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RESEARCH ARTICLE *Received: 15/3/2018, Accepted: 24/4/2018*

Estimation of the monthly average global and diffuse solar radiation for the city Bareilly, Uttar Pradesh, India

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Abstract: This paper presents a process to develop the monthly global and diffused solar radiation data for the city Bareilly, Uttar Pradesh in order to exploit the solar energy available at the location throughout the year. It is located in the northern zone of Uttar Pradesh at 28.367°N latitude and 79.4304°E longitude at an elevation of 268 meters. The values of monthly average global solar radiation are calculated using the regression constants in the model provided by Gopinathan. Kreith and Gupta model has been used for estimating the values of monthly average diffuse solar radiation. The calculated data has been analyzed and the result has been simulated through matlab.

Keywords: Solar constant, solar day length, Bareilly, Uttar Pradesh

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1. Introduction: Solar energy is a very large, inexhaustible and environmentally clean source of energy. It is sufficient to meet all the present and future energy demands of the world **[1].** A number of technologies have been developed to harness its potential. Solar radiation data provides information of how much the sun's energy strikes the surface at a place on earth during a particular period **[2]**. Such data is available for most of the developed countries of the world. India, being a tropical country receives adequate amount of sunshine for most of the time of the year but the parameters are measured only in a few meteorological stations. Hence to recognize its true potential, data should be available for each and every corner of the country. For places where it is not directly measured, solar radiation data can be estimated by using models and empirical correlation **[3]**. Presently, global solar radiation in India is measured at four work stations namely Delhi, Kolkata, Mumbai and Chennai **[4-5]**.Bareilly is the eighth largest metropolis in Uttar Pradesh and the 50thlargest city in India. It occupies an area of 4120 sq km and receives good amount of sunshine throughout the year **[6-7].** Solar radiation estimation can unlock the potential of solar energy making it a viable option for developing energy for this place.

2. Methodology: The Angstrom correlation has served as a basic approach to estimate global radiation for a long time. He was the first to relate the amount of sunshine received at a place, by a linear relation given as **[8-9] –**

$$\frac{\overline{H}_g}{\overline{H}_o} = a + b\left(\frac{\bar{S}}{\bar{S}_o}\right) \quad (1)$$

where $\overline{H}_g$ is the monthly average daily global solar radiation received on a horizontal surface (MJm^{-2}day^{-1}), $\overline{H}_o$ is the monthly average daily extraterrestrial radiation on a horizontal surface (MJm^{-2}day^{-1}), a and b are regression constants, $\bar{S}$ is the monthly average daily number of hours of bright sunshine, $\bar{S}_o$ is the monthly average daily maximum number of hours of possible sunshine.

The value of $\overline{H}_o$ is calculated as:

$$\overline{H_o} = \frac{24}{\pi} I_{sc}(1 + 0.033cos\frac{360n}{365})(\omega_s sin\varphi\ sin\delta + cos\varphi\ cos\delta\ sin\omega_s) \quad (2)$$

where I_{sc} is the solar constant having value of 1367 W/m^2, n is the average number of days in a month, φ is the latitude of the location, δ is the declination angle calculatedas:

$$\delta = 23.45 \sin\left(\frac{360(284+n)}{365}\right) \tag{3}$$

and ω_s is the sunset hour angle given as:

$$\omega_s = \cos^{-1}(-tan\delta\ tan\varphi) \tag{4}$$

Considering the value of ω_s in degree, the value of $\overline{S_o}$ is calculated as

$$\bar{S}_o = \frac{2\omega_s}{15} \tag{5}$$

Gopinathan considered the effects of latitude, elevation and established the following equation to calculate regression coefficients a and b of the Angstrom type correlation for global radiation **[10]**

$$a = -0.309 + 0.539 \cos\varphi - 0.0693\, h + 0.29\left(\frac{\bar{S}}{\bar{S}_o}\right) \tag{6}$$

$$b = 1.527 - 1.027 \cos\varphi + 0.0926h - 0.359\left(\frac{\bar{S}}{\bar{S}_o}\right) \tag{7}$$

where h is the elevation of the place. Usually (a+b) has values in the range of 0.6 for a moist and turbid atmosphere and 0.85 for a dry and dust free atmosphere **[11-12]**.

