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Direct Normal Radiation from Global Radiation for Indian Stations

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Abstract:

Direct Normal Radiation has been computed from global radiation for three Indian stations New Delhi, Jodhpur and Bhavnagar, because it was seen that it has a strong relation with global radiation. Here relation in the form of linear, quadratic and cubic equation, have been tried. A quadratic relation between direct normal radiation and global radiation gives best results. The differences in measured daily values of direct normal radiation and computed by the so developed quadratic relation is about ± 0.6% on daily basis. Difference on hourly basis, is within ± 11%.

***Keywords* — Direct normal radiation, global radiation, diffuse radiation.**

I. INTRODUCTION

Solar radiation and daylight are essential to life on the earth. Solar radiation affects the weather processes of the earth which determine the natural environment. Hence understanding of the physics of solar radiation and daylight is very important [1]. It is also equally important to determine the amount of energy intercepted by the earth's surface. Information on the availability of solar radiation is needed in many applications dealing with the harnessing of solar energy. The knowledge of monthly-mean values of the daily global and diffuse radiation on a horizontal surface is essential to design any solar energy system. However, the mean daily radiation is not always the most appropriate figure to characterize the potential utility of solar energy. While designing a solar energy system one also needs to know insolation values at hourly intervals for inclined and horizontal surfaces. Hourly values of radiation enable us to derive very precise information about the performance of solar energy systems. Such data is useful to engineers, architects and designers of solar systems as they endeavour to make effective use of solar energy [2].

Different studies indicate that the energy production cost of photovoltaic concentrators can occur at a fraction of the energy production cost of flat plate module systems in countries having high direct normal radiation [3]. The above statement of the cost reduction of energy generated is also applicable to the units that use the principle of solar thermal rather than solar PV. Light concentrators, used in solar photovoltaic and solar thermal applications, concentrates light by a factor of 10 or more; use only direct normal radiation [4].

The principal types of concentrators used in the solar thermal and or solar PV systems are parabolic trough, parabolic dish, and heliostat and Fresnel lens systems. A light-concentrating collector, with even moderate (more than 10 suns) concentration ratio, uses only direct normal solar radiation. Therefore, for performance analysis and design of the solar thermal PV concentrator system, knowledge of direct normal radiation for a given location and time is desirable. To calculate the efficiency of solar energy converters, particularly focusing systems, and for simulations of long-term process operations, the direct normal component of the incident solar radiation has to be known. Furthermore, hourly values of direct beam radiation allow one to derive precise information about the performance of solar energy systems. The ground measurements of direct beam radiation are mostly not available due to lack of standard meteorological stations and due to the cost of the equipment.

In the literature, there are basically two types of models for calculating direct normal irradiation: (i) radiative transfer models (also called parametric models) and (ii) decomposition models. The first ones take into account interactions on beam solar radiation with the terrestrial atmosphere, such as atmospheric scattering by air molecules, water and dust, and atmospheric absorption by O_3, H_2O and CO_2 [5]. The problem in the use of these models is the large amount of atmospheric information needed, which is not often measured at the meteorological stations. On the other hand, the decomposition models relate the direct normal radiation with other solar radiation measurements, especially the global solar irradiance on a horizontal surface [6]. Thus, decomposition models require simpler input data than the parametric models. In fact, decomposition models provide an estimate of the direct irradiance by means of simple empirical expressions both for cloudless and cloudy conditions.

The two types of correlations have been studied to calculate the direct normal irradiance as well as the global horizontal irradiance, from sunshine duration [7]. The direct normal component has been correlated with global horizontal component of solar radiation [8]. Correlation between direct normal radiation and global radiation for clear and overcast skies has been studied [9]. The hourly direct normal radiation was estimated from measured global irradiance in Spain [10]. Direct normal radiation can also be calculated from global and corrected diffuse horizontal radiation [11]. Geostationary satellites were used to derive solar global horizontal and direct normal irradiation maps in Spain [12].

Therefore, it has become increasingly important to estimate the amount of direct normal radiation available in a given region of any country, for feasibility study and successful implementation of concentrating solar thermal systems, and for the same reason it is also important for concentrating PV systems and PV/ thermal hybrid systems. It is seen that feasibility of concentrating thermal systems is much better in the desert area of Rajasthan in India, because the direct normal radiation availability is more and cost of land in these areas is less. The annual average availability of direct normal radiation is 5.63 kWh m^{-2} day^{-1} at Jodhpur. Hence, in this study we have chosen Jodhpur, Bhavnagar and New Delhi stations.

II. INPUT DATA

The Solar Radiation data, comprising of monthly mean hourly global and diffuse solar radiation for three Indian stations, [(New Delhi: Latitude - 28.63º N; Longitude - 77.2º E; Altitude - 219m; Climate – Composite); (Jodhpur: Latitude - 26.3º N; Longitude - 73.02º E; Altitude - 224m; Climate - Hot and Dry) and (Bhavnagar: Latitude - 21.75º N; Longitude - 72.18º E; Altitude - 11m; Climate - Hot and Humid)], chosen in this work, have been procured from Indian Meteorological Department, Pune. The data is averaged over a period of 1993 to 2000, for each of the three stations.

