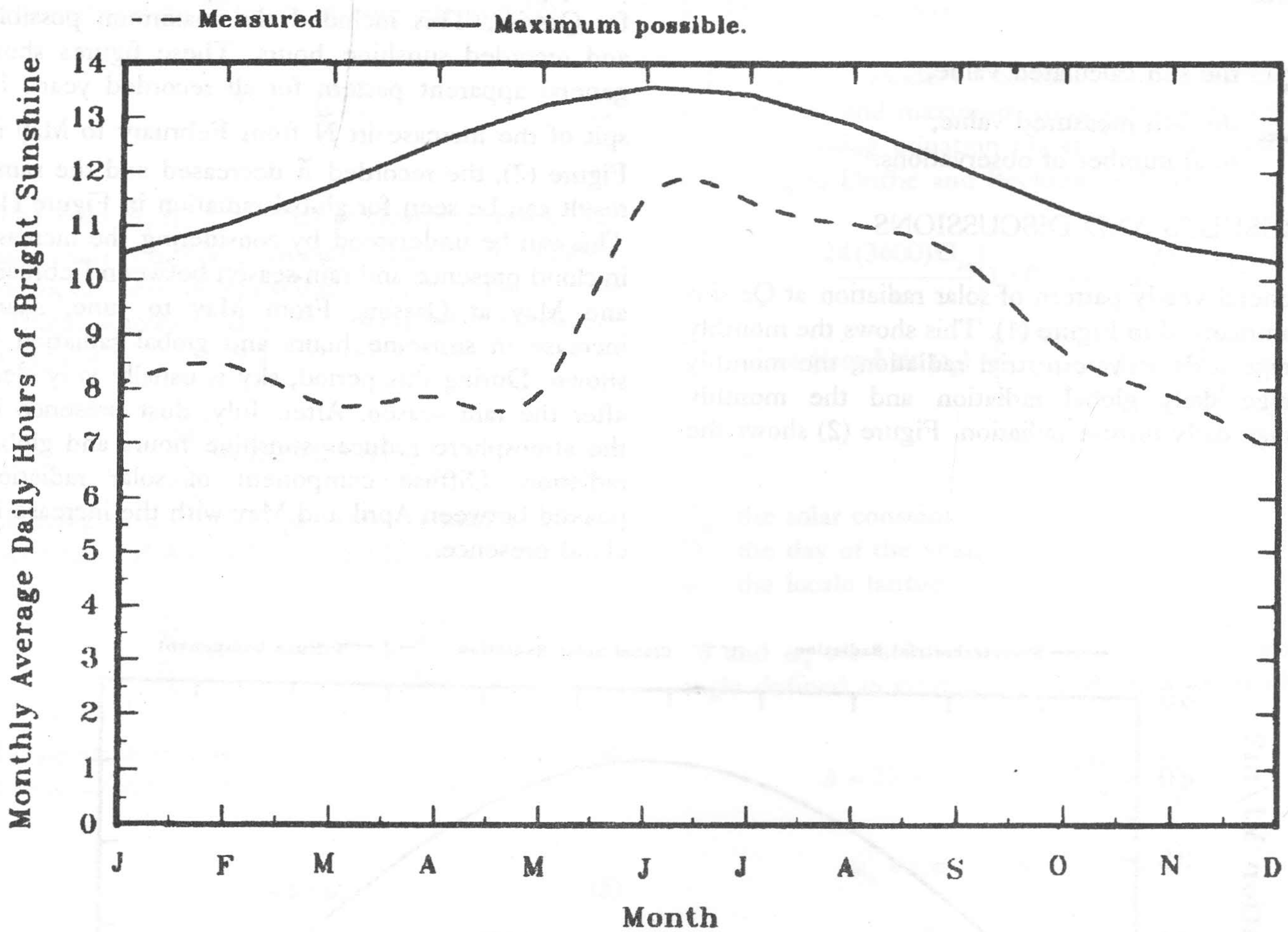

Figure 2. Monthly average daily hours of bright sunshine pattern at Qassim.

Using data collected a Qassim station from 1992 to 1994, calculation and regression analysis were conducted and yielded equation (13) for estimation of the monthly average daily radiation at Qassim.

$$\frac{\bar{H}}{\bar{H}_o} = 0.231 + 0.526\left(\frac{\bar{n}}{\bar{N}}\right) \qquad (13)$$

Comparison to models obtained by Kamel et al. (1993) for Asyuot (Egypt) and Srivastava et. al. (1993) for Lucknow (India) provided reasonable similarities. This is shown in Table (1). RMSE and MPE were minimum for equation (13) and results for Lucknow gave better estimation than that of Asyout.

For the monthly average daily diffuse irradiance, the best predicting model found to be equation (6). Table (1) shows the RMSE and MPE for that model. Other models such as equation (5) provided inaccurate results.

Table 1. Comparison of models application for Qassim.

	Station	Latitude	a	b	RMSE	MPE
Global Radiation	Qassim (Saudi Arabia)	26° 12′	0.231	0.526	0.5338	2.001
	Lucknow (India)	26° 45′	0.2006	0.5313	1.4466	2.013
	Asyout (Egypt)	27° 12′	0.222	0.501	1.5004	2.1871
Diffuse Radiation	Qassim	26° 12′	(6)		0.9933	7.172

5. CONCLUSION

For Qassim (26 12′ N latitude), the best fit for Angstrom type model for estimating the monthly average daily global radiation is with constants a = 0.231 and b = 0.526. For estimating the monthly average daily diffuse irradiation, the model developed by Collares-Pereira and Rabl was found to be the model with lowest relative error percentage (7.17%) for Qassim area.

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