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Computation of global solar radiation over monsoon trough region in summer (May to July)

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ABSTRACT

The attenuation coefficients a_1 and a_2 are evaluated using 15 years daily hourly global solar radiation data for May, June and July for 9 stations in the northwest and central India in the southwest monsoon trough region. These coefficients determine the attenuation of the global solar radiation due to the water vapor and dust. The spatial distribution of a_1 revealed a decreasing tendency from south to north and west to east with the advance of southwest monsoon. The coefficient a_1 reduced considerably in the month of July with the establishment of monsoon over the country. The estimated values of global solar radiation are compared with the observed values and it is found that they match each other reasonably. The root mean square error was 5-10% in May, 10-20 % in June and 15-22 % in July. The instantaneous global solar radiation for any station within the monsoon trough region can be computed with sufficient accuracy for fair weather conditions, using the areal mean values of a_1 and a_2 with the empirical equation suggested in this study which establishes a relationship between the global solar radiation and the sine of the solar elevation angle (q) within an average rmse of 15-20%.

Key words: Global solar radiation, Attenuation, Southwest monsoon, Solar elevation

Sun is the ultimate source of energy that is received on the earth. A knowledge of the solar radiation received at the earth's surface is of fundamental importance in understanding different biological and physical processes that take place at the earth-atmosphere interface.

Radiation measurements are generally made at a very limited number of stations in any region due to economical constraints. It is thus imperative to estimate the incident radiation, within an acceptable degree of accuracy, in places where no measurements are made by using indirect methods. A number of semi-empirical correction formulae were developed (Budyko, 1974, Reed, 1977) incorporating cloud amount and noon altitude of the sun to estimate the GSR. Lumb (1964) over North Atlantic region, Collier and Lockwood (1974,1975) over Harrogate computed hourly GSR for clear/cloudy sky using second degree relation between GSR and solar elevation. Recently, Munner *et al.* (1996,1997) developed the Meteorological Radiation Model (MRM) which requires three commonly measured parameters viz. hourly dry and wet bulb temperature and sunshine fraction. The MRM has been found to perform satisfactorily for the United Kingdom, Japan and other European sites. Maxwell (1998) has developed METSTAT model to estimate hourly values of direct, normal and diffuse horizontal and global solar radiation for those times and locations in USA for which measured data were not available. But for this model, the input pa-

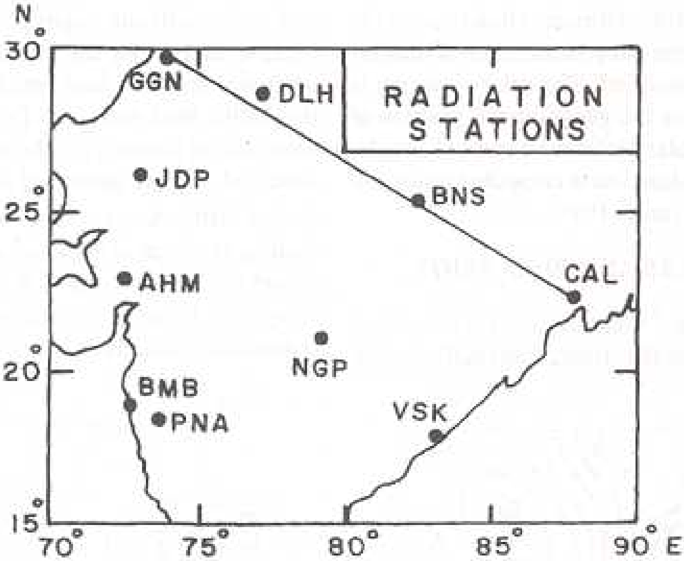

Fig. 1: Location map of the radiation stations in the monsoon trough region. The line joining Ganganagar (GGN) and Calcutta (CAL) shows the mean position of the monsoon trough.

During May (pre-onset) the atmosphere is cloudless over almost all stations. The dust particles are predominant in the air. This leads to high values of transmittance, whereas, during June, due to the incursion of moisture with the advance of monsoon, the transmittance values are reduced. In July (established phase of monsoon) precipitation is effective in the removal of aerosols from the atmosphere. This reduction of transmittance values are in accordance with the sudden fall in the Angstrom's Turbidity coefficient after the onset of monsoon as noticed by Mani *et al.*, (1969).

