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IMPROVED CORRELATION OF MONTHLY MEAN DAILY AND HOURLY DIFFUSE RADIATION WITH THE CORRESPONDING GLOBAL RADIATION FOR INDIAN STATIONS *

H.P. Garg **
International Centre for Theoretical Physics, Trieste, Italy

and

S.N. Garg
Centre for Energy Studies, Indian Institute of Technology,
New Delhi - 110 016 India.

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* To be submitted for publication.

** Permanent address: Centre for Energy Studies, Indian Institute of Technology, New Delhi - 110 016 India.

ABSTRACT

Several existing correlations between monthly mean ratios of global to extraterrestrial $(\bar{K}_T)$ and diffuse to global were tried for four Indian stations and found inadequate. New correlations were established for these stations and it was shown that these correlations are highly climate dependent. Classical equation of Liu and Jordon

$$r_d = \frac{\pi}{24} \left[\frac{\cos w - \cos w_s}{\sin w_s - w_s \cos w_s}\right]$$

was tried to find hourly diffuse and global radiation from daily sums of diffuse and global radiation respectively. It was suitably modified to suit the Indian data. Equations developed by Collares-Pereira and Rabl have shown excellent agreement with the observed values.

1. INTRODUCTION

Diffuse radiation on horizontal surface finds many applications, particularly in finding global radiation on tilted surface , illumination design inside a building etc. But as compared to measurement of global radiation, diffuse radiation is measured only at few places. Therefore, it becomes necessary to know if the diffuse radiation can be computed from some parameters, other than measurement. Liu and Jordon [1] through their classical work, as early as in 1960, have shown that there is a high degree of correlation between diffuse radiation and global radiation if statistical averages over a large period of time are taken. Statistical averages are necessary to smooth out day to day small fluctuations in weather conditions at a given station. Once this correlation is established for a station where both global and diffuse radiation are measured, then the same correlation could be applied for other stations with almost similar climatic conditions. Correlation study has been undertaken by several other investigators also. Page [3] developed linear correlation between daily global and daily diffuse radiation for ten widely separated stations individually, situated between 40°N and 40°S and then recommended the following average correlation:

$$\frac{\bar{D}}{\bar{G}} = 1.00 - 1.13\,\bar{K}_T \quad . \tag{1}$$

He used a solar constant of 2.0 ly/min (1396 W/m^2) in developing the correlation. Liu and Jordon have also used a solar constant of 2.0 ly/min and take the 16th of each month as the representative day for that month except for February when the 15th was used. Klein [4] gave a mathematical expression for Liu and Jordan's correlation which was based on a more realistic solar constant value of 1.94 ly/min (1351 W/m^2) and where actual mean day for every month was used. (This was found by actually summing the extra-terrestrial radiation for the whole month and dividing this sum by the number of days in that month and then comparing this value with the day which gave almost same estraterrestrial radiation per day.) His correlation is of the form.

$$\frac{\bar{D}}{\bar{G}} = 1.390 - 4.027\,\bar{K}_T + 5.531\,\bar{K}_T^{2} - 3.108\,\bar{K}_T^{3} \quad . \tag{2}$$

Ruth and Chant [5], Orgill and Hollands [6], Tuller [7] and Iqbal [8] have analysed Canadian station data and each one has developed correlation under different assumptions and conditions. Tuller analysed the monthly mean daily diffuse radiation data for four Canadian stations and developed the following linear correlation using a solar constant value of 1.95 ly/min (1358 W/m^2):

$$\frac{\bar{D}}{\bar{G}} = 0.84 - 0.62\ \bar{K}_T \quad . \tag{3}$$

By dropping Resolute data (as it is in polar circle and gives anomalous results), Iqbal improved upon (3) and gave the following linear expression:

$$\frac{\bar{D}}{\bar{G}} = 0.914 - 0.847\ \bar{K}_T \quad . \tag{4}$$

Choudhary [9] has analysed Indian data to establish Liu and Jordan type correlation for this region. But his data covered only a 3 months period and that too for one station, New Delhi. In view of these limitations, his results needed further investigation. But Choudhary has also shown that Liu and Jordan's correlation predicts lower diffuse radiation for New Delhi, a fact which has been invariably reported by every investigator subsequently.

The purpose of the present study is to check the adequacy of the various radiation models quoted above, for Indian stations. If found inadequate, to develop new correlation and check these against the measured long term radiation data. Data for this study were made available from Miss A. Mani's Book [10], Handbook of Solar Radiation of India. The radiation data conforms to the international standards and is based upon world radiometric reference (WRR), which becomes effective from July, 1981. Geographical coordinates of the four stations and length of radiation records used in this study are shown in Table 1.

2. ANALYSIS

Monthly mean daily extraterrestrial radiation on a horizontal surface, $\bar{H}_o$, is calculated using the following equations:

$$\bar{H}_o = \frac{24}{\pi}\,(r\ I_{sc})(\cos L \cos \delta \sin w_s + w_s \sin L \sin \delta) \tag{5}$$

$$\cos w_s = -\tan L \tan \delta \tag{6}$$

and

$$r = 1 + 0.033 \cos\left(\frac{360 \times n}{365}\right) \quad . \tag{7}$$

Factor r accounts for the varying earth-sun distance from day to day. Solar constant, I_{sc}, is taken as 1373 watts/m^2 (1.95 ly/min). Computed values of extraterrestial radiation and measured global and diffuse radiation for different months are shown in Table 2. Knowing global and extraterrestrial radiation, the clearness index,

$$\bar{K}_T = \frac{\bar{G}}{\bar{H}_o}$$

is found for each month and for each station. Similarly the diffuse ratio $\bar{D}/\bar{G}$ is also found. Values of $\bar{K}_T$ and $\bar{D}/\bar{G}$ for different months and for different stations are shown in Figs. 1 and 2 respectively. $\bar{D}/\bar{G}$ versus $\bar{K}_T$ plot is shown in Fig. 3.

