Empirical Models for the Estimation of Global Solar Radiation with Sunshine Hours on Horizontal Surface in Various Cities of Pakistan

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Abstract

In developing countries like Pakistan the global solar radiation and its components is not available for all locations due to which there is a requirement of using different models for the estimation of global solar radiation that use climatological parameters of the locations. Only five locations data of solar radiation data is available in Pakistan (Karachi, Quetta, Lahore, Multan and Peshawar). These locations almost encompass the different geographical features of Pakistan. For this reason in this study the Mean monthly global solar radiation has been estimated using empirical models of Angström, FAO, Glover Mc-Culloch, Sangeeta & Tiwari for the diversity of approach and use of climatic and geographical parameters. Empirical constants for these models have been estimated and the results obtained by these models have been tested statistically. The results show encouraging agreement between estimated and measured values. The outcome of these empirical models will assist the researchers working on solar energy estimation of the location having similar conditions.

Key words: Global solar radiation, empirical models, geographical parameters

Introduction

Solar radiation is the direct form of abundant permanent solar energy resource available on earth, due to nuclear fusion on Sun. Earth surface is receiving about one hundred thousand TW of this renewable energy of solar power at earth's surface at each moment. Clouds, gases, pollution (including aerosol) and other factor decreases this available power on surface and thus, earth gets about 800 times less solar energy from the Sun at each moment (Schiermeier et.al., 2008). Despite of the fact is that only 71 minutes of solar energy is good enough to satisfy the demand of solar energy n earth's population for one year. As a matter of fact about one thousand watts per square meters of solar energy reaches at landmass of the earth (so do Pakistan) (Intikhab et.al., 2011).

Solar Radiation and Sunshine duration are two of the most important variables in the energy budget of the earth. They play an important role in the performance evaluation of renewable energy systems and in many other applications like health, agriculture, construction, etc. Pakistan has adequate solar potential to support its energy demands, it is therefore important to harness this resource in view of finding a solution to energy shortage and environmental degradation that the country is facing. Solar energy is now considered to be the most effective and economic alternative resource. In a country like Pakistan, where interest in solar energy application has been growing for providing electricity especially to rural areas, the study of solar energy is an urgent need. An insight into this with special reference to photosynthesis and transpiration of crops has been deemed essential as Pakistan is basically an agricultural country. Knowledge of historical global solar radiation at large number of locations is required for the design and estimation of the performance of any solar energy system. The economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. Solar radiation data is available for most parts of the world, but is not available for many countries which cannot afford the measurement equipment and techniques involved. Several empirical models have been developed to calculate Global Solar radiation based on sunshine hours.

Earlier attempts has been made to obtain the Global solar radiation from climatic variables such as sunshine duration (Prescott, 1940, (Page 1964); Boisvert et al., 1990; Soler, 1990; Rietveld, 1978; Angström, 1924; Reddy , 1971; Sayigh, 1979; FAO Technical Paper-56, 1998; Glover and McCullouch,

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1958; Ahmad F. & Ulfat I., 2004; Ulfat et. al., 2005 and 2008) air temperature range (De Jong & Stewart, 1993; Hargreaves et al., 1985; Bristow & Campbell, 1984), precipitation (De Jong & Stewart, 1993) and cloud-cover (Barker, 1992; Davies & McKay, 1988; Brinsfield et al., 1984). Reddy (1971) suggested to incorporate geographical factors also.

Unfortunately solar energy measurement data is available only for few cities of Pakistan. The object of this study to compute solar radiation estimation for those stations and intercompare available solar radiation estimation method.

Methodology

There are many methods to estimate the global solar radiation (Ahmed F. and Ulfat, I., 2004; Ulfat et al., 2008). The equation postulated by (Angström , 1924) and modified by (Prescott, 1940) to its present form is by far the simplest of all the models presented:

$$H = Ho\left[A + B\left(\frac{n}{L_d}\right)\right] \qquad \text{……….......................... (1)}$$

Where	H	Incoming daily global solar radiation	(MJ m^{-2} d^{-1})
	H_0	Daily extra-terrestrial radiation	(MJ m^{-2} d^{-1})
	A and B	Empirical constant	
	n	Bright sunshine hours per day	(hr)
	L_d	Astronomical day length	(hr)

Where the Astronomical day length L_d is calculated by the following formula

$$L_d = \frac{2}{15}\cos^{-1}\left[-\tan(\phi)\tan(\delta)\right] \qquad \text{………………. (2)}$$