III. METHODOLOGY

The direct normal radiation (I_{bn}) has been computed from the measured values of global and diffuse solar radiation on horizontal surface by using the expression:

$$I_{bn} = \frac{I_{gh} - I_{dh}}{\cos \theta_z} \quad (1)$$

Here,

I_{gh}: global solar radiation on horizontal surface (MJ m^{-2} h^{-1})

I_{dh} : diffuse solar radiation on horizontal surface (MJ m^{-2} h^{-1})

θ_z : zenith angle (degree)

A computer programme, in MATLAB, was written to compute hourly values of I_{bn}. Hourly I_{bn} values were plotted against hourly I_{gh} values for a given location and from the shape of the plot, the type of correlation (linear, quadratic or of higher order) was decided. It was found that quadratic correlation as given below, fits best:

$$I_{bn} = a + b\,(I_{gh}) + c\,(I_{gh})^2 \quad (2)$$

Where, a, b and c are the regression coefficients, evaluated for each of the month and for each of the stations by using the regression technique.

On the basis of correlation, hourly and daily values of I_{bn} were computed and compared against the hourly and daily I_{bn} values obtained by using I_{gh} and I_{dh}.

IV. RESULTS AND DISCUSSION

In this work, it has been shown that direct normal radiation has strong correlation with global radiation: the point is to find out whether the correlation is linear, quadratic or of higher order. First of all, an attempt has been made to find a single correlation for the whole year, for each of the three stations: New Delhi, Jodhpur and Bhavnagar. Then, it is tried on seasonal basis and finally, on monthly basis for each of the three stations. The following paragraphs give the details of these correlations.

Plot of hourly I_{bn} with measured values of I_{gh}, for the whole year (annual basis) is shown in Fig. 1(a), for this station. It is seen that there is too much scattering of the points and there appears to be no correlation between I_{bn} and I_{gh}, on annual basis.

Fig. 1(b) shows the plot of hourly values of I_{bn} and I_{gh}, on the seasonal basis for the same station. From the figure it is evident that here too it is not possible to have a single definite correlation for a given season, because the points are scattered throughout.

On monthly basis, plot between I_{bn} and I_{gh} is shown in Fig. 1(c). The months here taken, for this purpose, are May, December and July, representing each of the three seasons, summer, winter and monsoon, respectively. This figure shows that there exists a quadratic relation between I_{bn} and I_{gh} for each of the months separately. Here it is noticed that the plot for December (winter) is highest, the reason being that in winter, the sun-earth distance is minimum and the other reason is the absence of turbid matter in the atmosphere.

A. New Delhi

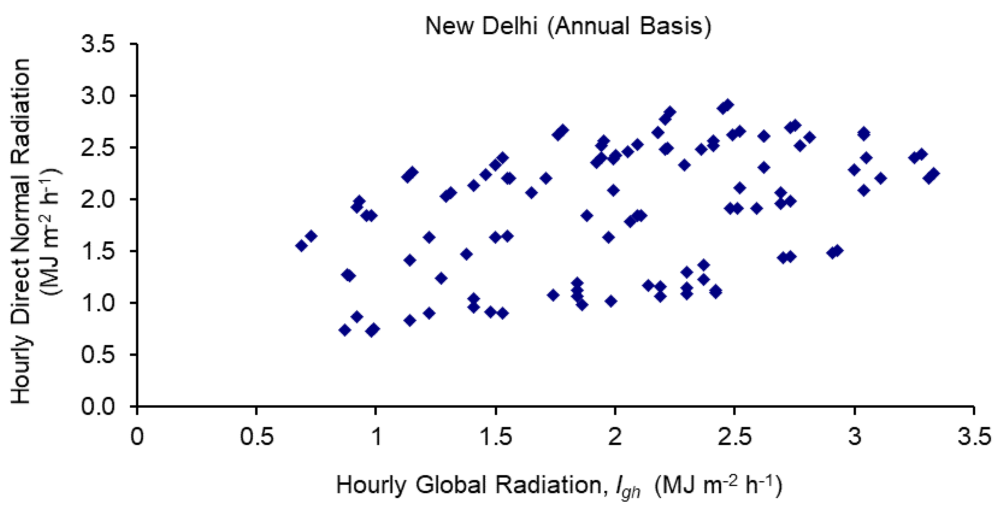

Fig. 1(a) On Annual Basis, too much scattering of points indicates no Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn})

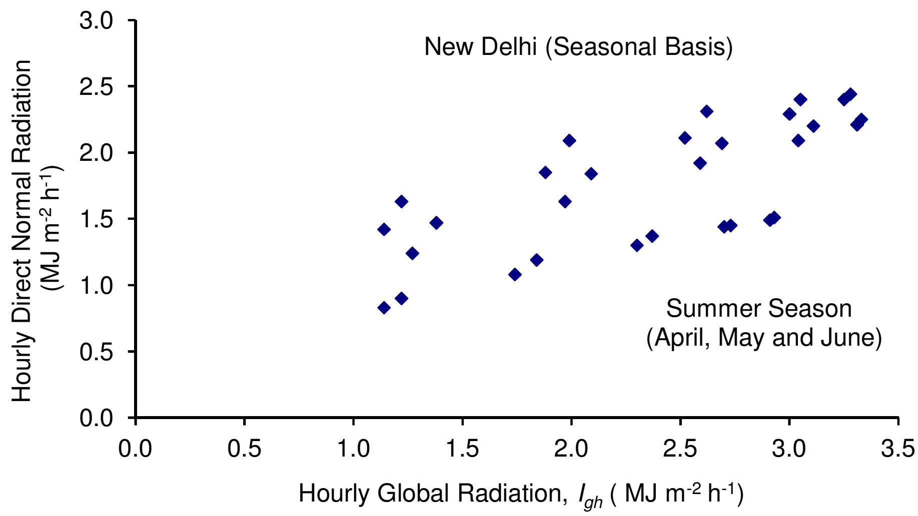

Fig. 1(b) On Seasonal Basis also, there seems to no good Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

