Recital of Some Existing Sunshine-Based Models of Global Solar Radiation for Selected Stations of Punjab, Pakistan: A Comparative Study

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Abstract: An essential requirement of design of a solar energy conversion system is the precise knowledge of the availability of global solar radiation and its components at the location of interest. In developing countries like Pakistan such data is not available for all locations owing to which there is need of employing different models for the estimation of global solar radiation that use climatological parameters of the location under study. In the present paper the monthly average daily global solar radiation at two stations (Lahore and Multan) in the Punjab province of Pakistan has been predicted using empirical models of Angstrom, Rietveld and Glover Mc Culloch. The performances of these models have been assessed employing different statistical tests. Punjab is the largest province of Pakistan by population and the global solar radiation data for a long period of time is available only for the stations mentioned above. This study will help solar energy research workers in the region to use the empirical models for the places with similar conditions and having no facilities of recording the radiation data.

Key Words: Global Solar Radiation, Empirical Models.

1. INTRODUCTION

Information concerning the accessibility of global solar radiation and its components at a specific site is vital for practical utilization of solar energy. In developing countries like Pakistan the lack of the facilities for recording solar radiation is an obstruction for most of the ventures. Due to this verity it becomes essential to imply empirical models based on various climatological factors. The most significant factor in this regard is the sunshine hours whose recording is quite often. In Pakistan the daily sunshine hours is recorded at more than 40 stations whereas the daily global solar radiation is recorded only at five stations. This paper presents a comparison to evaluate the prognostic ability of some existing empirical models based on sunshine hours called sunshine-based models for two stations of the region of Punjab, Pakistan.

Being largest by population and the second largest by area, Punjab is a very important province of Pakistan. It is situated at the eastern periphery of the Iranian Plateau and the northwestern border of the geologic Indian plate in South Asia [1]. Punjab is the only province of Pakistan that touches all the other provinces of the country and can thus be regarded as central region of the country. This significant geographical situation and a huge number of inhabitants greatly affects Punjab's stance on issues of state echelon. The selected stations from the province i.e., Lahore and Multan are two large and the only cities of this province where the global solar radiation data is measured.

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2. MODELS USED

2.1. Angström–Prescott–Page Model

The most commonly used sunshine based model used for the estimation of monthly average daily global solar radiation (H) measured in MJm^{-2} is of Angstrom [2] developed later by Page [3] is given as

$$H=H_0\,[a+b\,(n/N)]$$

where H_0 is the monthly average daily extraterrestrial radiation, n is the day length, N is the maximum possible sunshine duration, and a and b are empirical coefficients signifying the measure of the overall atmospheric transmission under the total cloudy condition (n/N = 0) and the rate of increase of H/H_0 with n/N respectively. These are also referred as Angstrom coefficients and there value has been reported for a number of stations [4]. We have previously reported their values for Karachi, Pakistan [5,6]. In the present paper we report the values of these constants for Lahore and Multan for the first time considering a long-range data of 25 years, which has not been done so far.

The monthly average daily extraterrestrial solar radiation on a horizontal surface i.e., H_0 is one of the basic input parameter for estimation and can be calculated with fair amount of accuracy from the geographical information of a particular place in MJm^{-2}[7].

2.2. Rietveld Model

Rietveld examined several published values of the a and b coefficients [8] and pointed out that a is related linearly

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and b hyperbolically to the appropriate mean value of n/N [9]:

$$a = 0.10 + 0.24\ (n/N)$$
$$b = 0.38 + 0.08\ (N/n)$$

Thus evaluating "a" and "b" by the equations suggested one could estimate H using Angström model.

2.3. Glover-Mc Culloch Model

It is a well-established fact that the performance of a sunshine based model considerably enhances with the introduction of geographic factors. One such example is the model proposed by Glover and Mc Culloch [7]:

$$H = H_0\ [0.29 \cos \varphi + 0.52\ (n/N)]$$

where φ is the latitude of the location.

3. DATA ANALYSIS

In order to assess the performance of the models used for estimation of the models we used several statistical test methods namely the mean percentage error (MPE), the mean bias error (MBE), the root mean square error (RMSE) and t-statistics.

3.1. Mean Percentage Error (MPE)

The mean percentage error can be defined as the percentage deviation of the monthly average daily radiation values estimated by the model used from the measured values. It is thus calculated as:

$$MPE = (1 / n) \sum \{(H_c - H_m) / H_m\}$$

where H_c is calculated value and H_m is the measured value of the average daily global solar radiation. Its ideal value is zero.

3.2. Mean Bias Error (MBE)

By the mean bias error one can have an idea of the divergence between the monthly average daily radiation values estimated by the model used and the measured values. It is given as:

$$MBE = (1 / n) \sum (H_c - H_m)$$

It essentially furnishes the information on the long-term performance of the correlations by allowing a comparison of the actual deviation between calculated and measured values term by term. As in the case of MPE the ideal value of MBE is also zero.

3.3. Root Mean Bias Error (RMSE)

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. It can be given as:

$$RMSE = \{(1 / n) \sum (H_c - H_m)^2\}^{0.5}$$

RMSE can never be negative and its ideal value is zero.

