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Monthly Average Solar Radiation and Angstrom-Prescott Model for Islamabad, Pakistan †

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Abstract: For any solar energy utilization, it is essential to know the value of radiation on an hourly basis and monthly basis. Generally, for Islamabad, Pakistan, available data are limited, and it is difficult to correctly evaluate the harnessed solar energy. In this paper, the monthly average solar radiation of Islamabad on an hourly basis has been presented, as compared to the available yearly average data in the literature. Moreover, the Angstrom–Prescott constant for Islamabad, Pakistan, has been calculated. The proposed relation has the error of radiation less than 1.5%.

Keywords: solar radiation; extraterritorial solar radiation; Islamabad; Pakistan; angstrom constant

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1. Introduction

Monthly average values of the clear sky solar radiation component for Islamabad, Pakistan, specifically for 9AM, 12PM, and 3PM, have been presented by P. Akhter et al. [1]. However, correlations have been proposed by Firaz Ahmad et al. [2] to obtain monthly average daily radiation at Karachi, Pakistan. Using various empirical relations, the mean monthly solar radiation has been estimated for Karachi, Quetta, Lahore, Multan, and Peshawar by Gadiwala M. S. [3]. Ulfat et al. have proposed the Angstrom constant for global and diffuse radiation for Islamabad [4]. G Salima et al. have determined the Angstrom constant for estimating solar radiation in Malawi [5]. S A M Maleki et al. have revisited the various solar radiation models [6].

2. Monthly Average Solar Radiation

The daily extraterrestrial solar radiation on horizontal surface (H_{oh}) is calculated from [7]:

$$H_{oh} = G_o^* t_s \left[1 + 0.033 \cos\left(360 \frac{d}{365}\right)\right] [\sin(\varnothing)\sin(\delta) + \frac{180}{\pi \omega_s} \cos(\varnothing)\cos(\delta)\sin(\omega_s)] \quad (1)$$

where G_o* is the solar constant (G_o* = 1366 w/m^2). d is the day of the year starting from 1st January, as d = 1 and φ = 33.738° is the latitude of Islamabad. δ is declination and ω_s is the hour angle at sunset.

To calculate the average monthly radiation, the midday of the month has been considered. Using Equation (1), the average monthly extraterrestrial solar radiation on a clear day of Islamabad is presented in Figure 1.

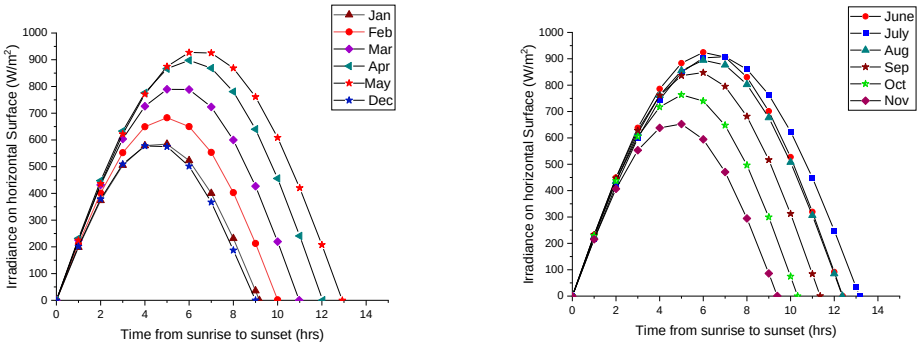

Figure 1. Monthly average solar irradiance of Islamabad.

3. Angstrom–Prescott Model for Islamabad, Pakistan

The daily solar radiation on the horizontal surface on earth (H_h) is given by the Angstrom–Prescott relation [8]:

$$\frac{H_h}{H_{oh}} = a + b\frac{n}{N} \quad (2)$$

The application of Equation (2) involves the parameters N and H_{oh} that are determined using the geographical information of the location under consideration only, where n/N is the fraction of possible sunshine, N is the maximum possible bright sunshine duration, and n is actual bright sunshine duration. The value of N is calculated from the metrological data of sunrise and sunset. It approximately takes 30 min from sunrise to reach full brightness and approximately 30 min before sunset when the brightness starts to reduce. This fact has been considered while calculating the N value. a and b are the Angstrom constants.

To evaluate the Angstrom constant (a, b), global solar radiation on the horizontal surface on earth (H_h) is taken from P. Akhter et al. [1] at 12:00 pm noon. Global extraterrestrial solar radiation on the horizontal surface (H_{oh}) is calculated using Equation (1). The actual bright sunshine duration (n) is evaluated from weather and climate [9]. Since the data pertain to the total hours of average bright sunshine of the month, the daily average value is calculated by diving by the total number of days of the month (see Table 1).