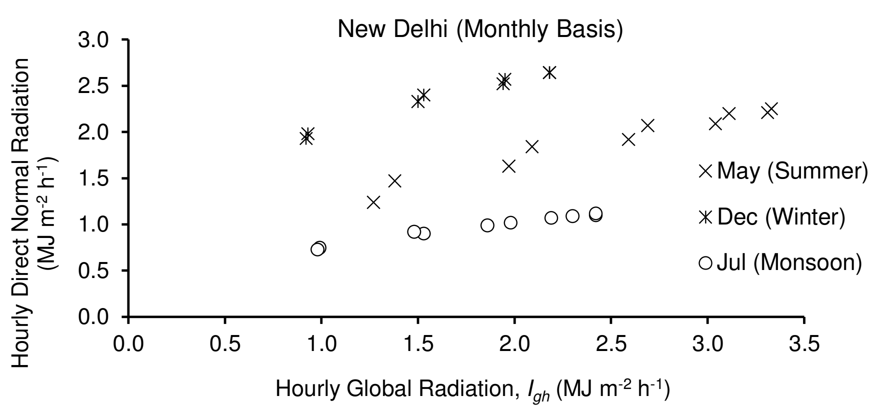

Fig. 1(c) On Monthly Basis, it is evident that there is a Definite Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

The curve for July (monsoon) is lowest, as there are rains and cloudy weather in this month, in Delhi. Plot for May (summer) is intermediate, the reason being presence of turbid matter in the atmosphere.

From the shapes of the plot, it is evident that quadratic equation can be fitted between I_{bn} and I_{gh} as:

$$I_{bn} = a + b\,(I_{gh}) + c\,(I_{gh})^2$$

Table 1

New Delhi: Values of regression coefficients *a, b* and *c* of the quadratic equation $I_{bn} = a + b(I_{gh}) + c(I_{gh})^2$ for each of the months and comparison of Daily Direct Normal Radiation, computed from I_{gh} and I_{dh}; and that from quadratic Eq.2.

Month	Value of Regression Coefficients			Daily Direct Normal Radiation ($MJ\ m^{-2}\ day^{-1}$)	
	a	*b*	*c*	from I_{gh} and I_{dh}	from quadratic
Jan	0.0596	2.3017	-0.5553	17.88	17.87
Feb	0.0383	2.0690	-0.4225	19.17	19.20
Mar	0.0271	1.7135	-0.2857	19.47	19.48
Apr	0.0951	1.4164	-0.2205	20.96	20.96
May	0.1198	1.1190	-0.1490	18.91	19.00
Jun	0.0119	0.8383	-0.1140	12.55	12.54
Jul	0.0300	0.8516	-0.1711	9.66	9.66
Aug	0.0454	1.0123	-0.2282	10.51	10.51
Sep	0.1028	1.4992	-0.3072	17.23	17.20
Oct	0.2191	2.0112	-0.4145	23.24	23.12
Nov	0.1026	2.4472	-0.5449	21.16	21.18
Dec	0.0999	2.5297	-0.6414	19.00	19.02

I_{bn} : Direct Normal Radiation, $MJ\ m^{-2}\ h^{-1}$
I_{gh} : Global Radiation, $MJ\ m^{-2}\ h^{-1}$
I_{dh} : Diffuse Radiation on Horizontal, $MJ\ m^{-2}\ h^{-1}$

Another option can be fitting straight line to the data, but it is not a good choice as, in general I_{bn} should approach zero as I_{gh} approaches zero, on a clear day. Based on method Least Square Error, the regression coefficients have been determined and the same are shown in Table 1. As values of 'a' are very small (less than 0.2), so, it shows that I_{bn} approaches zero as I_{gh} approaches zero. The values of these coefficients depend on the location i.e. latitude, longitude and altitude at the stations. The coefficient values also depend upon the weather conditions at the station. The values of daily direct normal radiation computed from I_{gh} and I_{dh}; and that from quadratic equation, are also shown in this table for each of the twelve months. From this table, it is seen that values of Daily I_{bn}, computed from quadratic equation, varies from 9.66 MJ m^{-2} day^{-1} to 23.12 MJ m^{-2} day^{-1} over the year. The value of daily I_{bn} is highest in the month of October and it is lowest in July. In Delhi, the month of October is clear and the sun-earth distance is also lesser than summer/monsoon months, thus the radiation value is highest in this month. In July and August, Delhi has rains and clouds and that is the reason that daily I_{bn} is lowest in these two months. In summer months (April, May and June), the value of I_{bn} is highest in April (20.96 MJ m^{-2} day^{-1}) and it is lowest in June (12.54 MJ m^{-2} day^{-1}), because in June in Delhi the turbid matter is maximum due to the higher temperature induced convective currents, and also towards the end of this month, the clouds set in at this place. On the other hand, April is a clearer month and thus the I_{bn} component is more significant in this month. There exists fog and day length is smallest in the month of December and January and that is the reason that these months have comparatively lesser I_{bn}. During winter months, daily I_{bn} value varies from 17.87 MJ m^{-2} day^{-1} (January) to 21.18 MJ m^{-2} day^{-1} (November).