By using least square technique, correlation between $\bar{K}_T$ and $\bar{D}/\bar{G}$ have been found for each station separately as well as for all the 4 stations taken together. The correlations are as follows:

New Delhi $\quad \bar{D}/\bar{G} = 1.23 - 1.45\ \bar{K}_T \qquad (8)$

Calcutta $\quad \bar{D}/\bar{G} = 1.34 - 1.61\ \bar{K}_T \qquad (9)$

Poona $\quad \bar{D}/\bar{G} = 1.64 - 2.05\ \bar{K}_T \qquad (10)$

Madras $\quad \bar{D}/\bar{G} = 1.24 - 1.32\ \bar{K}_T \qquad (11)$

Combined $\quad \bar{D}/\bar{G} = 1.36 - 1.62\ \bar{K}_T \qquad (12)$

For comparison purpose, Eqs. (8-12) are plotted in Fig. 4. Results of Liu and Jordan Klein, Page, Tuller and Iqbal are also shown in the same diagram. Computed values of regression coefficients (a,b); coefficient of correlations, r and standard error of estimation for each station individually as well as for all the stations collectively, are shown in Table 3.

Using Eqs. (8-11) monthly diffuse radiation is calculated for each station and the same is compared with the measured data as shown in Figs. 5-9. Diffuse radiation is also calculated using equations developed by other investigators (Eqs. (1-4)) and their results are also shown in these figures.

Liu and Jordan have shown that ratio of hourly to daily diffuse radiation (monthly mean) at a given latitude is the same as the ratio of hourly to daily extraterrestrial radiation for the same latitude. The ratio for extraterrestrial radiation is determined from solar geometrical relations and it is as follows:

$$r_d = \frac{\pi}{24} \left(\frac{\cos w \;\; \cos w_s}{\sin w_s - w_s \;\; \cos w_s} \right) \tag{13}$$

We have tried to see if this ratio fits Indian stations also. Eq. (13) is plotted in Fig. 9 (continuous curves) for different day lengths (day length = $2\,w_s/15$). Experimental values of the diffuse fraction (=hourly/daily) were calculated and are shown by the marked points for all the 4 stations in the same figure. A similar type of graph is prepared for global fraction (Fig. 10). Figs. 9-10 show that Eq. (13) does not predict the observed values very accurately. So new relations were developed for diffuse fraction as well as for global fraction (shown in next section). Utilising the new relations diffuse fraction and global fraction are computed for different hours of the day and the results so obtained are compared with the observed ones as shown in Tables 4 and 5. Diffuse and global fraction are also calculated using Eq.(13) and these results are also shown in the same tables. Results could have been better shown by graphs but due to the difficulty that observed and predicted values are so close to each other that these cannot be shown distinctly on the same graph, these have been shown in tables.

3. RESULTS AND DISCUSSION

3.1 Monthly mean daily radiation

Fig. 1 shows variation of monthly mean clearness index $\bar{K}_T$ in different months of the year. It is seen that $\bar{K}_T$ varies approximately from 0.4 to 0.7 round the year for all the four stations. During rainy months, which are different for different stations, $\bar{K}_T$ goes as low as 0.4 i.e. only 40% of the extraterrestrial radiation reaches the earth. Monthly mean $\bar{K}_T$ are much different from daily K_T values, which vary form 0.1 to 0.8 for the stations considered. This is expected also as K_T reflects the climatic conditions on a particular day while $\bar{K}_T$ represents the climatic conditions averaged over 30 (or 31) days. During clear months, K_T becomes as high as 0.7. For all the stations, clear months are generally winter months, except for Madras which has rains during November and December. Fig. 2 shows the variation of monthly mean diffuse ratio, $\bar{D}/\bar{G}$, with the months of the year. It shows that $\bar{D}/\bar{G}$ varies from 0.20 to 0.75 approximately round the year for all the 4 stations. During clear months, diffuse ratio (monthly) is low, which implies that most of the global radiation arrives in the form of direct radiation and only a small fraction appears in the form of diffuse radiation. During rainy months, $\bar{D}/\bar{G}$ is as high as 0.75 i.e. 75% of the global radiation appears as diffuse radiation and only 25%, as direct radiation. This is because during rainy months the atmosphere is heavily loaded with water vapours which absorb a significant part of the direct radiation. Water vapour also scatters the radiation. Figs. 1-2 together show the average climatic conditions of the 4 stations in different months. It is seen that these 4 stations have very different climatic conditions. Poona appears to have exceptionally clear weather from January to May. This station also has very thick clouds during the rainy months which is evident from very low $\bar{K}_T$ and high $\bar{D}/\bar{G}$ values. Calcutta, being a highly industrialised city, has highly polluted atmosphere and hence a larger fraction of the diffuse radiation. This results in low clearness index $\bar{K}_T$ and high diffuse ratio $\bar{D}/\bar{G}$ round the year. Madras is a coastal station, which has comparatively lesser fluctuations in its climatic conditions. But apart from July, August and September as rainy months, this station has rains during October, November and December also. New Delhi has October, November and December as clear months and July, August as rainy months.

Fig. 3 shows the variation of $\bar{D}/\bar{G}$ when plotted against $\bar{K}_T$ for all the 4 stations taken together. It is evident that for the same value of $\bar{K}_T$, $\bar{D}/\bar{G}$ shows large variation. This is because every station has its own climatic conditions. There are many combinations of direct and diffuse radiation which will add to give same global radiation and hence same $\bar{K}_T$ value. But each combination will give different $\bar{D}/\bar{G}$ ratio. Which combination will be applicable, depends upon the type of climatic conditions prevailing on that station. Least square fitting curve for all the stations taken together is also shown in Fig. 3

Fig. 4 shows that regression curves for the 3 stations, New Delhi, Calcutta and Madras are very close to each other but much different from the regression curve for Poona. This is again because Poona has exceptionally clear months and also exceptionally thick clouds during rainy months. When the present curves are compared with the work of other investigators, it is seen that Liu and Jordan predict lower diffuse radiation. Although Klein's relation is based upon a revised solar constant value, it also runs very close to the Liu and Jordan relation and hence predicts lower diffuse radiation. Tuller, Iqbal and Page relations also appear to be regional ones, highly depending upon the local conditions of the station. The Page relation gives lower diffuse radiation for the concerned range of $\bar{K}_T$. Tuller and Iqbal relation gives lower diffuse radiation for $K_T < 0.5$ and high diffuse radiation for $K_T > 0.5$. This shows that regression fitting should be done for each station individually (wherever radiation data is available). To find a single universal formula for correlation will involve a large amount of error. One important point concerns the range of $\bar{K}_T$ in this study. All the regression equations are valid for $0.4 < \bar{K}_T < 0.7$. In literature also most of the stations have reported this range only which implies that regression equations are seldom needed outside this range. Apart from climatic condition dependence, correlation may depend upon latitude also. But it is difficult to study the dependence of correlation on each parameter separately.