The diffuse radiation $\overline{H}_d$can be estimated by an empirical formula illustrated in equation (8) which correlates the diffuse solar radiation component $\overline{H}_d$ to the global solar radiation$\overline{H}_g$. This linear expression was obtained when the available Indian data was analyzed **[13].**

$$\frac{\overline{H}_d}{\overline{H}_g} = 1.411 - 1.696\left[\frac{\overline{H}_g}{\overline{H}_o}\right] \tag{8}$$

The ratio $\overline{H}_g/\overline{H}_o$ is denoted by $\overline{K}_T$ and is called the monthly average clearness index **[14].** This parameter indicates the degree of clearness of the atmosphere.

3. Results and discussion: The monthly average global solar radiation for the city Bareilly has been calculated by the above provided Gopinathan Model while Kreith and Gupta model has been used for estimation of diffuse radiation. Table 1 shows the calculated values of input parameters for estimation of both global and diffuse radiation.

Table (1): Calculated values of Input Parameters for the city Bareilly.

Month	n (starting from 1st anuary)	δ (in degrees)	ω_s (in radians)
January	16	-21.0963	1.3609
February	45	-13.6198	1.4396
March	75	-2.4177	1.5480
April	105	9.4149	1.6604
May	136	19.0306	1.7581
June	166	23.3144	1.8057
July	197	21.3537	1.7835
August	228	13.4550	1.7003
September	258	2.2169	1.5917
October	289	-9.9663	1.4758
November	319	-19.1478	1.3822
December	350	-23.3717	1.3353

Table (2) depicts the values of monthly average daily number of hours of bright sunshine ($\bar{S}$), monthly average daily maximum number of hours of possible sunshine ($\bar{S}_o$.) and monthly average daily extraterrestrial radiation ($\overline{H}_o$). The regression constant values vary all over the year due to the variation in possible sunshine hour ratio. The approximate values of*a* and*b* for Bareilly can be obtained as *0.3371* and *0.4124* respectively.

Table (2): Values of regression coefficient and clearness index for Bareilly, Uttar Pradesh.

Month	$\bar{S}$ (in hour)	$\overline{S_o}$ (in hour)	$\overline{H_o}$ (MJ/m^2-day)
January	7.4000	10.3969	22.1175
February	8.1000	10.9977	26.4281
March	8.4000	11.8258	32.1668
April	9.5000	12.6849	37.0668
May	9.1000	13.4312	40.0242
June	7.3000	13.7942	40.9703
July	5.4000	13.6249	40.3815
August	5.8000	12.9896	38.0589
September	7.1000	12.1597	33.8469
October	8.9000	11.2741	28.1112
November	8.6000	10.5592	23.1223
December	7.5000	10.2008	20.7070

In Table (3), the values calculated for monthly global solar radiation ($\overline{H_g}$), diffuse solar radiation ($\overline{H}_d$) and clearness index ($\overline{K}_T$) have been shown.

Table (3): Complete Solar Radiation Data for Bareilly, Uttar Pradesh, India

Month	$\overline{H_g}$ (MJ/m^2-day)	$\overline{H}_d$ (MJ/m^2-day)	$\overline{K}_T$
January	13.9906	4.7313	0.6326
February	16.9911	5.4475	0.6429
March	20.3276	6.8956	0.6319
April	24.0171	7.4956	0.6479
May	24.7159	8.9887	0.6175
June	22.2319	10.9090	0.5426
July	18.6614	11.7050	0.4621
August	18.8018	10.7762	0.4940
September	19.3633	8.5343	0.5721
October	18.6537	5.5273	0.6636
November	15.5529	4.2025	0.6726
December	13.3020	4.2766	0.6424

In Figure (1, 2 and 3), the values calculated for $\overline{H_g}$, $\overline{H}_d$ and $\overline{K}_T$, have been plotted respectively, after simulation through matlab.