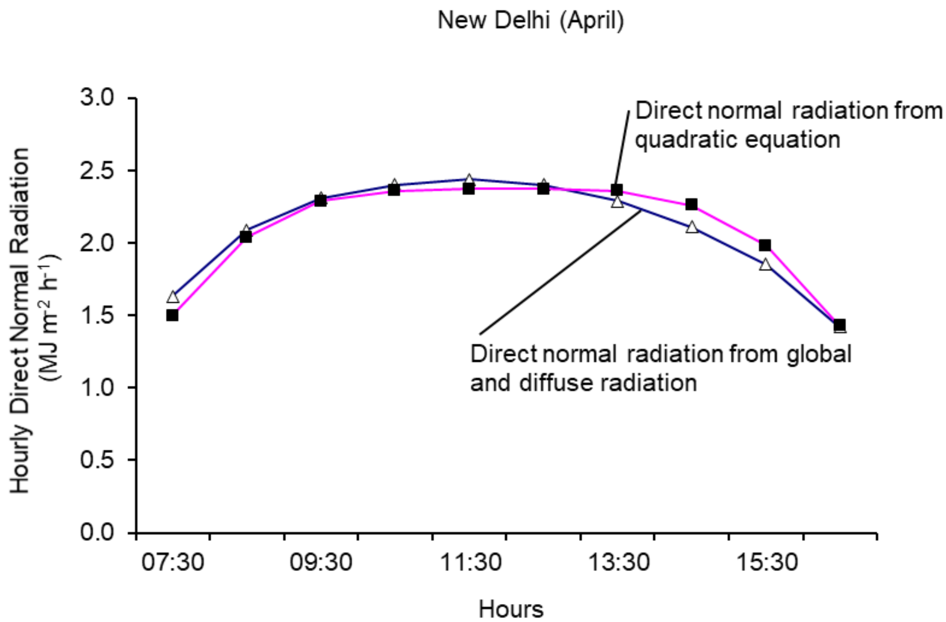

Fig. 1(d) Hourly Comparison of Direct Normal Radiation (I_{bn}) computed from the measured values of I_{gh} and I_{dh} ; and that by using quadratic Eq. 2.

The daily I_{bn} values computed by using quadratic equation and those obtained from measured I_{gh} and I_{dh} are shown in columns 5 and 6 of this table and it is seen that these are very close to each other (within ± 0.5%).

Maximum variation is in the month of October and its value is 0.52% only. So, it is very clear that quadratic equation is quite adequate for prediction of I_{bn}.

The hourly comparison of I_{bn} computed from quadratic equation and that from measured values of I_{gh} and I_{dh} has been shown graphically, in Fig. 1(d). It is shown here only for one month (April) to avoid the repetition as the trend is same for other months also. Hourly value of I_{bn}, computed in two ways, are very close to each other, within variation of ± 7% for this station.

Jodhpur

The plot between computed hourly values of I_{bn} and measured values of I_{gh}, for the whole year, is shown in Fig. 2(a) for this station. Figure shows that the points are scattered throughout and there seems to be no correlation between I_{bn} and I_{gh}, on annual basis.

On seasonal basis, the plot of hourly I_{bn} and I_{gh} is shown in Fig. 2(b) for this station. The Fig. 2(c) shows the plot of hourly I_{bn} and measured values of I_{gh} on the monthly basis. The months considered here, for this purpose are May, December and July, representing three different seasons, summer, winter and monsoon, respectively. It is seen from the figure that there exists a definite quadratic relation between I_{bn} and I_{gh}, separately for each month. It is noticed here that the curve for December (winter) is highest for this station also like that of Delhi and reason is same: absence of turbid matter in this month and also earth-sun distance being minimum.

The curve for July (monsoon) is lowest and that of May (summer) is intermediate. Reason is that July is a rainy/cloudy month; hence I_{bn} is lowest in this month. At Jodhpur, in the month of May the dust particles amount increases in atmosphere due to higher temperature induced convective currents and it reduces the intensity of I_{bn} in this month.

From the shapes of the various plots, it is evident that quadratic equation can be fitted between I_{bn} and I_{gh} for this station too:

$$I_{bn} = a + b\,(I_{gh}) + c\,(I_{gh})^2$$

Option of fitting a straight line to the data is not a better choice, as explained earlier in the case of Delhi station, that generally I_{bn} should approach zero as I_{gh} approaches zero, on a clear day.