Table 3 shows high values of correlation coefficient and low values for standard error of estimation.

Figs. 5-8 show the comparison of diffuse radiation, calculated by using Eqs. (1-4) and Eqs. (8-11), with the measured data as well as comparison among themselves for different months of the year. For New Delhi (Fig. 5), Page and Liu and Jordan's relations give low diffuse radiation values for all the 12 months. Iqbal's relation gives higher diffuse radiation from September to March but lower radiation during the rainy months. Although present correlations also show this type of trend of higher and lower values, it is the best fitting in the present circumstances. For Calcutta, Pooma and Madras also (Figs. 6-8), Page and Liu and Jordan predict low diffuse radiation. Iqbal is much closer to the measured values among the 3 correlations tested. The present correlation fits best for Poona where Iqbal's correlation also fails miserably.

3.2 Monthly mean hourly radiation

Liu and Jordan tested the theoretical ratio, Eq. (13), for two widely separated stations and found an excellent agreement between the experimental ratio and those computed by means of Eq. (13). This ratio has also been tested for Canadian stations by Iqbal [11] and he also reported good agreement. But when this ratio was tested for Indain stations, the results are as shown in Fig. 9.

Experimental ratios are shown by the marked points and continuous curves are the plots of Eq. (13) for different values of w_s. It is seen that for 'HOURS FROM SOLAR NOON' (HFSN) = $\frac{1}{2}$ and $1\frac{1}{2}$ hours, experimental points lie below the curves, for HFSN = $2\frac{1}{2}$, experimental points lie very closely on the curve and for HFSN = $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{1}{2}$; experimental points lie above the curve. For HFSN = $6\frac{1}{2}$, experimental points lie both below and above the curve. It is also seen that there are some points which lie exactly on the curve for all values of HFSN. When the experimental ratios were closely scrutinized it was found that such points, which lie exactly on the curve for all values of HFSN, correspond to rainy months only. If we exclude these rainy month points for all the stations, HFSN = $\frac{1}{2}$, $1\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{1}{2}$ will have no point which will lie exactly on the curve. This necessiates a new correlation for the Indian stations. The new correlation is of two forms. For rainy months, new correlation is the same as the theoretical ratio, Eq. 13. For other months the new correlation is:

$$r = \frac{\pi}{24}\left(\frac{\cos w - \cos w_s}{\sin w_s - w_s \cos w_s}\right) + 0.010 \sin 3\,(w - 0.65) \quad (14)$$

Hourly diffuse ratios have been calculated using new correlations. Eq. (14) as well as the theoretical ratios, Eq. (13), and the values thus obtained have been compared with the observed hourly diffuse ratios, as shown in Table 4. Although the values were compared for all the 4 stations Table 4 shows comparison for two stations only, New Delhi and Poona. This is because the same trend is observed for the other two stations also. It is seen that the difference between the observed ratios and those calculated using Eq. (13), has been much narrowed by using Eq. (14). Fig. 10 shows the monthly mean (hourly/daily) global fraction as a function of length of day (or w_s, sunset hour angle) with HFSN running as parameter. The observed global fraction is shown by the points while continuous curves are the graph of Eq. (13). Comparing to Fig. 9, a reverse trend is observed here. For HFSN = 1/2 and $1\frac{1}{2}$, observed points lie above the curve; for HFSN = $2\frac{1}{2}$ observed points lie closely on the curve and for HFSN = $3\frac{1}{2}$, $4\frac{1}{2}$. $5\frac{1}{2}$ and $6\frac{1}{2}$ observed points lie below the curve. This is because of the following fact. It has been found (results not shown in this manuscript) that hourly/daily ratio for direct radiation is higher than theoretical ratio, Eq. (13) for HFSN = $\frac{1}{2}$, $1\frac{1}{2}$ is equal to theoretical ratio for HFSN = $2\frac{1}{2}$, and is less than theoretical ratio for HFSN = $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{1}{2}$ and $6\frac{1}{2}$. As direct radiation constitutes the major portion of the global radiation, so ratios for global radiation will follow the same pattern as the ratio for direct radiation. Why ratio for direct radiation is less in the morning and more near the solar noon as compared to theoretical ratio, finds a simple explanation. Direct radiation undergoes a set pattern of attenuation the whole day. Because of attenuation, daily sums of direct radiation on the ground is much less than the daily sums of extraterrestrial radiation. For extraterrestrial radiation, it is the angle of incidence which determines the amount of radiation falling on a horizontal surface at a particular hour, but for a ground based observer, apart from angle of incidence, it is the attenuation also, which determines this amount. As attenuation is maximum in the morning and least at solar noon, therefore, ratio for direct radiation is lesser in the morning and higher at solar noon, when compared to the theoretical ratio. Also, experimental points show less scattering in Fig. 10 than in Fig. 9. Another fact is that when theoretical ratios are zero; experimental ratios are not zero, rather experimental ratios extend toward the left. This is because of some diffuse radiation arrival (twilight) before sunrise and after sunset. One more point is observed in Fig. 10, for all values of HFSN except $2\frac{1}{2}$ even for rainy months, one hardly sees any point lying on the curves itself which is in contradiation to the observation made in Fig. 9. All this shows that Eq. (13) is not sufficient to find hourly global radiation from daily sums, on a statistical basis. The new correlation is:

$$r = \left(\frac{\cos w - \cos w_s}{\sin w_s - w_s \cos w_s}\right) - 0.008 \sin 3 (w - 0.65) \qquad (15)$$

Monthly mean global fractions have been calculated using Eqs. (13) and (15) and values so obtained have been compared with the observed monthly mean global fractions, as shown in Table 5. As for diffuse radiation, in this case also results were prepared for all the 4 stations but to avoid repetition results are shown only for New Delhi and Poona. It is evident from Table 5 that Eq. (14) gives results which are much closer to the observed values.