3.4. t-Statistics

In general MPE, MBE and RMSE are the statistical gauges with which one can compare the models. Owing to the fact that one cannot have any idea concerning the statistical significance of the model, a supplementary indicator namely t-statistic was used. It not only permits the comparison of models but also identify if the given model is statistically significant at a particular confidence level. The t-statistic is derived in [8] and is given by

$$t = \{(n-1)\ MBE^2 / (RMSE^2 - MBE^2)\}^{0.5}$$

4. RESULTS AND DISCUSSION

Table **1** highlights the geographical information pertaining to the station studied. Moreover Table **2** and **3** show the input parameters for the estimation of daily average global solar radiation for these stations. Table **4** and **5** give the values of measured and calculated values of monthly average global solar radiation for Lahore and Multan respectively whereas Table **6** and **7** summarizes the statistical tests employed for Lahore and Multan respectively.

It is obvious that the calculated values of H at both the stations under consideration are in nice agreement with the measured values for all the months of the year

It is also worth mentioning that the percentage error for all the models tested does not go beyond ±13% for the locations. It was found that Angstrom model has the lowest values of MPE, MBE, and RMSE showing the best outcome among all the models when we make a simple comparison. Also, the MBE values of are close to zero thus making it a kind of ideal for such estimations. However the values of t-test are a bit higher indicating that it is statistically less significant. In this regard Rietveld model is highly significant being having the least values of the t-test. Thus in general we can say that Angstrom model can be considered excellent giving a precise estimation for H at both stations with acceptable errors. Therefore, it has been concluded that this model is highly recommended for use to estimate H at any location in Punjab, Pakistan.

Table 1. Geographical Information

Station	Longitude	Latitude
Lahore	74°22'E	31°32'N
Multan	71°36'E	30°15'N

Table 2. Input Parameters for Lahore

Month	H_0	n/N
January	20.13	0.674
February	24.89	0.699
March	30.64	0.616
April	36.11	0.764
May	39.54	0.703
June	40.78	0.639
July	40.07	0.563
August	37.33	0.548
September	32.54	0.702
October	26.52	0.816
November	21.22	0.796
December	18.76	0.663

Table 3. Input Parameters for Multan

Month	H_0	n/N
January	20.89	0.643
February	25.55	0.660
March	31.12	0.624
April	36.33	0.756
May	39.53	0.689
June	40.65	0.633
July	39.98	0.575
August	37.45	0.700
September	32.95	0.748
October	27.12	0.743
November	21.95	0.763
December	19.54	0.615

5. CONCLUSION

The empirical models used to estimate H over the selected stations of the province of Punjab in Pakistan have been the one used for many stations around the globe indicating the fact that these are quite universal. These models are based on the sunshine hours, which is a frequently measured parameter. The models were compared on the basis of the statistical error tests; the mean percentage error (MPE), mean bias error (MBE), root mean square error (RMSE) and t-test. To determine the statistical significance of these estimates, the critical value for the two-sided t-statistic is computed at 99% level of significance with 'n-1' degrees of freedom (i.e., 3.106) obtained via standard statistical table and compared with the calculated values. According to the results, the Angstrom model showed the best estimation of the global solar radiation on a horizontal surface for the stations. Therefore this model is extremely recommended for predicting H at any location having similar climate conditions.

Table 4. Values for H for Lahore

Month	H_m	H_c Angstrom	H_c Rietveld	H_c Glover
Jan.	9.87	10.08	12.04	12.03
Feb.	13.78	12.61	15.27	15.19
Mar.	17.61	14.92	17.22	17.45
Apr.	20.58	18.89	23.64	23.27
May	21.07	20.08	24.32	24.23
Jun.	20.51	20.06	23.50	23.65
Jul.	19.34	18.93	21.20	21.78
Aug.	20.43	17.51	19.40	19.90
Sep.	18.97	16.52	20.02	19.92
Oct.	14.28	14.25	18.19	17.86
Nov.	10.73	11.27	14.29	13.96
Dec.	9.62	9.34	11.09	11.11

Table 5. Values of H for Multan

Month	H_m	H_c Angstrom	H_c Rietveld	H_c Glover
Jan.	10.89	11.21	12.09	12.12
Feb.	13.59	13.85	15.05	15.17
Mar.	17.13	16.64	17.64	17.90
Apr.	21.16	20.42	23.57	23.86
May	22.86	21.66	24.00	24.06
Jun.	21.56	21.81	23.27	23.56
Jul.	21.50	20.59	21.45	21.97
Aug.	20.29	18.45	22.99	23.02
Sep.	20.17	15.15	21.21	21.07
Oct.	15.26	12.35	17.37	15.26
Nov.	12.55	10.41	14.33	12.55
Dec.	10.44	0.663	10.97	10.44

Table 6. Results of Statistical Tests for Lahore

	Angstrom	Rietveld	Glover Mc.
MPE	-0.0535	0.1345	0.1336
MBE	-1.0257	1.9492	1.9633
RMSE	1.5208	2.4443	2.3517
t-test	3.0393	4.3833	5.0300

Table 7. Results of Statistical Tests for Multan

	Angstrom	Rietveld	Glover Mc.
MPE	-0.1446	0.0836	0.0623
MBE	2.1547	1.3867	1.1317
RMSE	3.4219	1.5848	1.4667
t-test	2.6884	5.9939	4.0224

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