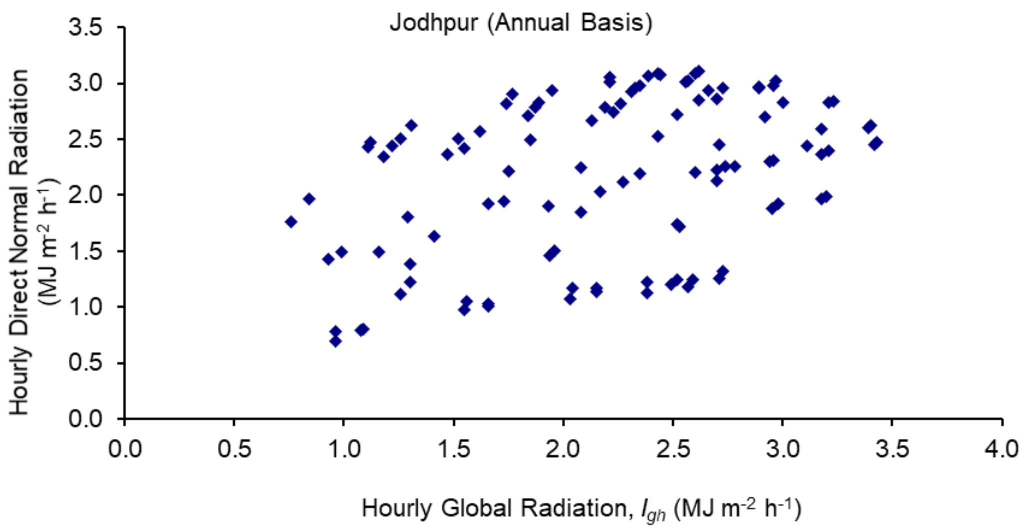

Fig. 2(a) On Annual Basis, too much scattering of points indicates no Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

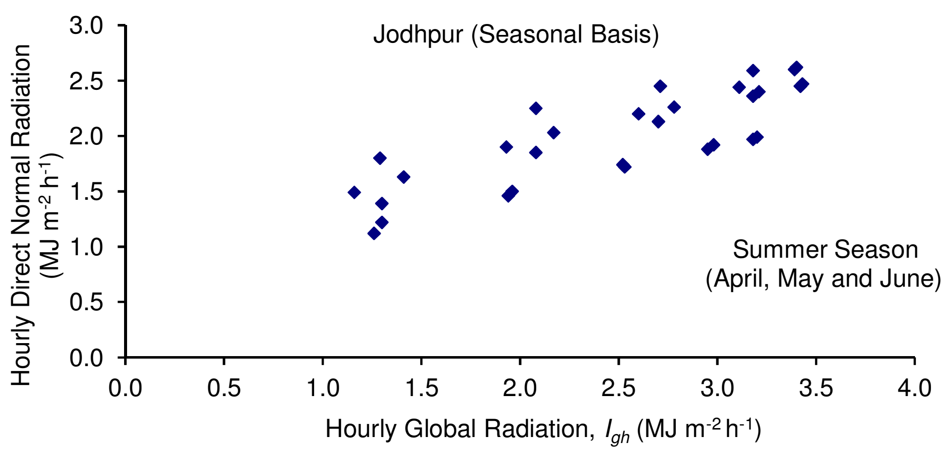

Fig. 2(b) On Seasonal Basis also, there seems to no good Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn})

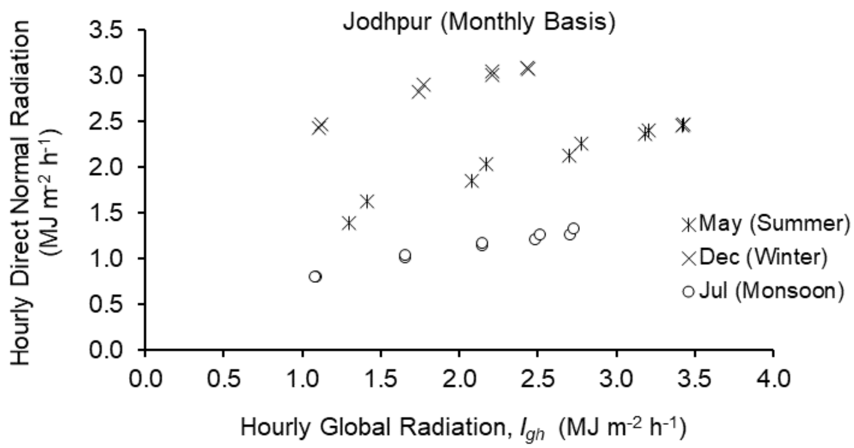

Fig. 2(c) On Monthly Basis, it is evident that there is a Definite Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

Table 2

Jodhpur: Values of regression coefficients *a, b* and *c* of the quadratic equation $I_{bn} = a + b(I_{gh}) + c(I_{gh})^2$ for each of the months and comparison of Daily Direct Normal Radiation, computed from I_{gh} and I_{dh}; and that from quadratic Eq. 2.

Month	Value of Regression Coefficient			Daily Direct Normal Radiation (*MJ m^{-2} day^{-1}*)	
	a	*b*	*c*	from I_{gh} and I_{dh}	from quadratic
Jan	0.1404	2.4857	-0.5444	22.19	22.26
Feb	0.1258	2.1572	-0.4155	22.05	22.17
Mar	0.1154	1.7672	-0.2919	21.15	21.23
Apr	0.1374	1.4015	-0.2040	22.34	22.33
May	0.1225	1.2121	-0.1583	20.97	21.03
Jun	0.0711	0.9878	-0.1254	16.52	16.53
Jul	0.0363	0.8356	-0.1414	10.97	10.98
Aug	0.0258	0.9110	-0.1777	10.52	10.54
Sep	0.1022	1.6216	-0.3040	20.18	20.17
Oct	0.3069	2.0613	-0.4013	26.10	26.02
Nov	0.1115	2.6014	-0.5701	23.15	23.21
Dec	0.1723	2.7404	-0.6478	22.85	22.95