Φ = latitude in degree

δ = Solar declination angle in degree

H_0 is determined using equation defined by Duffi and Beckman (1991)

$$Ho = \frac{24}{\pi} I_{SC}\left[1 + 0.033\cos\left(\frac{360\ n}{365}\right)\right]\left[\cos(\phi)\cos(\delta)\sin(\omega_S) + \frac{2\pi\,\omega_S}{360}\sin(\phi)\sin(\delta)\right] \qquad \text{…(3)}$$

Isc = solar constant in M J m^{-1}

ω_s = sunset hour angle

The regression constants A and B have a physical meaning: A can be considered as the fraction of extra terrestrial radiation on overcast days. Sum of A and B can be considered as the fraction of radiation received on clear days. For several regions in Europe, the Middle East and Northern Africa the Angström-Prescott constants have been established by (Supit, 1994) and (Supit & van Kappel, 1998).

Quality of the radiation estimates obtained with equation (1) depends on the quality of the data used to establish these regression constants. Supit (1994) showed that in many cases there is no relation between the latitude and the coefficients, although such a relation is frequently used to estimate these regression constants.

Mean monthly sunshine hour data and mean monthly solar radiation (MJm^{-1}) data has been obtained from Computerized Data Processing Centre, Karachi for the period 1961-2009. Four models, Food and

Agriculture Organization (FAO) UNO (1988), Rietveld (1978), Glover Mc-Culloch (1958) and Tiwari & Sangeeta (1997) have been used to estimate the empirical constants. Regression constants, in the proposed work for the five stations, have also been calculated by the help of sunshine hour data using well known Angstrom equation (1).

The Food and Agriculture Organization (FAO) proposed to calculate A and B as

$$A = 0.25 \qquad (4)$$

$$B = 0.50 \qquad (5)$$

In Rietveld model, A and B has been computed as fallows

$$A = 0.10 + 0.24\,(n/L_d) \qquad (6)$$

$$B = 0.38 + 0.08\,(n/L_d) \qquad (7)$$

In Glover Mc-Culloch model included latitudinal factor and suggested to calculated A and B as

$$A = 0.29\cos(\phi) \qquad (8)$$

$$B = 0.52 \qquad (9)$$

The coefficients A and B can be estimated by adopting Tiwari & Sangeeta model as

$$A = -0.110 + 0.235\cos(\phi) + 0.323\,(n/L_d) \qquad (10)$$

$$B = 1.449 - 0.553\cos(\phi) - 0.694\,(n/L_d) \qquad (11)$$

The results of these models were assessed by the statistical tests like Mean Percentage Error (MPE), Root Mean Square Error (RMSE), Mean Bias Error (MBE), and t-statistic. MPE, MBE and RMSE are the statistical gauges with which one can compare the models.

The MPE can be defined as the percentage deviation of the monthly average daily radiation values estimated by the model used from the measured values. The signs of errors are neglected and percentage errors are added up to obtain the mean.

$$MPE = \left(\frac{1}{n}\right)\sum\left[\frac{H_{est} - H_{mes}}{H_{mes}}\right] \qquad (12)$$

Where H_{est} is calculated value and H_{mes} is the measured value of the average daily global solar radiation and n is the number of observations.

The Mean Bias Error gives an idea of the divergence between the monthly average daily radiation values estimated by the model used and the measured value. A positive value shows over estimation and a negative value is under estimation. Over estimation of an individual observation will cancel under estimation in a separate observation.

$$MBE = \left(\frac{1}{n}\right)\sum\left(H_{est} - H_{mes}\right) \qquad (13)$$

It gives the long term performance of the correlation by allowing a comparison of the actual deviation between calculated and measured values term by term.

The Root Mean Bias Error yields the same idea of the divergence between the monthly average daily radiation values estimated by the model used and the measured values as given by MBE. However the information is relevant to the short-term performance.

$$RSME = \sqrt{\left(\frac{1}{n}\right)\sum\left(H_{est} - H_{mes}\right)} \qquad \ldots\ldots\ldots\ldots (14)$$

The ideal value for MPE and MBE would be Zero. RSME can never be negative and the lower the value the more accurate the estimate.

Results and Discussions

The calculation of Astronomical day length using equation 2, extraterrestrial radiation using equation 3, Sunshine hour and mean monthly global solar radiation were employed to obtain the empirical constants A and B in equation 1.

The input parameters are in $MJm^{-2}d^{-1}$ and hours d^{-1} for all the five stations i.e. Karachi, Quetta, Lahore, Multan and Peshawar. The proposed empirical constants A and B for these stations were obtained by employing Angstrom Model using standard computer software(s) and correlated with these four models together with observed data. Value of constants A and B were 0.3403, 0.3533, 0.03182, 0.1828, 0.3099 and 0.3858, 0.4492, 0.3314, 0.589, 0.4552 for Karachi, Quetta, Lahore, Multan and Peshawar respectively.