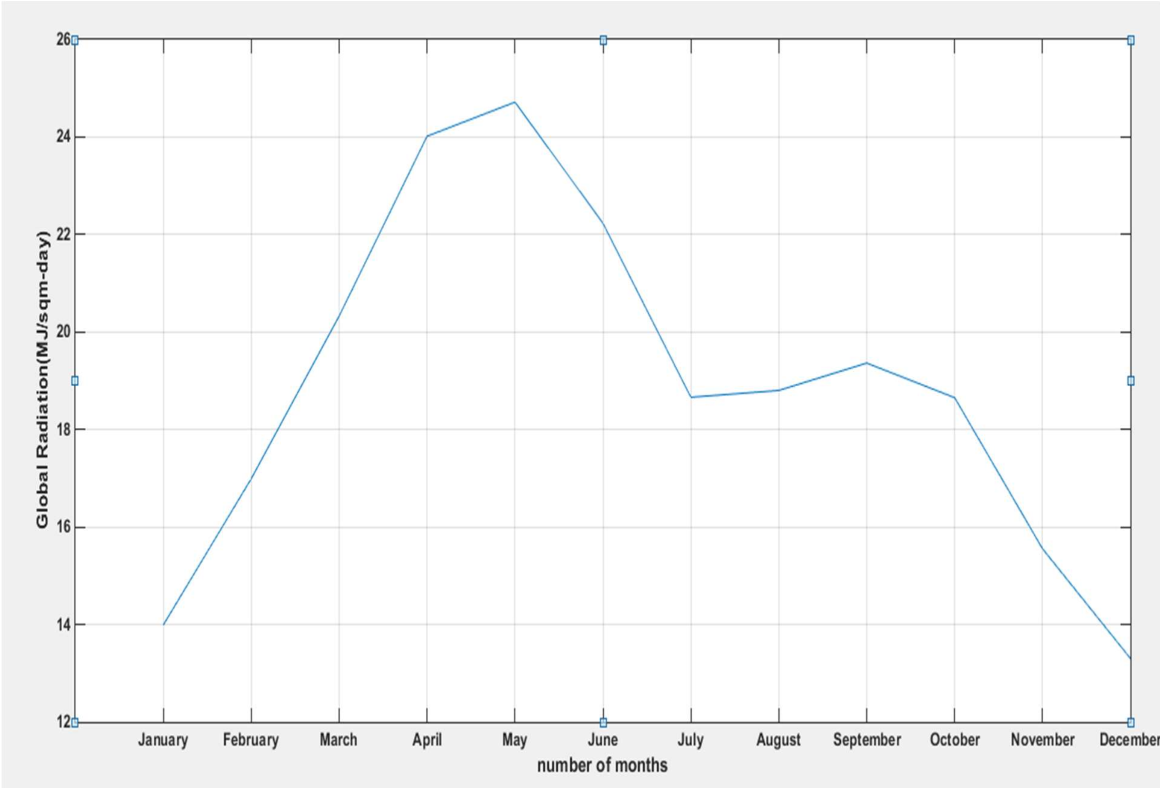

Figure (1): Monthly variation of global solar radiation for Bareilly.