I_{bn} : Direct Normal Radiation, *MJ m^{-2} h^{-1}*
I_{gh} : Global Radiation on Horizontal, *MJ m^{-2} h^{-1}*
I_{dh} : Diffuse Radiation on Horizontal, *MJ m^{-2} h^{-1}*

The regression coefficients a, b and c of the quadratic equation have been determined using regression analysis and the same are shown in Table 2, for this station. For this station the values of 'a' are very small (less than 0.3), showing that I_{bn} approaches zero as I_{gh} approaches zero. The daily values of I_{bn}, computed from quadratic equation, are shown in the last column of this table. It is seen that daily I_{bn} varies from a minimum of 10.54 MJ m^{-2} day^{-1} in the month of August to maximum of 26.02 MJ m^{-2} day^{-1} in October. The reason is, October is a clear month and there are rains and cloudy weather at Jodhpur in July and August.

At Jodhpur rains starts in June and continue till August and that is why, during these three months, I_{bn} is very low. April is a clear month and thus I_{bn} value is highest (22.33 MJ m^{-2} day^{-1}) in this summer month. In winter months, the daily I_{bn} value is comparatively higher (23.21 MJ m^{-2} day^{-1}) in November than the values in December and January, the reason being that November month has lesser fog than other two months.

Columns 5 and 6 of this table show the values of daily I_{bn} obtained from the measured values of I_{gh} and I_{dh} and those computed from the quadratic equation. It is seen here that these two values are very close to each other (within ± 0.50% approx.), for this station also. In the month of February the difference is highest (0.54% only). So, from this, it is clear that for this station also the quadratic equation is quite suitable to predict I_{bn}.

Fig. 2(d) shows the hourly comparison of I_{bn} computed by using quadratic equation and that obtained from measured I_{gh} and I_{dh}. For this station also, to avoid repetition it is shown for April month only because of similar trend for other months. The values of hourly I_{bn}, computed by two ways, are found to be very close to each other within variation of ± 9% for this station.

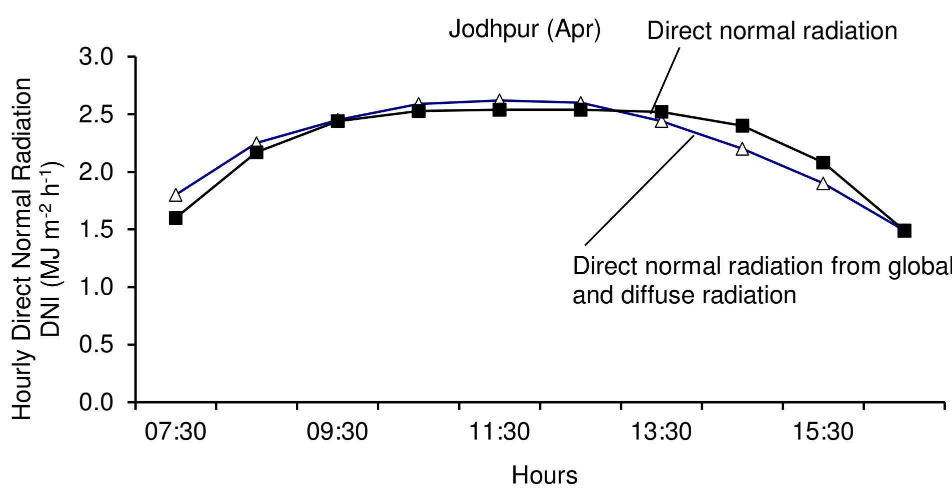

Fig. 2(d) Hourly Comparison of Direct Normal Radiation (I_{bn}) computed from the measured values of I_{gh} and I_{dh} ; and that by using quadratic Eq. 2.

B. Bhavnagar

On annual basis, the plot of hourly values of I_{bn} with measured values of I_{gh}, is shown in Fig. 3(a). Figure shows that the points are widely spread throughout and there appears to be no correlation between I_{bn} and I_{gh}, for the whole year.

The plot of hourly I_{bn} with measured values of I_{gh}, on seasonal basis, is shown in Fig. 3(b), for this station. From the figure it is evident that, here too, it is not possible to have a single definite correlation for a season for this station.

Fig. 3(c) shows the plot of hourly values of I_{bn} with measured I_{gh}, on monthly basis.

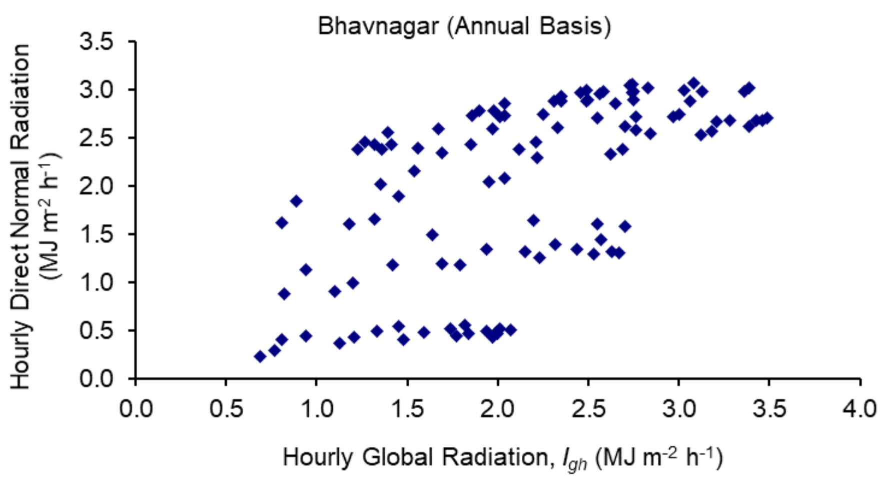

Fig. 3(a) On Annual Basis, too much scattering of points indicates no Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