Collares-Pereira and Rabl have also developed expressions to get hourly global radiation from daily global radiation. The expressions are as follows:

$$r = \frac{\pi}{24} (a + b \cos w) \left\{ \frac{\cos w - \cos w_s}{\sin w_s - w_s \sin w_s} \right\} , \qquad (16)$$

where

$$a = 0.4090 + 0.5016 \sin (w_s - 1.047)$$

$$b = 0.6609 - 0.4767 \sin (w_s - 1.047) .$$

When these expressions were applied to Indian stations, results obtained were in excellent agreement with the observed values. This ensures the validity of these expressions for Indian stations also. But Eqs. (14) and (15) are much simpler as compared to Collares-Pereira's equations. It remains to be seen whether Eqs.(14)and(15) are valid for stations outside India. If found adequate, then these equations may be accepted as an alternative to Collares-Pereira equations.

4. CONCLUSIONS

Correlation between monthly mean diffuse and global radiation is highly climate dependant. As climatic conditions change very much from region to region, therefore correlation for every individual region or station must be established separately. Attempting to evolve a universal correlation will give a large amount of error. Regional correlation in the present study is adequate to predict mean diffuse radiation from mean global radiation within 10% error. A few of the predictions also show error beyond 10%. Theoretical relationship to derive hourly diffuse radiation from daily sums (monthly mean), as employed by Liu and Jordan, is adequate for rainy months only for Indian stations. It has to be suitably modified to suit clear months. For global radiation, theoretical relationship is not adequate for any season . An additional term has been provided to ensure its suitability. Results predicted by Eqs. (13)and(14) are almost identical to the results shown by Collares-Pereira and Rabl.

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NOMENCLATURE

$\bar{G}$	monthly mean global radiation, on a horizontal surface, $MJ/m^2/day$
$\bar{D}$	monthly mean diffuse radiation on a horizontal surface, $MJ/m^2/day$
$\bar{H}_o$	*monthly mean extraterrestrial radiation on a horizontal surface,* $MJ/m^2/day$
$\bar{K}_T$	clearness index, diamensionless ratio
L	latitude of the station, (^oN)
δ	declination, (o)
I_{sc}	solar constant, $I_{sc} = 1373\ W/m^2$
w_s	sunset hour angle, radians
n	no. of the day of the year
HFSN	hours from solar noon

Diffuse ratio = Daily diffuse/daily global

Diffuse fraction = hourly diffuse/daily diffuse

Global fraction = hourly global/daily global

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TABLE 1

Indian Stations and their Geographical Parameters used in the study

Station	Latitude (N)	Longitude (E)	Elevation (masl)	Length of Radiation Record used
New Delhi	28°35'	77°12'	216	1957 - 1978
Calcutta	22°39'	88°27'	6	1957 - 1978
Poona	18°32'	73°51'	559	1957 - 1978
Madras	13°00'	80°11'	16	1957 - 1978

TABLE 3

Regression equations and other parameters of monthly mean $\bar{D}/\bar{G}$ as a function of $\bar{K}_T$

Station	Regression a	Coefficients b	Correlation coefficient r	Standard Error of estimation S.E.
New Delhi	1.23	- 1.37	- 0.93	0.04
Calcutta	1.34	- 1.61	- 0.96	0.04
Poona	1.64	- 2.05	- 0.99	0.03
Madras	1.24	- 1.42	- 0.93	0.04
All stations combined	1.36	- 1.62	- 0.95	0.05

TABLE 2

Monthly average daily extraterrestrial (EXT.), global (G)
and diffuse (D) radiation on a horizontal surface.

(Unit. $MJ/m^2/day$)

Month	New Delhi			Calcutta			Poona			Madras		
	EXT.	G	D	EXT.	G	D	EXT.	G	D	EXT.	G	D
Jan.	22.16	14.35	4.46	25.59	15.21	5.40	27.83	19.08	4.00	30.67	18.84	6.72
Feb.	26.79	18.00	5.31	29.66	18.11	6.27	31.47	22.22	4.29	33.66	22.65	6.21
Mar.	32.23	22.10	6.70	34.17	20.88	7.77	35.30	24.52	5.73	36.53	24.80	6.63
Apr.	37.20	24.57	8.90	37.90	22.76	9.57	38.16	25.77	7.43	38.20	24.92	7.62
May	40.15	26.14	10.52	39.76	23.49	11.14	39.27	26.29	8.05	38.34	23.52	9.24
Jun.	41.14	23.56	12.74	40.22	17.88	11.52	39.39	21.18	11.94	38.01	20.97	10.29
Jul.	40.60	19.20	11.29	39.89	16.71	11.43	39.20	16.34	12.50	37.99	19.45	11.19
Aug.	38.17	18.19	9.82	38.42	16.07	10.51	38.77	16.48	12.57	38.01	20.08	10.85
Sep.	33.87	20.17	7.75	35.35	17.19	9.36	36.15	19.10	10.54	36.92	20.56	9.28
Oct.	28.24	19.28	5.27	30.83	16.41	7.32	32.42	20.40	6.25	34.43	17.44	8.13
Nov.	23.16	16.28	4.11	26.44	15.75	5.54	28.57	18.85	4.40	31.33	15.63	7.29
Dec.	20.79	13.83	4.02	24.33	14.76	4.81	26.67	17.78	4.09	29.48	15.38	7.35

TABLE 4 (cont.)

Aug. (Rainy month)	Obs.	0.122	0.113	0.099	0.080	0.055	0.027	0.002	0.129	0.122	0.103	0.078	0.048	0.019	0.001
	Eq.13	0.121	0.114	0.100	0.080	0.055	0.028	0.008	0.124	0.116	0.101	0.080	0.054	0.024	0.000
	Eq.13	0.121	0.114	0.100	0.080	0.055	0.028	0.008	0.124	0.116	0.101	0.080	0.054	0.024	0.000
Sep. (Rainy month)	Obs.	0.124	0.117	0.102	0.080	0.056	0.023	0.000	0.127	0.118	0.100	0.077	0.047	0.017	0.000
	Eq.13	0.128	0.120	0.103	0.080	0.051	0.019	0.008	0.129	0.120	0.103	0.080	0.051	0.018	0.000
	Eq.13	0.128	0.120	0.103	0.080	0.051	0.019	0.008	0.129	0.120	0.103	0.080	0.051	0.018	0.000
Oct.	Obs.	0.122	0.115	0.105	0.087	0.058	0.016	0.000	0.123	0.118	0.105	0.084	0.055	0.017	0.000
	Eq.13	0.137	0.127	0.107	0.079	0.044	0.016	0.008	0.134	0.124	0.105	0.079	0.047	0.010	0.000
	Eq.14	0.127	0.120	0.107	0.086	0.054	0.013	0.000	0.124	0.117	0.106	0.086	0.057	0.017	0.000
Nov.	Obs.	0.128	0.122	0.108	0.087	0.049	0.006	0.000	0.126	0.120	0.109	0.087	0.055	0.012	0.000
	Eq.13	0.146	0.133	0.110	0.076	0.035	0.006	0.008	0.139	0.128	0.106	0.078	0.042	0.002	0.000
	Eq.14	0.136	0.126	0.110	0.083	0.045	0.000	0.000	0.129	0.121	0.108	0.085	0.052	0.009	0.000
Dec.	Obs.	0.139	0.130	10110	0.082	0.021	0.002	0.000	0.126	0.121	0.110	0.087	0.053	0.009	0.000
	Eq.13	0.150	0.137	0.111	0.074	0.030	0.016	0.008	0.141	0.130	0.108	0.078	0.040	0.002	0.000
	Eq.14	0.140	0.130	0.111	0.081	0.040	0.000	00.000	0-131	0.123	0.108	0.085	0.050	0.000	0.000