The empirical relationship between GSR and solar elevation according to HU83 is given as,

$$GSR = a_1 \sin \theta - a_2 \quad \text{.................. (2)}$$

Where θ is the solar elevation and a_1 and a_2 are empirical coefficients in units of Wm^{-2}. These turbidity coefficients describe the average attenuation of GSR due to the water vapor and dust at a given site. We have used the above relation to compute attenuation coefficients a_1 and a_2 separately for 9 Indian stations by linear regression (least square) method. To determine these coefficients the GSR for $\theta \geq 10$ degrees only has been considered in order to ignore the refraction effects of atmospheric curvature (Raju et al.,1999). Gueymard and Vignola (1998) have shown that the coefficients in their model are different for solar zenith angle $Z \leq 75°$ and $Z > 75°$. For $Z \leq 75°$, psudolinearity in turbidity is observed by them. Kambezidis *et al.*, (1998) while estimating the Linke and Unsworth Monteith turbidity factors in the visible spectrum for Anthes, Greece rejected the irradiance values for a solar altitude $< 5°$. Further, Hay (1979), in connection with an analysis of the Angstrom-Page regression, suggested use of the time period when the sun is more than $5°$ above the horizon to compensate for the dead band of the instruments that register the insolation. Thus our consideration of data for $\theta \geqslant 10°$ is justified. The solar elevation is computed from the geographical position of the station, solar declination and hour angle. The solar declination is computed following Rachele and Tunic (1994).

RESULTS AND DISCUSSION

Table 3 illustrates the published values (HU83) for the attenuation coefficients a_1 and a_2 for different regions. The computed mean a_1 and a_2 for the month of May averaged over the study area are also presented in this Table. Such estimates for the nine monsoon trough stations for the months of May, June and July are presented in Table 4. The spatial distributions of a_1 and a_2 for the three months are given in Figures 2 and 3. Values of a_1 and a_2 (Tables 3 and 4) during dry period (May) are found to be comparable with the published values (HU83) in Table 3.

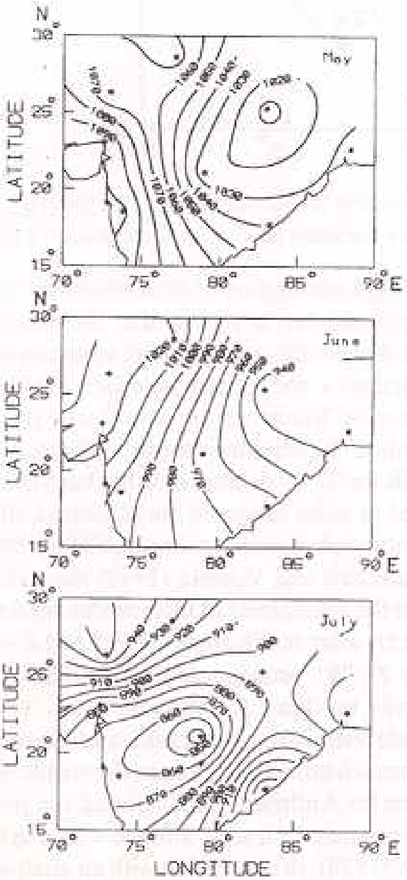

Fig. 2 : Spatial distribution of the coefficient a_1 for the months May, June and July.

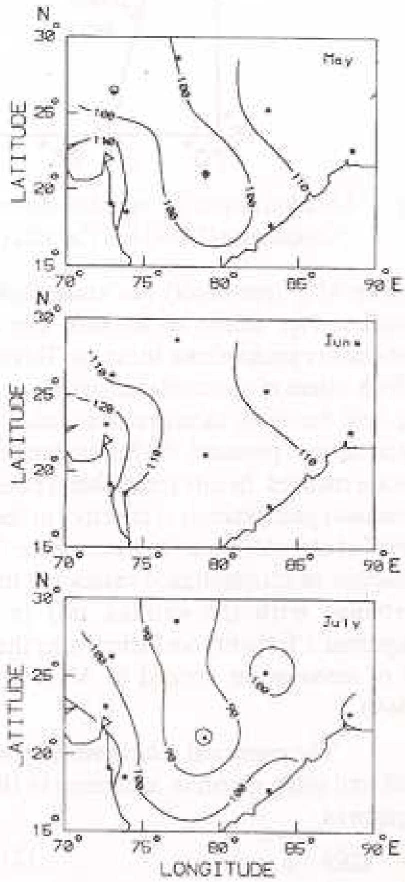

Fig. 3 : Spatial distribution of the coefficient a_2 for the months May, June and July.