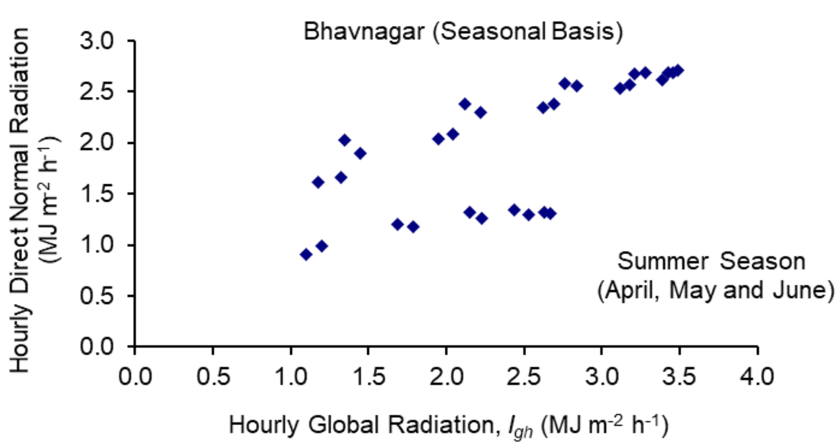

Fig. 3(b) On Seasonal Basis, also there seems to no good Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

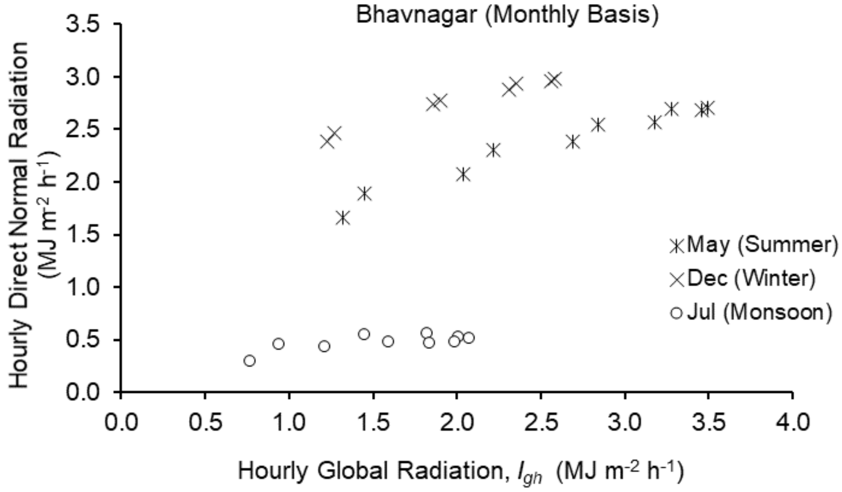

Fig. 3(c) On Monthly Basis, it is evident that there is a Definite Correlation between Hourly Global Radiation (I_{gh}) and Direct Normal Radiation (I_{bn}).

Table 3

Bhavnagar: Values of regression coefficients *a, b* and *c* of the quadratic equation $I_{bn} = a + b(I_{gh}) + c(I_{gh})^2$ for each of the months and comparison of Daily Direct Normal Radiation, computed from I_{gh} and I_{dh}; and that from quadratic Eq. 2.

Month	Value of Regression Coefficient			Daily Direct Normal Radiation ($MJ\ m^{-2}\ day^{-1}$)	
	a	*b*	*c*	from I_{gh} and I_{dh}	from quadratic
Jan	0.1478	2.3794	-0.4920	22.72	22.81
Feb	0.2003	2.0244	-0.3668	22.62	22.76
Mar	0.1790	1.7854	-0.2871	22.48	22.62
Apr	0.1974	1.5157	-0.2384	23.48	23.54
May	0.1692	1.4008	-0.1979	23.51	23.58
Jun	0.0302	1.0498	-0.2150	12.12	12.14
Jul	0.0028	0.5750	-0.1621	4.75	4.74
Aug	0.0037	0.5285	-0.1498	4.27	4.28
Sep	0.0912	1.2203	-0.2584	13.69	13.72
Oct	0.3177	1.8018	-0.3417	23.85	23.85
Nov	0.1688	2.2434	-0.4558	22.01	22.12
Dec	0.2300	2.4387	-0.5472	22.12	22.25

I_{bn} : Direct Normal Irradiation, $MJ\ m^{-2}\ h^{-1}$
I_{gh} : Global Radiation, $MJ\ m^{-2}\ h^{-1}$
I_{dh} : Diffuse Radiation on Horizontal, $MJ\ m^{-2}\ h^{-1}$

For this purpose, the months chosen are May, December and July, representing three different seasons: summer, winter and monsoon, respectively. Figure shows that a quadratic correlation exists between the I_{bn} and I_{gh} for each of the months, separately. For this station also it is noticed that the plot for December (winter) is highest and that of July (monsoon) is lowest. The curve for May (summer) is intermediate.