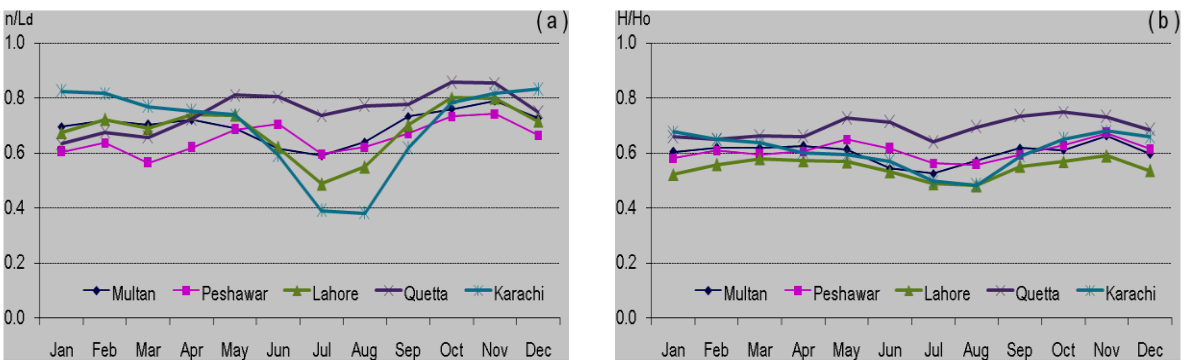

Figure 1: Variation of **(a)** n/L_d and **(b)** H/H_0 at Karachi, Quetta, Lahore, Multan and Peshawar

The relation of measured to that possible sunshine hour (n/L_d) has been shown in Figure 1a and clearness index K_t (ratio of measured/observed horizontal terrestrial radiation H to the calculated or estimated horizontal extra terrestrial radiation H_0) in Figure 1b. The dip in the month of June to August indicates the less sunshine hour and cloudiness related with summer monsoonal period for Karachi. The same is true for Lahore and Multan. The less sunshine hour and cloudiness are more prominent for Quetta during the western disturbance or winter monsoon period from December to April. However the situation for Peshawar is slightly interesting as it experiences the effects of both summer and winter monsoon.

Karachi receives minimum solar radiation in December (15.0 MJm^{-2} in average about 5.1 hours) and maximum in May (23.6 MJm^{-2} in average about 9.7 hours). Being a hill station, minimum and maximum radiation at Quetta recorded as 13.4 MJm^{-2} in average about 6.6 hours and 29.4 MJm^{-2} in average about 11.3 hours; at Lahore, 10.1 MJm^{-2} in average 6.9 hours and 22.7 MJm^{-2} in average about 10.0 hours ; Multan, in average 7.1 hours about 11.3 MJm^{-2} and in average 9.3 hours about 24.6 MJm^{-2}; and at Peshawar, 10.6 MJm^{-2} in average about 6.1 hours and 26.0 MJm^{-2} in average about 10.1 hours.

Mean monthly global solar radiation in $MJm^{-2}d^{-1}$ have been calculated by the help of equations 1, 4 to 11, and for the proposed models and have been depicted in Figure 2.