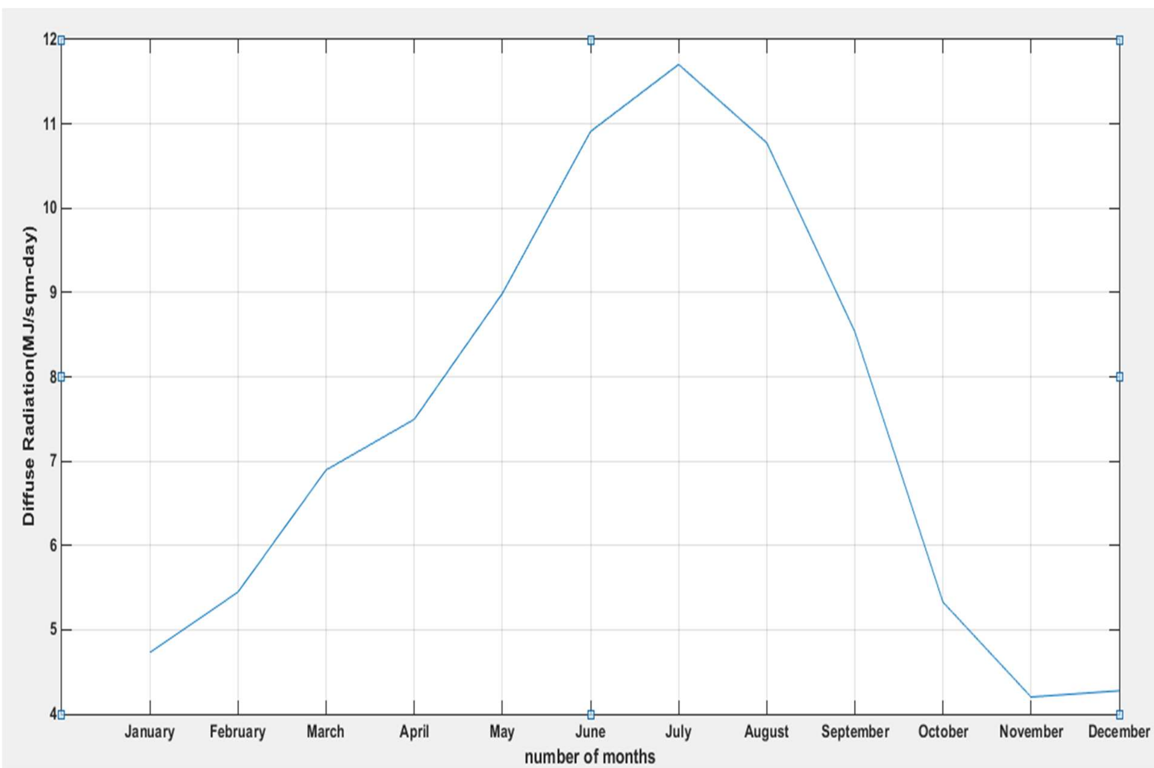

Figure (2): Monthly variation of diffuse solar radiation for Bareilly.

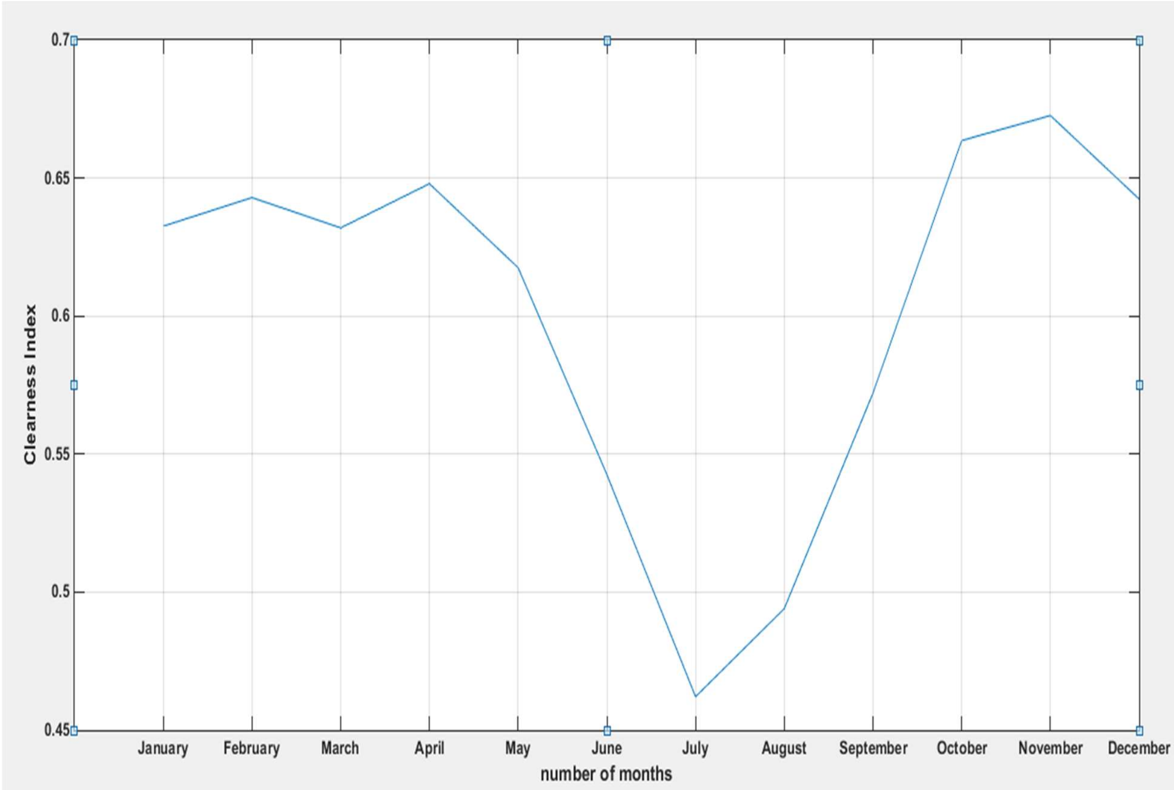

Figure (3): Monthly variation of clearness index for Bareilly.

4. Conclusions: Results have shown that the maximum and minimum values of global solar radiation are obtained in the month of May and December respectively. The maximum and minimum values of diffuse solar radiation are obtained in the month of July and November respectively. The sky over Bareilly is clear for most of the months except for July and August, when the clearness index is less than 50%. Hence, May is the most appropriate month for using solar energy in Bareilly city as it receives the maximum amount of solar radiation in this month. The data that has been calculated through this work may play vital role in solving the energy crisis problem in Bareilly by the solar energy conversion process.

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