TABLE -

Comparison of observed and theoretically calculated ratio of hourly to daily diffuse radiation for New Delhi and Poona

Month		New Delhi							Poona						
		Hours from solar noon							Hours from solar noon						
		$\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{2}$	$6\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{2}$	$6\frac{1}{2}$
Jan	Obs.	0.140	0.130	0.112	0.82	0.041	0.002	0.000	0.119	0.116	0.107	0.089	0.058	0.012	0.000
	Eq.13	0.148	0.135	0.110	0.075	0.033	0.000	0.000	0.140	0.129	0.108	0.078	0.041	0.000	0.000
	Eq.14	0.138	0.128	0.110	0.83	0.043	0.000	0.000	0.130	0.122	0.108	0.085	0.051	0.007	0.000
Feb.	Obs.	0.129	0.123	0.108	0.085	0.051	0.009	0.000	0.113	0.111	0.103	0.089	0.063	0.020	0.000
	Eq.13	0.140	0.129	0.108	0.078	0.041	0.001	0.000	0.136	0.126	0.106	0.079	0.045	0.008	0.003
	Eq.14	0.130	0.122	0.108	0.085	0.051	0.008	0.000	0.126	0.119	0.106	0.086	0.055	0.015	0.000
Mar.	Obs.	0.120	0.114	0.104	0.087	0.061	0.023	0.000	0.108	0.107	0.103	0.089	0.066	0.027	0.000
	Eq.13	0.132	0.122	0.105	0.080	0.049	0.015	0.000	0.131	0.122	0.104	0.080	0.049	0.016	0.003
	Eq.14	0.122	0.115	0.105	0.087	0.059	0.022	0.000	0.121	0.115	0.104	0.087	0.059	0.023	0.000
Apr.	Obs.	0.112	0.108	0.098	0.084	0.062	0.033	0.002	0.105	0.105	0.100	0.087	0.066	0.033	0.001
	Eq.13	0.124	0.116	0.101	0.080	0.054	0.025	0.000	0.126	0.118	0.102	0.080	0.053	0.022	0.003
	Eq.14	0.114	0.109	0.101	0.087	0.064	0.032	0.000	0.116	0.111	0.102	0.087	0.063	0.029	0.000
May	Obs.	0.108	0.105	0.097	0.084	0.065	0.038	0.005	0.106	0.106	0.098	0.086	0.066	0.037	0.003
	Eq.13	0.118	0.111	0.098	0.079	0.057	0.032	0.006	0.122	0.115	0.100	0.080	0.055	0.027	0.003
	Eq.14	0.008	0.104	0.098	0.087	0.067	0.039	0.006	0.112	0.108	0.100	0.087	0.065	0.034	0.000
June (Rainy month)	Obs.	0.113	0.107	0.096	0.080	0.059	0.034	0.005	0.120	0.112	0.099	0.080	0.055	0.028	0.002
	Eq.13	0.115	0.109	0.096	0.079	0.058	0.034	0.010	0.120	0.113	0.099	0.080	0.055	0.029	0.001
	Eq.13	0.115	0.109	0.096	0.079	0.058	0.034	0.010	0.120	0.113	0.099	0.080	0.055	0.029	0.001
July (Rainy month)	Obs.	0.118	0.110	0.097	0.079	0.056	0.031	0.004	0.128	0.118	0.102	0.078	0.050	0.022	0.003
	Eq.13	0.116	0.110	0.097	0.079	0.057	0.033	0.008	0.121	0.114	0.100	0.080	0.055	0.028	0.000
	Eq.13	0.116	0.110	0.097	0.079	0.057	0.033	0.008	0.121	0.114	0.100	0.080	0.055	0.028	0.000

TABLE 5 (cont.)

Sep.	Obs.	0.000	0.014	0.044	0.076	0.103	0.124	0.134	0.000	0.012	0.041	0.074	0.104	0.127	0.135
	Eq 13	0.000	0.019	0.051	0.060	0.103	0.120	0.128	0.000	0.018	0.051	0.080	0.103	0.120	0.129
	Eq 15	0.000	0.013	0.043	0.074	0.103	0.125	0.136	0.000	0.013	0.043	0.074	0.103	0.126	0.137
Oct.	Obs.	0.000	0.006	0.037	0.074	0.107	0.130	0.142	0.000	0.007	0.037	0.074	0.107	0.130	0.143
	Eq. 13	0.000	0.006	[illegible]	0.079	0.107	0.127	0.137	0.000	0.010	0.047	0.079	0.106	0.124	0.134
	Eq.15	0.000	0.000	0.036	0.073	0.107	0.132	0.145	0.000	0.005	0.039	0.074	0.106	0.130	0.142
Nov.	Obs.	0.000	0.002	0.028	0.070	0.109	0.136	0.151	0.000	0.004	0.033	0.072	0.108	0.134	0.147
	Eq.13	0.000	0.000	0.035	0.076	0.110	0.133	0.146	0.000	0.002	0.042	0.076	0.108	0.128	0.139
	Eq.15	0.000	0.000	0.027	0.071	0.110	0.139	0.154	0.000	0.000	0.034	0.073	0.108	0.134	0.147
Dec.	Obs.	0.000	0.001	0.022	0.067	0.110	0.141	0.157	0.000	0.003	0.031	0.071	0.108	0.136	0.150
	Eq.13	0.000	0.090	0.030	0.074	0.111	0.137	0.150	0.000	0.000	0.040	0.078	0.108	0.130	0.141
	Eq.15	0.000	0.000	0.022	0.069	0.111	0.142	0.158	0.000	0.000	0.032	0.072	0.108	0.136	0.149

TABLE 5

Comparison of observed and theoretically calculated ratio of hourly to daily global radiation for New Delhi and Poona.