Distributions of a_1 and a_2

The magnitude of a_1 decreases gradually from May to July over all stations. It also decreases from south to north and west to east. In May, high values of about 1100 Wm^{-2} occurred over Pune (PNA), Mumbai (BMB) and Ahmedabad (AHM) along the west coast of India while low values (1022 to 1006 Wm^{-2}) occurred over the central parts of India i.e. at Nagpur (NGP) and Varanasi (BNS). In June high values (1025 Wm^{-2}) shifted to desert region i.e. at Jodhpur (JDP) and AHM and low values (930 Wm^{-2}) are concentrated along the east coast of India at Calcutta (CAL) and Varanasi (BNS). In July, high values (953 Wm^{-2}) continued over desert region (JDP) and along the monsoon trough region while the lowest value (833 Wm^{-2}) occurred at Nagpur (NGP). Along the east coast of India, the values are fairly high (955 Wm^{-2}) at Vizag (VSK). The mean values of a_1 for the entire monsoon trough region are 1061 Wm^{-2}, 986 Wm^{-2} and 894 Wm^{-2} for May, June and July respectively.

The low values of the coefficient a_2 (90 Wm^{-2}) are concentrated along the monsoon trough in May. This coefficient does not show any large variation from May to July. The areal mean values of a_2 for the entire monsoon trough region are 106 Wm^{-2}, 112 Wm^{-2} and 99 Wm^{-2} for May, June and July respectively. HU83 obtained a_1 and a_2 as 990 and 30 Wm^{-2} respectively at De-Bilt (Netherlands) and Cabauw under clear sky conditions. It is to be noted that Gul *et al.*, (1998) have evaluated the GSR under cloudless sky with the same formula for a few stations north of 50 N and they found that a_1 varies from 910 to 1024 Wm^{-2} while a_2 varies from 30 to 54 Wm^{-2}.

In India, during May, relative humidity (RH) is quite low (20-50%) due to prevailing dry weather in summer, while it increases gradually with the advance of monsoon and reaches very high values upto 85-95% in July. However, dust is high in May and it reduces in June and July. The gradual decreasing trend of a_1 from May (highest) to July (lowest) implies that a_1 decreases with increasing RH from May to July. Recently Devara *et al.*, (1997) found that the aerosol loading over Pune (PNA) exhibits minimum during the southwest monsoon (June to September), gradually builds-up during the post monsoon (October and November) and reaches a maximum value in winter (December to February) and remains same up to May. Similar situation may also prevail over the other Indian stations as the monsoon advances from May to July. The decrease in a_1 for overall region from May to July is also in confirmity of the atmospheric transmittance values shown in Table 2. Our results over the Indian region further confirm that water vapor and dust play an important role in receiving GSR.

Comparison of computed and observed global solar radiation

The GSR values for all 9 stations for May, June and July for 15 years are computed using the mean values of a_1 and a_2 through the empirical relation given (equation 2). The scatter diagrams for three stations along the monsoon trough (CAL, DLH and JDP) are shown in Figure 4. The straight lines in the figures show one to one correspondence between computed and observed values. It is seen from the figures that during May, the scatter is comparatively least at all stations. It increases in June and July. Large scatter over CAL is attributable to the incursion of high moisture with the advance and establishment of monsoon over the region. Figure 5 (a,b,c) shows the comparison of estimated and observed mean hourly values of GSR for the same three

