Average Daily Global Radiation and its Diffuse Component over Quetta, Pakistan – Comparison of Measured and Empirically Predicted Data

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ABSTRACT

Measured sunshine hours data are used to predict the values of average monthly daily global radiation on a horizontal surface over Quetta, Pakistan. The predicted values are compared with measured data and the agreement is found to be good. The diffuse component of the daily global radiation is also predicted by several empirical relationships obtained from the literature, using measured values of sunshine hours and cloudiness index. The empirical relationship due to Liu and Jordan is found to be justified.

INTRODUCTION

Extensive research and development on solar energy utilization over the last few decades has now proved that there are no technical barriers to the widespread application of solar energy to meet our energy requirements. Several solar energy technologies have been accepted commercially, such as solar space heating and cooling systems, thermal power generation, stills, pumps, dryers and solar photovoltaic cells for electricity generation. In all such applications as a first step, it is necessary to know the characteristics of the solar radiation for the particular site. Since accurate long term data will probably not be available, it becomes important to make estimates by empirical relationships. This paper proposes and tests such relationships for Quetta, where the only parameters measured regularly are sunshine hours and daily global radiation on a horizontal surface.

AVERAGE DAILY GLOBAL RADIATION ON HORIZONTAL SURFACES

A number of authors have proposed various empirical relationships for the prediction of daily global radiation on a horizontal surface.[1-7] Most of these relationships are complicated and involve a number of input parameters which are not experimentally measured for many places. For example Swartman et al.[1] requires measurements of relative humidity, Reddy[2] and Sabbagh et al.[3] in addition to relative humidity also consider air temperature, rainfall etc; cloud cover is taken into account by Bennett[4]; Majumdar et al.[5] and Goldberg[6] make use of air mass with a few other parameters. In developing countries especially, data for most of these meteorological parameters are scarce. Therefore for the present study of the average daily global radiation a well known and established correlation, the modified form of Angstrom's relation, developed by Prescot[7] was used. The relation is a simple one, requiring only a few input parameters. These parameters are either available from the local observatory or can readily be computed. The relation is:

$$H/H_o = a + b\, n/N_d \quad \ldots\ldots (1)$$

where a and b are regression coefficients, evaluation of which is discussed in the section "Monthly Average Daily Global Radiation". Other quantities are defined in the list of nomenclature.

The values of H_o can conveniently be computed by the relation found in reference (8), which is:

$$H_o = (24/\pi)\, IE_o\, sinL\, sinD\, [(\pi/180^\circ)w - tanw] \quad \ldots\ldots (2)$$

The average values of daily extraterrestrial radiation, H_o, were obtained by taking the average over the whole month instead of considering a particular day for each month, as used by different investigators[9,10].

The Cooper's relation[11]:

$$N_d = (2/15)\cos^{-1}(tanL\, tanD) \quad \ldots\ldots (3)$$

was applied for the computation of the day length and the average was taken over the whole month.

Mani and Rangarajan[12] have reviewed the above and other empirical relationships in their study of solar radiation parameters for India. Included in their study was the modified effective daylength parameter of Hay[13] and the effect of reflections between ground and a cloud base. The daylength is modified because N_d, computed by equation 3, does not represent the actual conditions when a Campbell-Stokes sunshine recorder is used. The sensitised card used in the recorder gets burnt only when the sun is at an elevation of 5° or more above the horizon. The accuracy and measurement period of the measured data in our results does not warrant such additional corrections.

MONTHLY AVERAGE DIFFUSE RADIATION ON A HORIZONTAL SURFACE

The intensity of the solar radiation after entering the earth's atmosphere is considerably reduced due to scattering and absorption. The actual reduction in the intensity depends upon the atmospheric conditions and the precise contents of the atmosphere, such as dust, smoke, water vapour, air molecules and other suspended matter. About half of the scattered radiation from a clear sky reaches the earth as diffuse radiation and constitutes about 15-20% of the global radiation on a horizontal surface. Therefore, the knowledge of the diffuse component of the global radiation at a particular place is important for the design and the assessment of solar energy systems.