Month		New Delhi Hours from solar noon 1/2	1-1/2	2-1/2	3-1/2	4-1/2	5-1/2	6-1/2	Poona Hours from solar noon 1/2	1-1/2	2-1/2	3-1/2	4-1/2	5-1/2	6-1/2
Jan.	Obs.	0.000	0.001	0.024	0.068	0.108	0.130	0.155	0.000	0.004	0.033	0.072	0.109	0.135	0.149
	Eq.13	0.000	0.000	0.033	0.075	0.110	0.135	0.148	0.000	0.000	0.041	0.078	0.108	0.129	0.140
	Eq.15	0.000	0.000	0.025	0.070	0.110	0.141	0.156	0.000	0.000	0.033	0.072	0.108	0.135	0.146
Feb.	Obs.	0.000	0.004	0.033	0.066	0.107	0.133	0.145	0.000	0.007	0.037	0.075	0.108	0.131	0.143
	Eq.13	0.000	0.001	0.041	0.073	0.108	0.129	0.140	0.000	0.006	0.045	0.079	0.106	0.126	0.136
	Eq.15	0.000	0.000	0.033	0.072	0.108	0.135	0.148	0.000	0.002	0.037	0.073	0.106	0.131	0.144
Mar.	Obs.	0.000	0.011	0.043	0.076	0.105	0.126	0.138	0.000	0.011	0.042	0.076	0.106	0.128	0.140
	Eq.13	0.000	0.015	0.049	0.080	0.105	0.122	0.132	0.000	0.016	0.049	0.080	0.104	0.122	0.131
	Eq.15	0.00	0.009	0.041	0.074	0.105	0.128	0.140	0.000	0.010	0.041	0.074	0.104	0.127	0.139
Apr.	Obs.	0.001	0.018	0.047	0.078	0.103	0.121	0.131	0.000	0.015	0.045	0.075	0.103	0.124	0.135
	Eq.13	0.000	0.025	0.054	0.080	0.101	0.116	0.124	0.000	0.022	0.0533	0.080	0.102	0.118	0.126
	Eq.15	0.000	0.020	0.045	0.074	0.101	0.121	0.132	0.000	0.017	0.045	0.074	0.102	0.123	0.134
May	Obs.	0.002	0.023	0.051	0.078	0.101	0.116	0.127	0.001	0.019	0.047	0.076	0.101	0.120	0.131
	Eq.13	0.006	0.032	0.057	0.079	0.098	0.111	0.118	0.000	0.027	0.055	0.080	0.100	0.115	0.122
	Eq.15	0.006	0.026	0.049	0.074	0.098	0.117	0.126	0.000	0.021	0.047	0.074	0.100	0.120	0.130
Jun.	Obs.	0.003	0.025	0.050	0.076	0.059	0.115	0.127	0.001	0.020	0.048	0.077	0.102	0.119	0.128
	Eq.13	0.010	0.024	0.058	0.079	0.096	0.109	0.115	0.001	0.029	0.056	0.080	0.099	0.113	0.120
	Eq.15	0.010	0.026	0.050	0.073	0.096	0.114	0.123	0.001	0.023	0.098	0.074	0.099	0.119	0.128
Jul.	Obs.	0.002	0.025	0.051	0.078	0.100	0.117	0.126	0.001	0.019	0.046	0.076	0.102	0.121	0.133
	Eq.13	0.006	0.033	0.057	0.079	0.097	0.110	0.116	0.000	0.028	0.055	0.080	0.100	0.114	0.121
	Eq.15	0.008	0.026	0.049	0.074	0.097	0.115	0.124	0.000	0.023	0.047	0.074	0.100	0.119	0.129
Aug.	Obs.	0.001	0.021	0.049	0.078	0.101	0.119	0.129	0.000	0.016	0.044	0.076	0.103	0.124	0.130
	Eq.13	0.000	0.028	0.055	0.080	0.100	0.114	0.121	0.000	0.024	0.054	0.080	0.101	0.116	0.124
	Eq.15	0.000	0.022	0.047	0.074	0.100	0.119	0.12[illegible]	0.000	0.015	0.046	0.074	0.101	0.122	0.132