Table 1. Data for evaluating the Angstrom constant.

Month	Average Sun Shine Month	n	N	n/N	H_h	H_{oh}	H_h/H_{oh}
	(hr/Month)	(hr)	(hr)		(Global)	(Global) Calculated	(Global) Calculated
1	196	6.323	9.18	0.688	561	839	0.668
2	189	6.750	10.2	0.661	674	956	0.705
3	202	6.516	10.98	0.593	762	1134	0.671
4	249	8.300	12.05	0.688	866	1246	0.695
5	311	10.032	12.93	0.775	928	1333	0.696
6	298	9.933	13.4	0.741	897	1352	0.663
7	260	8.387	13.17	0.636	912	1302	0.700
8	249	8.032	12.38	0.648	875	1222	0.716
9	262	8.733	11.37	0.768	793	1216	0.652
10	274	8.839	10.33	0.855	690	1091	0.632
11	249	8.300	9.4	0.882	555	936	0.592
12	194	6.258	8.93	0.700	489	836	0.584

Figure 2 shows the plot of H_h/H_{oh} vs. n/N, along with the fitted curve. The Angstrom constants obtained by fitting a linear curve are $a = 0.92697 \pm 0.0485$ and $b = -0.35362 \pm 0.06104$. The Angstrom–Prescott model for Islamabad, Pakistan, is given by:

$$\frac{H_h}{H_{oh}} = 0.92697 - 0.35362 \frac{n}{N} \quad (3)$$

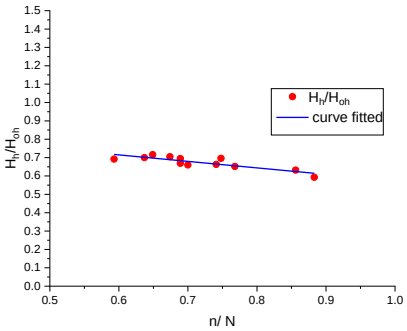

Figure 2. Linear curve fitting to obtain the Angstrom constant.

The predicted values by Equation (3) are compared with the calculated values given in Table 2. The error is less than 1.5%. Hence, the proposed model can be confidently used to calculate global solar radiation on the horizontal surface on earth at Islamabad, Pakistan.

Table 2. Comparison of calculated results (Equation (2)), predicted by Equation (3).

Month	*n/N*	H_h/H_{oh} (Global) Calculated	H_h/H_{oh} (Predict)	Error %
1	0.688	0.668	0.683	−1.476
2	0.661	0.705	0.692	0.012
3	0.593	0.671	0.717	−0.045
4	0.688	0.695	0.683	0.011
5	0.775	0.696	0.652	0.043
6	0.741	0.663	0.664	−0.001
7	0.636	0.700	0.701	−0.001
8	0.648	0.716	0.697	0.018
9	0.768	0.652	0.655	−0.003
10	0.855	0.632	0.624	0.008
11	0.882	0.592	0.614	−0.021
12	0.700	0.584	0.679	−0.094

Ulfat et al. [5] have proposed the Angstrom model as

$$\frac{H}{H_o} = 0.2883 + 0.5519 \frac{n}{N} \quad (4)$$

The proposed model for the prediction of global solar radiation on horizontal surface by Equations (3) is compared with the Ulfat model given by Equation (4). The result is given in Table 3. It is observed that that, in some cases, the Ulfat model's error is up to 18%. Conversely, our proposed model error is less than 1.5%.

Table 3. Comparison of the proposed model with the Ulfat model.

Month	H/H_o (Global) Calculated	H/H_o Predicted	H/H_o Predicted % Error	H/H_o Ulfat	H/H_o Ulfat % Error
1	0.668	0.683	−1.476	0.668	0.024
2	0.705	0.692	0.012	0.653	5.149
3	0.671	0.717	−0.045	0.615	5.613
4	0.695	0.683	0.011	0.668	2.657
5	0.696	0.652	0.043	0.716	−2.033
6	0.663	0.664	−0.001	0.697	−3.395
7	0.700	0.701	−0.001	0.639	6.069
8	0.716	0.697	0.0185	0.646	6.966
9	0.652	0.655	−0.003	0.712	−6.007
10	0.632	0.624	0.008	0.760	−12.807
11	0.592	0.614	−0.021	0.775	−18.266
12	0.584	0.679	−0.094	0.675	−9.013

4. Conclusions

The monthly average solar radiation of Islamabad, Pakistan, is provided, and the Angstrom–Prescott model for Islamabad, Pakistan, is proposed. The proposed model predicts global solar radiation within a 1.5% error.

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