If at the location concerned, as at Quetta, the diffuse radiation data are not available, then these can be obtained by a correlation applicable to a nearby station, where diffuse radiation is recorded. In order to have a better understanding for the prediction of monthly average diffuse radiation on a horizontal surface, two different types of correlations, classified according to the input parameters, were selected.

a. Monthly average diffuse radiation, expressed in terms of the fraction of maximum possible sunshine hours and using extraterrestrial radiation. Sunshine hours n have to be measured. In this category, the relation proposed by Iqbal[14] is:

$$H_d/H_o = 0.163 + 0.478n/N_d - 0.655(n/N_d)^2 \quad (4)$$

b. Monthly average diffuse radiation, treated as a fraction of monthly average daily global radiation and expressed in terms of cloudiness index $K_T = H/H_o$. There are two commonly used correlations which make use of cloudiness index as an input parameter. Global radiation on a horizontal surface, H, has to be measured. The first relation considered here is due to Liu and Jordan[15] developed by Klein[10]:

$$H_d/H = 1.390 - 4.027\,K_T + 5.531\,(K_T)^2 - 3.108\,(K_T)^3 \quad (5)$$

The other relation is proposed by Page[16], and is valid for locations between $L = 40°$N and 40°S (Quetta lies at $L = 30.18°$N):

$$H_d/H = 1.00 - 1.13\,K_T \quad (6)$$

DISCUSSION OF RESULTS

a. Monthly Average Daily Global Radiation, H

The regression coefficients a and b of relation (1) have been computed using least square techniques for the period 1957-84. For this, the measured data for the number of bright sunshine hours (1969-85) and the average daily global radiation (1957-84) were obtained from the local meteorological station in Quetta. The evaluated results are:

$$a = 0.43$$
$$b = 0.36$$
$$r = 0.93$$

r being the correlation coefficient. Thus the empirical relationships for Quetta becomes:

$$H/H_o = 0.43 + 0.36n/N_d \quad (7)$$

The estimated and measured values of daily global radiation are given in Table 1 and Fig. 1. Estimated values correspond very well with the measured data and the percentage differences are very small. Therefore relation 7 may perhaps be used at the locations having similar climatic conditions to Quetta.

Table 1
Monthly average daily global radiation H_d (MJm^{-2})
Comparison of estimated and measured data for Quetta, Pakistan.

Months	Measured H	Estimated H (Eq. 7)	% Difference
Jan	14.1	13.6	3.5
Feb	16.7	16.9	−1.2
Mar	20.6	20.7	−0.5
Apr	24.4	25.0	−2.4
May	28.8	28.3	1.7
Jun	29.7	29.6	0.3
Jul	26.9	27.4	−1.8
Aug	25.9	26.5	−2.3
Sept	24.2	24.2	0.0
Oct	20.5	20.3	1.0
Nov	16.0	16.0	0.0
Dec	13.5	13.3	1.5

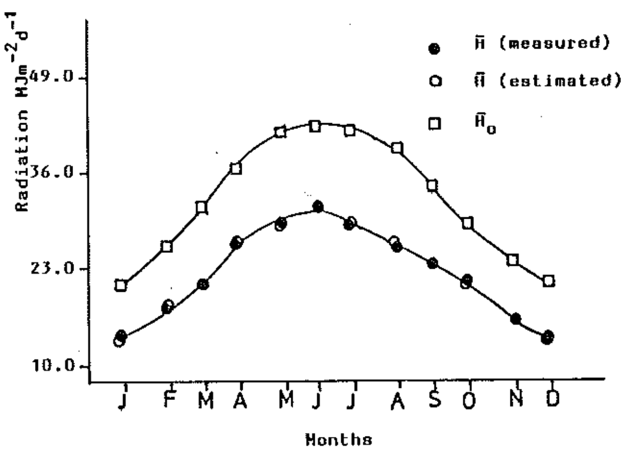


Fig. 1 Monthly variations in extraterrestrial radiation and comparison of measured and empirically predicted monthly average daily global radiation over Quetta, Pakistan.