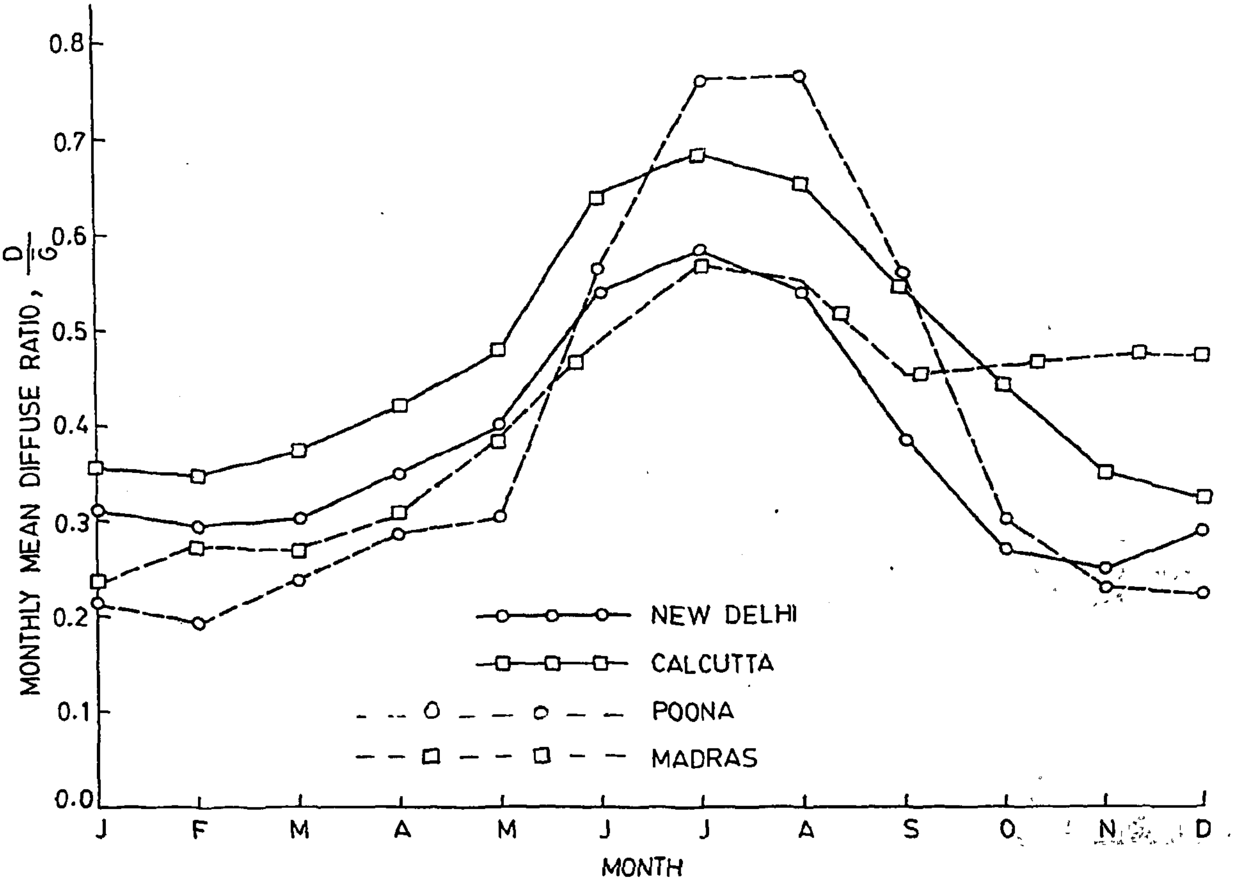

Fig. 2 - Values of $\bar{D}/\bar{G}$ in different months for four stations

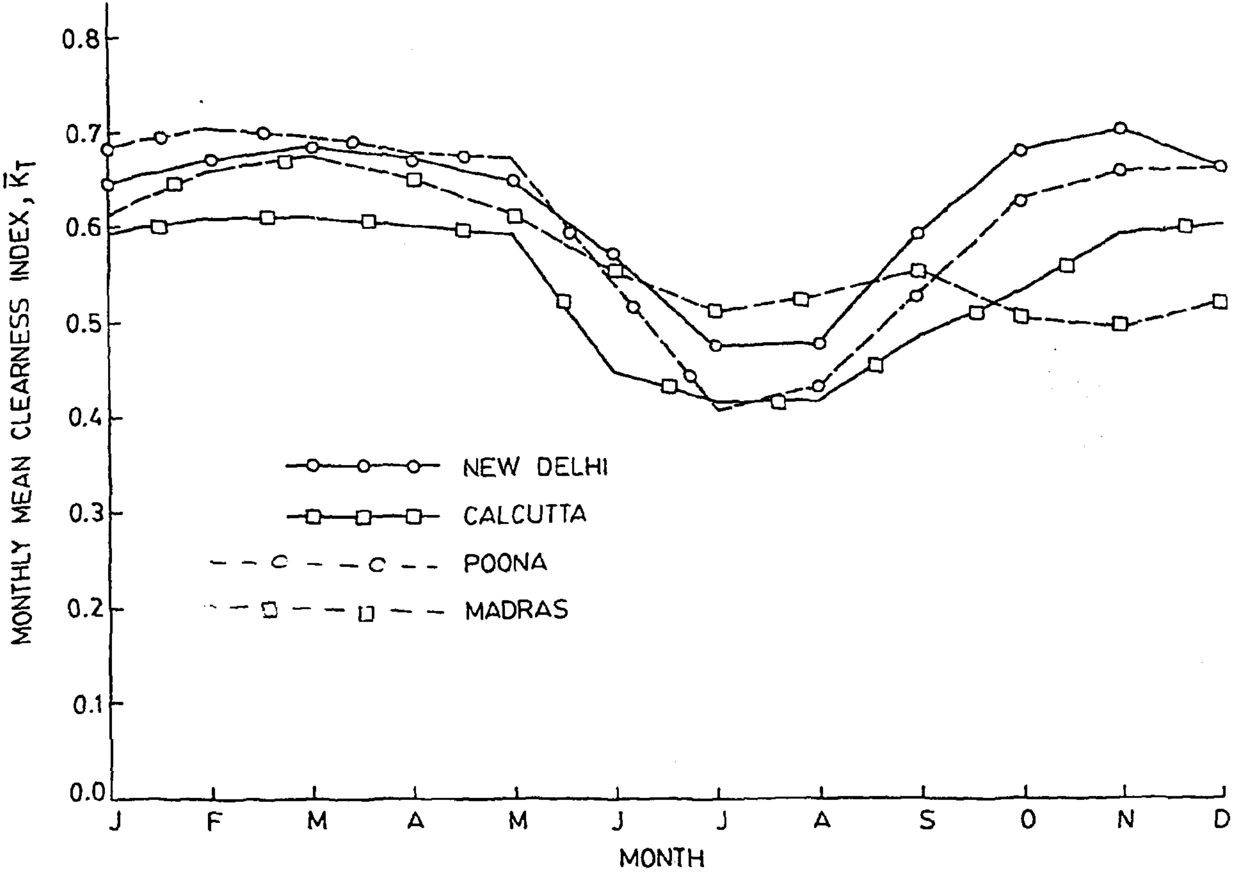

Fig. 1 - Values of $\bar{K}_T$ in different months for four stations

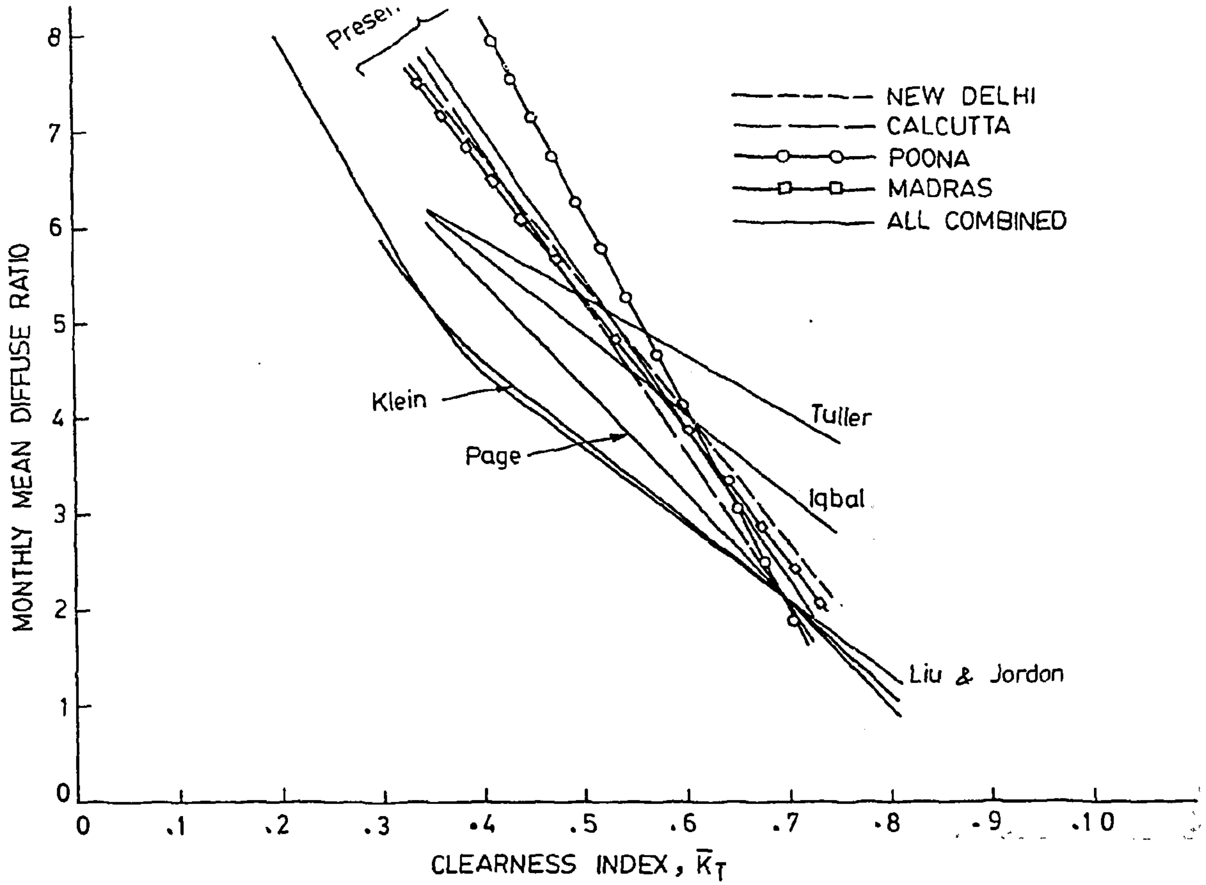