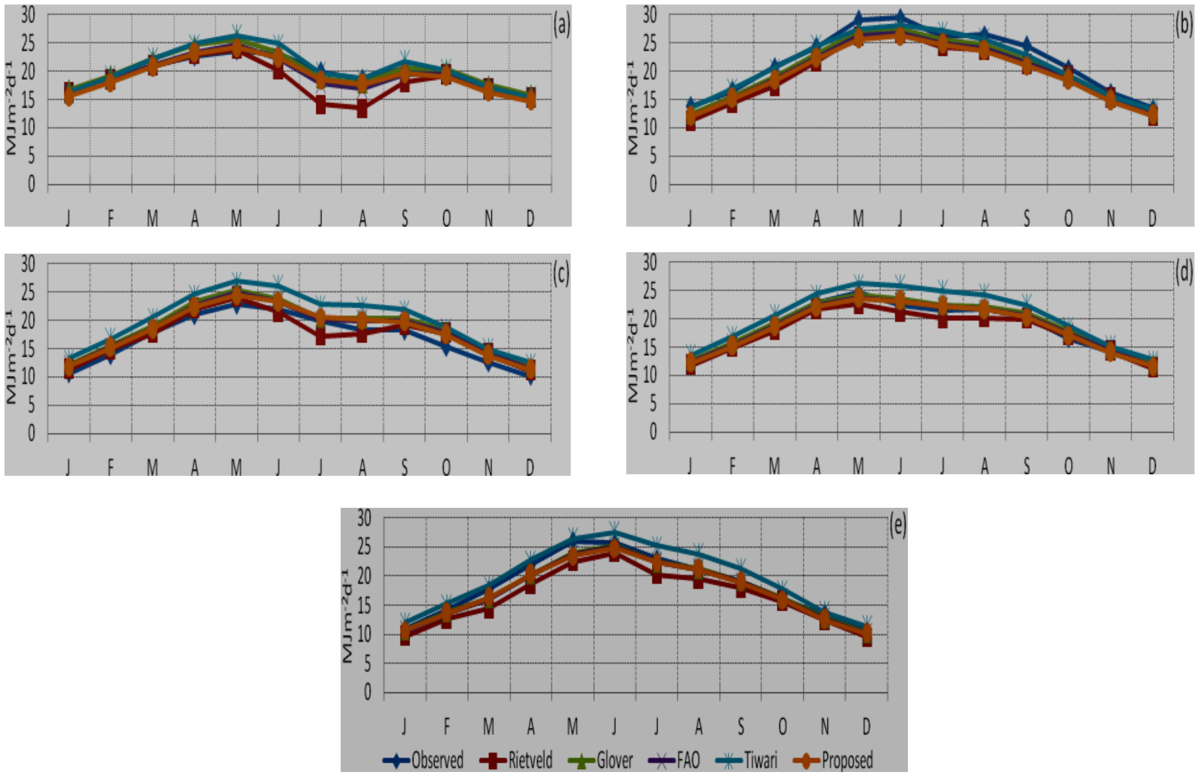

Figure 2: Estimation of Mean Monthly Global Solar Radiation Using Different Models for **(a)** Karachi **(b)** Quetta **(c)** Lahore **(d)** Multan **(e)** Peshawar

Statistical tests have applied on all the six models. Glover Mc-Culloch, FAO, and proposed empirical constants are not much significant for Quetta, Lahore. Tiwari & Sangeeta empirical model are not considerable for Lahore, Multan and Peshawar. Rietveld coefficients for the estimation of global solar radiation are acceptable for Lahore and Multan.

MPE estimation for Glover Mc Culloch model was 0.0282, -0.0642, 0.1158, 0.0272 and -0.0349, RMSE was 0.7583, 1.1762, 1.3571, 0.6831 and 0.8114 and MBE was 0.575, -1.3833, 1.8417, 0.4667and -0.6583 for station Karachi, Quetta, Lahore, Multan and Peshawar respectively. For FAO model, MPE was -0.0197, -0.0882, 0.0921, 0.0058 and -0.0416, MBE was -0.3667, -1.9083, 1.4500, 0.0750, -0.7750, and RSME was 0.6055, 1.3814, 1.2042, 0.2739, 0.8803 for Karachi, Quetta, Lahore, Multan and Peshawar respectively. The values of MPE, MBE and RSME for Tiwari and Sangeeta model were, 0.0426, -0.0231, 0.1980, 0.1034, v0.0729; v0.9167, -0.5333, 3.2583, 1.925, 1.3167; 0.9574, 0.7303, 1.8051, 1.3874, 1.1475 for Karachi, Quetta, Lahore, Multan and Peshawar respectively. Keeping the same order of stations, MPE, MBE and RSME for Rietveld model were -0.0698, -0.1103, 0.0372, -0.0408, -0.1035; -1.3917, -2.333, 0.4667, -0.8417, -1.9083; 1.1797, 1.5275, 0.6831, 0.9174, 1.3814 respectively. Error estimation for proposed model MPE, MBE and RSME for Karachi -0.0263, -0.4833, 0.6952 for Quetta -0.1028, -2.2417, 1.4972 for Lahore 0.0828, 1.3083, 1.1438, for Multan -0.0034, -0.0833, 0.2887 and for Peshawar -0.0436, -0.8167 and 0.9037 respectively.

Conclusion

The statistical tests reveal the fact that no single model can be used with higher degree of perfection for the estimation of global solar radiation at different geographical and climatic locations in Pakistan. These models are based on observed sunshine hours (climatic parameter). The obtained results of equations 12 to 14 can be used to gauge the type of model best suited for the geographical location having same climatic condition. Results were concluded that the Angstrom model is the best estimation on horizontal surface of the stations and therefore highly recommended for predicting solar radiation at any location having similar climate condition.

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