b. *Monthly Average Daily Diffuse Radiation, H_d*

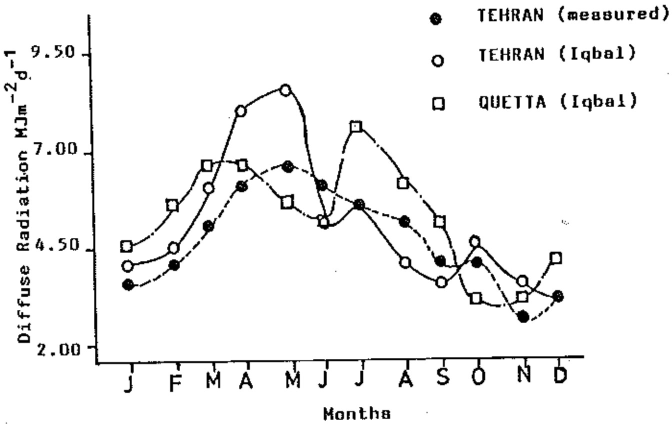
Because experimental values of diffuse radiation are not available in Quetta it is difficult to justify a correlation for making their estimates. However, in order to obtain a rough estimate of monthly average daily diffuse radiation, a nearby station in Tehran is considered where the diffuse radiation is recorded. Tehran is situated at latitude 35.68°N, altitude 1191m, whereas Quetta is at 30.18°N and 1799m. The monthly average values of daily global radiation for Tehran were obtained from reference (17). Diffuse radiation and sunshine hours for Tehran were available from the Meteorological Office, International Services, Bracknell[18]. The monthly average daily diffuse radiation on horizontal surfaces has been computed both for Tehran and Ouetta using three correlations 4-6 and applying the respective local data. In order to evaluate the accuracy of these correlations the estimated and measured values for Tehran are compared in Table 2 and Fig. 2 (a-c). It appears from the results that the three correlations are capable of showing the same pattern of seasonal variation. The results from relation 4, by Iqbal, are much scattered. Relation 6, due to Page, overestimates throughout the year. The estimated values by relation 5 (Liu and Jordan) are close to the measured data for Tehran. The differences between the estimates made

Table 2
Monthly average daily diffuse radiation (MJm^{-2})
Comparison of estimated and measured data for Tehran

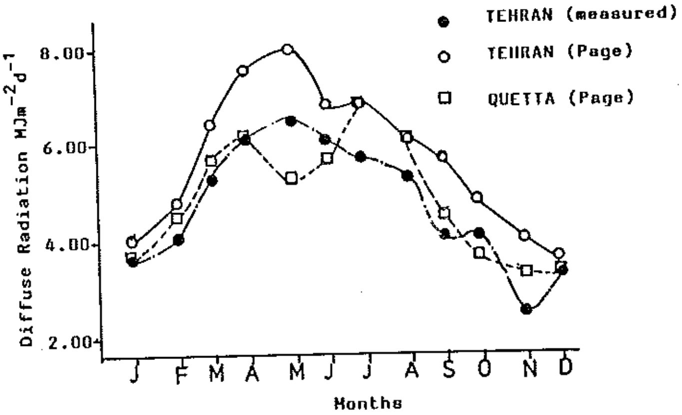
Month	Measured H_d	Estimated H_d		
		Iqbal (Relation 4)	Page (Relation 6)	Liu & Jordan (Relation 5)
Jan	3.4	3.8	3.9	3.3
Feb	3.9	4.7	4.9	4.2
Mar	5.1	5.9	6.4	5.5
Apr	5.9	8.0	7.5	6.5
May	6.3	8.3	8.0	7.2
Jun	5.8	5.1	6.9	6.8
Jul	5.7	5.4	6.8	6.6
Aug	5.0	4.2	6.0	6.0
Sep	4.1	3.6	5.5	5.3
Oct	4.0	4.7	4.8	4.4
Nov	2.3	3.6	4.0	3.5
Dec	3.2	3.2	3.6	3.0

% Differences from Measured

	Iqbal (Relation 4)	Page (Relation 6)	Liu & Jordan (Relation 5)
Jan	11.8	14.7	–2.9
Feb	20.5	25.6	7.2
Mar	15.7	25.5	7.8
Apr	35.6	27.1	10.2
May	31.8	27.0	14.3
Jun	–12.1	19.0	17.2
Jul	–5.3	19.3	15.8
Aug	–16.0	20.0	20.0
Sep	–12.2	34.1	29.3
Oct	17.5	20.0	10.0
Nov	56.5	73.9	52.2
Dec	00.0	12.5	–6.2