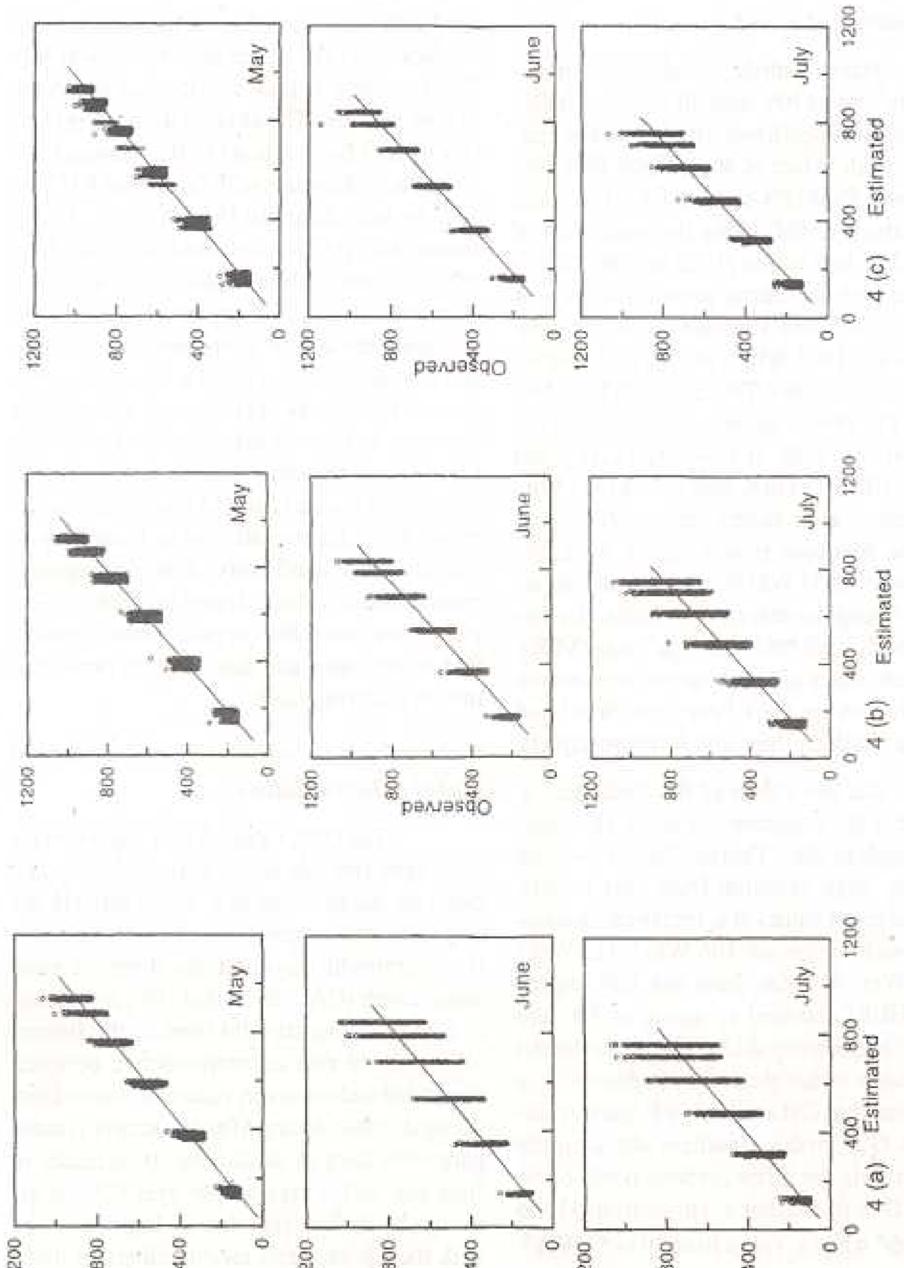

Fig. 4 : Comparison of estimated global solar radiation using the empirical relation with the observed values for the months May, June and July: (a) Calcutta (CAL), (b) New Delhi (DLH) and (c) Jodhpur (JDP).