It is further noticed here, that the July curve is even lower in comparison to corresponding curves of New Delhi and Jodhpur. The reason is that there are too much rains and clouds at Bhavnagar in this month. December month is a clear one and in the month of May there is existence of turbid matter, and thus the December curve is highest and May curve is intermediate.

The shapes of these curves show that the quadratic equation can be fitted adequately between I_{bn} and I_{gh} as:

$$I_{bn} = a + b\,(I_{gh}) + c\,(I_{gh})^2$$

The choice of fitting a straight line to the data is not a good choice here also, as in general, I_{bn} should approach zero as I_{gh} approaches zero, on a clear day. Based on regression technique, the regression coefficients a, b and c of the above quadratic equation are determined for this station and the same are shown in Table 3. For this station too, the values of coefficient 'a' are very small (less than 0.3), hence it shows that I_{bn} approaches zero as I_{gh} approaches zero.

Column 6 of this table shows the values of daily I_{bn} computed by using quadratic equation, these values vary from minimum (4.28 MJ m^{-2} day^{-1}) in the month of August to maximum (23.85 MJ m^{-2} day^{-1}) in October. This is because in October the atmosphere is clear whereas in July and August there are rains and clouds at this station. During the winter months (November to January), I_{bn} varies from 22.12 MJ m^{-2} day^{-1} to 22.81 MJ m^{-2} day^{-1}. In summer months (April to June), the I_{bn} is lowest in June (12.14 MJ m^{-2} day^{-1}) and it is higher in April and May (about 23.5 MJ m^{-2} day^{-1}). The reason is that there is existence of turbid matter in June and also in the middle of June clouds set in at Bhavnagar. Daily I_{bn}, obtained from I_{gh} and I_{dh} and that computed from quadratic equation, is listed in columns 5 and 6 of this table. The comparison of these values shows that they are very close to each other; the variation is within ± 0.6%. The maximum variation for this station is 0.62% in the month of February.

Fig. 3(d) shows the hourly comparison of I_{bn} computed by using quadratic equation and that obtained from I_{gh} and I_{dh}. It is seen for this station that the variation is within ± 10%.

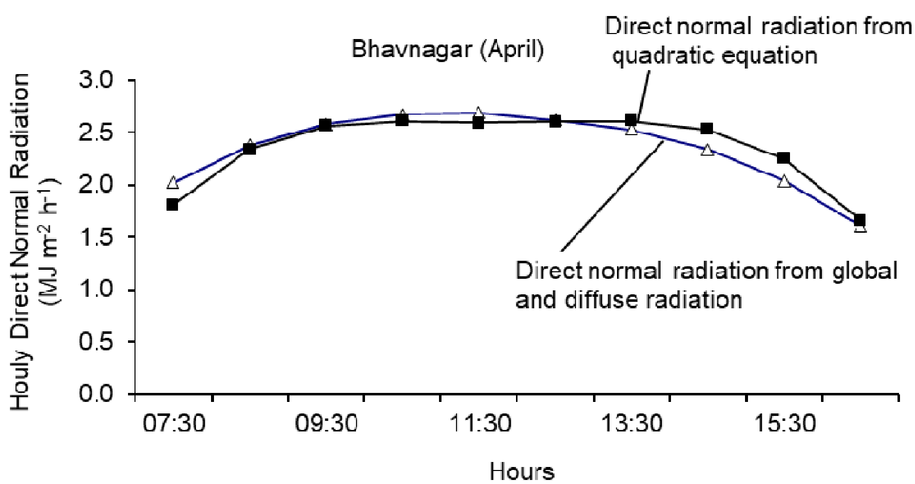

Fig. 3 (d) Hourly Comparison of Direct Normal Radiation (I_{bn}) computed from the measured values of I_{gh} and I_{dh} ; and that by using quadratic Eq. 2.

V. CONCLUSIONS

Plot of hourly I_{bn} with measured values of I_{gh}, on annual basis as well as on seasonal basis show too much scattering of points and hence, no single correlation can be formed between these two variables on annual or seasonal basis. On monthly basis, plots show a definite correlation, of quadratic nature, between I_{gh} and I_{bn}. On the basis of least square error, coefficients of correlation have been found for each month and for each of the three stations.

The comparison of hourly values of I_{bn}, computed from quadratic equation and those from measured I_{gh} and I_{dh}, is like this:

The agreement is within ± 7% for New Delhi; ± 9% for Jodhpur and ± 10% for Bhavnagar, in the month of April.

For all months and all stations, the difference between the two values of hourly I_{bn} is less than ± 11%.

The daily I_{bn} values computed by using quadratic equation and those obtained from the measured values of I_{gh} and I_{dh} are found to be very close to each other, for each of the three stations and the difference is within ± 0.60%. The maximum variation in daily I_{bn} computed by these two methods is 0.52%, in the month of October, for New Delhi. For the other two stations Jodhpur and Bhavnagar, it is maximum in the month of February and the respective differences are 0.53% and 0.62%.

From the above scenario, it can be concluded that so obtained quadratic equations are adequate to predict I_{bn} from the measured values of I_{gh} for the stations having similar weather conditions as the analysed ones.

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