2(a)



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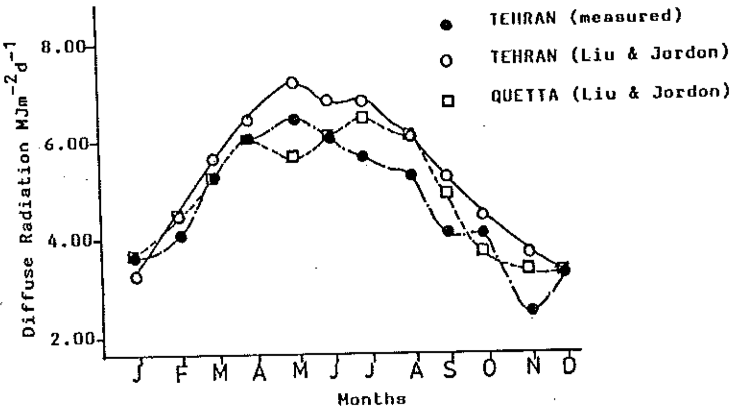

2(c)

Fig. 2 Monthly average daily diffuse radiation – Comparison of measured values for Tehran, and theoretically predicted for Quetta and Tehran using:
a. Relation 4, proposed by Iqbal.
b. Relation 6, proposed by Page.
c. Relation 5, proposed by Liu and Jordan.

through Page and through Liu and Jordan are small. Therefore both the later correlations are found applicable for Tehran, and hence can be used for making an estimate of monthly average daily diffuse radiation for Quetta and other locations having a similar climate. The estimated diffuse radiation for Quetta is given in Table 3, and Fig. 2 (a-c).

Table 3
Estimated monthly average daily diffuse radiation H_d (MJm^{-2}) at Quetta. The three named relationships 4, 5, 6 are used.

Months	Estimated H_d		
	Iqbal (Relation 4)	Page (Relation 6)	Liu & Jordan (Relation 5)
Jan	4.6	3.6	3.5
Feb	5.3	4.6	4.4
Mar	6.7	5.5	5.3
Apr	6.7	6.1	6.0
May	5.7	5.4	5.7
Jun	5.1	5.5	5.8
Jul	7.3	6.7	6.6
Aug	5.9	6.0	6.0
Sep	4.1	4.5	4.8
Oct	3.2	3.5	3.8
Nov	3.2	3.2	3.3
Dec	3.8	3.1	3.1

CONCLUSION

Based on the available sunshine hours data from the local meteorological station, an Angstrom type empirical correlation for the prediction of monthly average daily global radiation on a horizontal surface has been proposed for Quetta, Pakistan. The correlation has been checked against the measured values. A reasonable agreement between measured and estimated values is seen with minor percentage differences. The proposed correlation is thus quite satisfactory. It has the advantage that very little computation is involved and a single measured input parameter, i.e. sunshine hours, is required.

In the absence of measured data of diffuse radiation it is not possible to propose or establish a suitable empirical correlation for their prediction over Quetta. However, for an approximate estimate, a correlation found to be applicable to a nearby station, say Tehran, may be used. After checking the accuracy of different correlations against the measured data of Tehran, it is suggested that the Liu and Jordan correlation may be used for an estimate of monthly daily diffuse radiation. Page's correlation can also be used. These correlations only provide an approximate estimate of diffuse radiation for Quetta. In order to establish reliable correlations, measurements of diffuse radiation over a long period are required.

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NOMENCLATURE

E_o Eccentricity correction factor

H Daily global radiation on horizontal surface ($MJm^{-2}d^{-1}$)

H_o Extraterrestrial radiation on horizontal surface ($MJm^{-2}d^{-1}$)

H_d Daily diffuse radiation on horizontal surface ($MJm^{-2}s^{-1}$)

I Solar constant, 4.921 $MJm^{-2}h^{-1}$

n Time of bright sunshine hours as measured (h)

N_d Day length (h)

w Sunset hour angle (degrees)

D Declination (degrees)

L Latitude (degrees)

Note: the text mainly refers to monthly averages

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