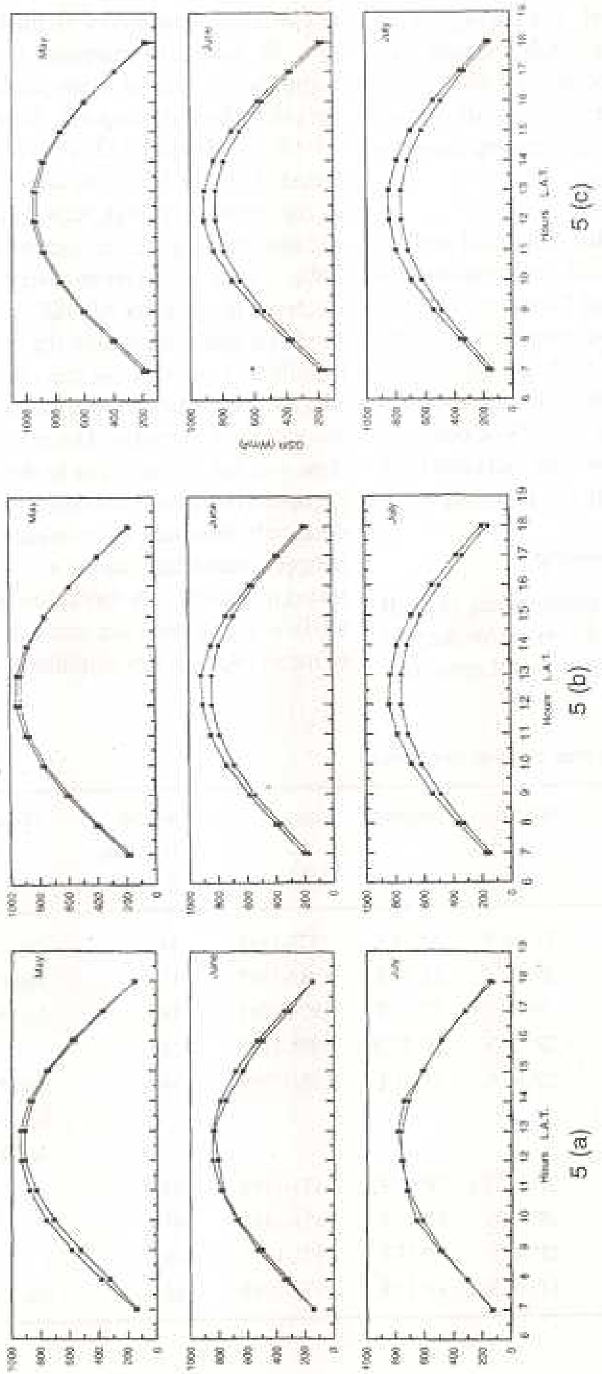

Fig. 5 : Comparison of estimated (square) hourly mean global solar radiation with the observed (circle) mean hourly values for the months of May, June and July: (a) Calcutta (CAL), (b) New Delhi (DLH) and (c) Jodhpur (JDP).

stations. Here it is seem that estimated values are close to the observed ones during the dry period i.e. May, whereas in July, the estimated values differ from the observed values due to variation in atmospheric moisture, cloud amounts and cloud type depending upon the strength of the monsoon.

Table 5 gives the computed and observed mean values of GSR for the months of May, June and July for all 9 stations. The root mean square error (rmse) between computed and observed values of GSR are also shown in the Table. The rmse in May varies from 35 to 108 Wm^{-2} i.e. from 5 to 20 % of observed mean values of GSR. The rmse increases from June (10 to 22 %) to July (15 to 22 %).

Validation of the relationship

Daily hourly mean values of GSR were estimated for these 9 stations for the year 1990 with equation (2) using areal mean values (Table 4) of a_1 and a_2. The estimated values are then compared with the observed values. We have also computed GSR values by using the above areal mean values of a_1 and a_2 for other three stations viz. Jaipur (26°49'N, 75°48'E), Bhopal (23°17'N,77°21'E) and Patna (25°36'N,85°10'E) which are situated in the monsoon trough region and which are not used to compute the coefficients a_1 and a_2. Table 6 gives rmse and its percentage with the observed mean value of GSR. It is seen from the Table that during May, the performance is excellent (rmse < 10%) except over Mumbai and Calcutta where clouds are present during the month of May also. The rmse increases in June and July. This is due to the fact that our regression equations are based on fair weather data only obtained by considering the data between mean and mean + 3 s.d.values as stated in section 2. A limitation of the present study is that it does not account for overcast or mean overcast sky conditions.

Table 1 : Duration of global solar radiation data record

S.No.	station	abbre-viation	latitude	longitude	years	months May,June & July	Missing months
1	Ahmedabad	AHM	23° 04'N	72° 38'E	1971-1985	44	July 1984
2	Varanasi	BNS	25° 18'N	83° 01'E	1982-1985	10	May1982,July 1982
3	Mumbai	BMB	19° 07'N	72° 51'E	1971-1985	44	July1972
4	Calcutta	CAL	22° 39'N	88° 27'N	1980-1985	18	-
5	Jodhpur	JDP	26° 18'N	73° 01'E	1971-1985	39	May 1978, June 1978, July 1977,78,79,80
6	Nagpur	NGP	21° 06'N	79° 03'E	1971-1985	45	-
7	New Delhi	DLH	28° 35'N	77° 12'E	1971-1985	45	-
8	Pune	PNA	18° 32'N	73° 51'E	1971-1985	45	-
9	Vishakhapatanam	VSK	17° 43'N	83° 14'E	1971-1985	45	May1980

Table 2 : The Solar Transmittance at True Solar Noon for Global Solar Radiation on a horizontal surface

S.No.	station	May	June	July
1	AHM	0.704	0.653	0.558
2	BNS	0.621	0.585	0.555
3	BMB	0.713	0.633	0.538
4	CAL	0.652	0.592	0.552
5	JDP	0.678	0.657	0.604
6	NGP	0.668	0.623	0.533
7	DLH	0.673	0.649	0.593
8	PNA	0.716	0.630	0.546
9	VSK	0.671	0.613	0.609

Table 3 : The attenuation coefficients a_1 and a_2 for different regions during dry period

S.No.	Location	a_1 (Wm^{-2})	a_2 (Wm^{-2})	Reference
1	Bosten (42°13'N,71°07'W)	1098	65	Haurwitz (1945)
2	North Atlantic (52°30'N,20°00'W)	1100	50	Lumb (1964)
3	Harrogate (54°00'N,01°30'W)	990	30	Collier and Lockwood (1974)
4	Hamburg (53°38'N,09°50'E)	910	30	Kasten and Czeplak (1980)
5	De-Bilt (52°06'N,05°11'E)	1041	69	Holtslag and van Ulden (1983)
6	Monsoon Trough Region in India	1060	106	Present study for May *

* Values of a_1 and a_2 for individual stations are given in Table 4.

Table 4 : Attenuation coefficients a_1 and a_2 for the stations in the monsoon trough region for the months of May, June and July (Units : Wm^{-2})

S.No.	Station	May		June		July	
		a1	a2	a1	a2	a1	a2
1	AHM	1100.8	112.8	1026.5	127.4	878.8	105.0
2	BNS	1006.4	118.0	932.0	114.1	896.8	105.2
3	BMB	1101.6	115.2	1005.1	127.4	862.8	121.8
4	CAL	1034.0	119.1	935.9	115.7	871.6	88.2
5	JDP	1059.8	89.1	1025.7	107.0	952.7	98.3
6	NGP	1022.7	88.9	964.6	99.9	833.0	77.1
7	DLH	1074.9	100.6	1020.9	105.3	931.1	84.6
8	PNA	1103.0	108.3	995.4	108.4	861.5	101.5
9	VSK	1039.7	102.5	964.9	102.2	954.5	107.6
	MEAN	1060.3	106.1	985.7	111.9	893.6	98.8

Table 5 : Comparison of computed and observed mean values of the Global Solar Radiation (GSR) for the months of May, June and July for 9 Indian stations (Units: Wm^{-2})

S.No.	Stn	comp May	comp June	comp July	obs May	obs June	obs July	rmse %) May	rmse (%) June	rmse (%) July
1	AHM	649.5	593.1	510.5	625.9	564.5	509.6	5.9	10.3	16.3
2	BNS	586.1	551.4	528.8	633.5	576.2	515.2	9.9	10.3	14.7
3	BMB	650.3	569.8	473.2	628.5	556.5	500.2	6.7	13.3	20.7
4	CAL	596.3	537.0	512.4	625.2	560.1	500.0	8.7	16.7	19.6
5	JDP	650.3	624.6	575.9	631.7	575.4	515.8	5.4	9.9	14.9
6	NGP	624.9	581.0	500.0	631.6	568.3	503.0	5.6	10.9	18.0
7	DLH	648.3	620.8	570.2	630.4	573.5	516.6	6.4	11.0	17.0
8	PNA	651.8	578.3	490.1	622.3	553.0	497.7	7.3	11.8	17.7
9	VSK	633.7	572.3	557.2	642.4	561.7	506.2	5.9	12.3	18.1

Table 6 : Root mean square error and its percentage with the observed mean GSR for independent data set for the year 1990

S.No.	Station	May rmse Wm^{-2}	rmse (%)	June rmse Wm^{-2}	rmse (%)	July rmse Wm^{-2}	rmse (%)
1	AHM	37.0	5.9	49.5	8.7	130.2	30.4
2	BNS	60.3	10.6	68.1	12.5	143.9	34.4
3	BMB	67.1	11.3	87.5	15.6	143.8	34.0
4	CAL	69.5	11.7	91.9	16.6	131.5	28.1
5	JDP	29.2	4.8	28.4	4.7	67.5	12.7
6	NGP	63.2	10.1	109.4	19.8	128.9	28.8
7	DLH	43.8	7.2	56.0	8.9	100.6	17.0
8	PNA	46.2	7.3	87.2	16.4	99.0	20.8
9	VSK	42.0	6.6	87.0	15.5	101.9	19.9
10	Jaipur	40.5	6.6	32.1	5.5	69.7	14.1
11	Bhopal	58.3	9.5	107.8	20.1	130.0	30.0
12	Patna	53.2	9.2	55.2	9.9	136.6	31.0

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