Fig. 4 - Regression fitting for the four stations and comparison wi equations of other Authors

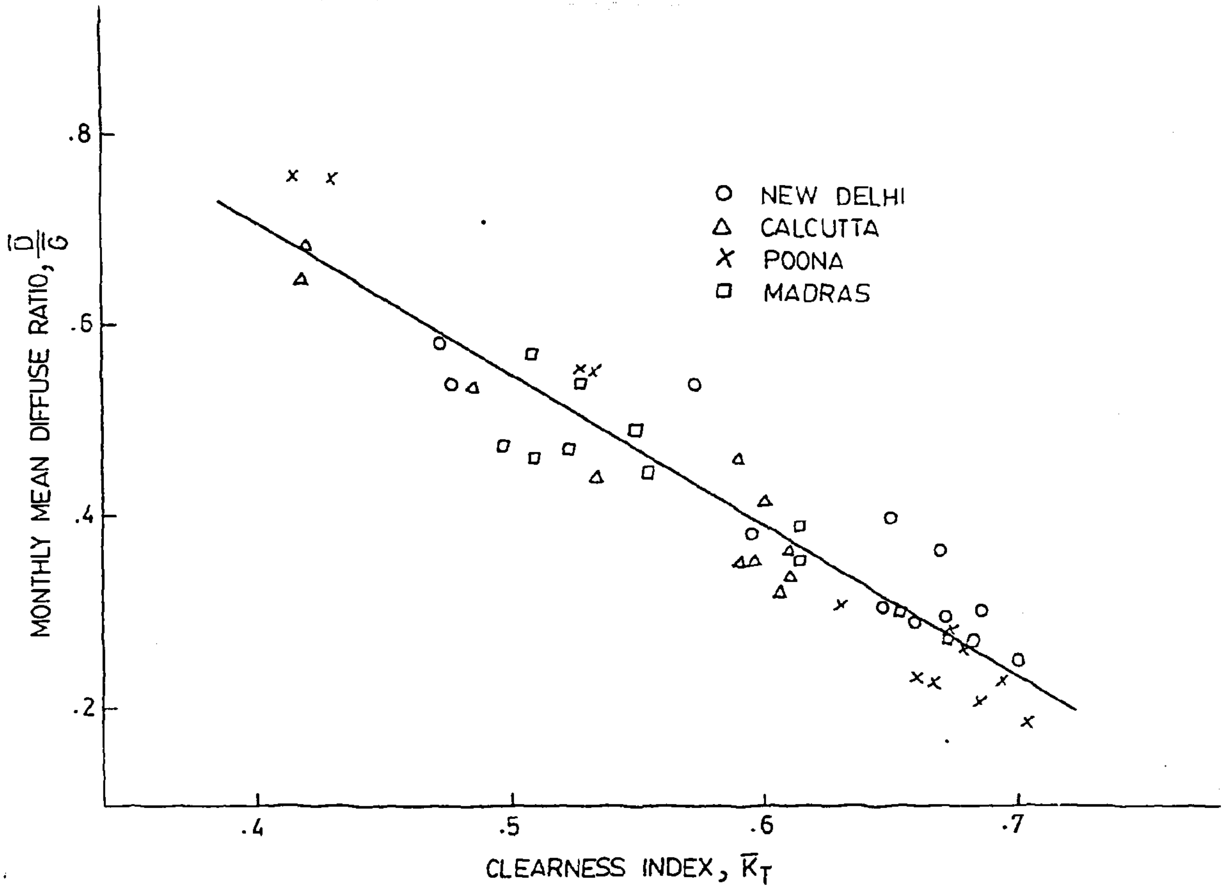

Fig. 3 - Observed diffuse ratio $\bar{D}/\bar{G}$ as a function of $\bar{K}_T$ for all the four stations

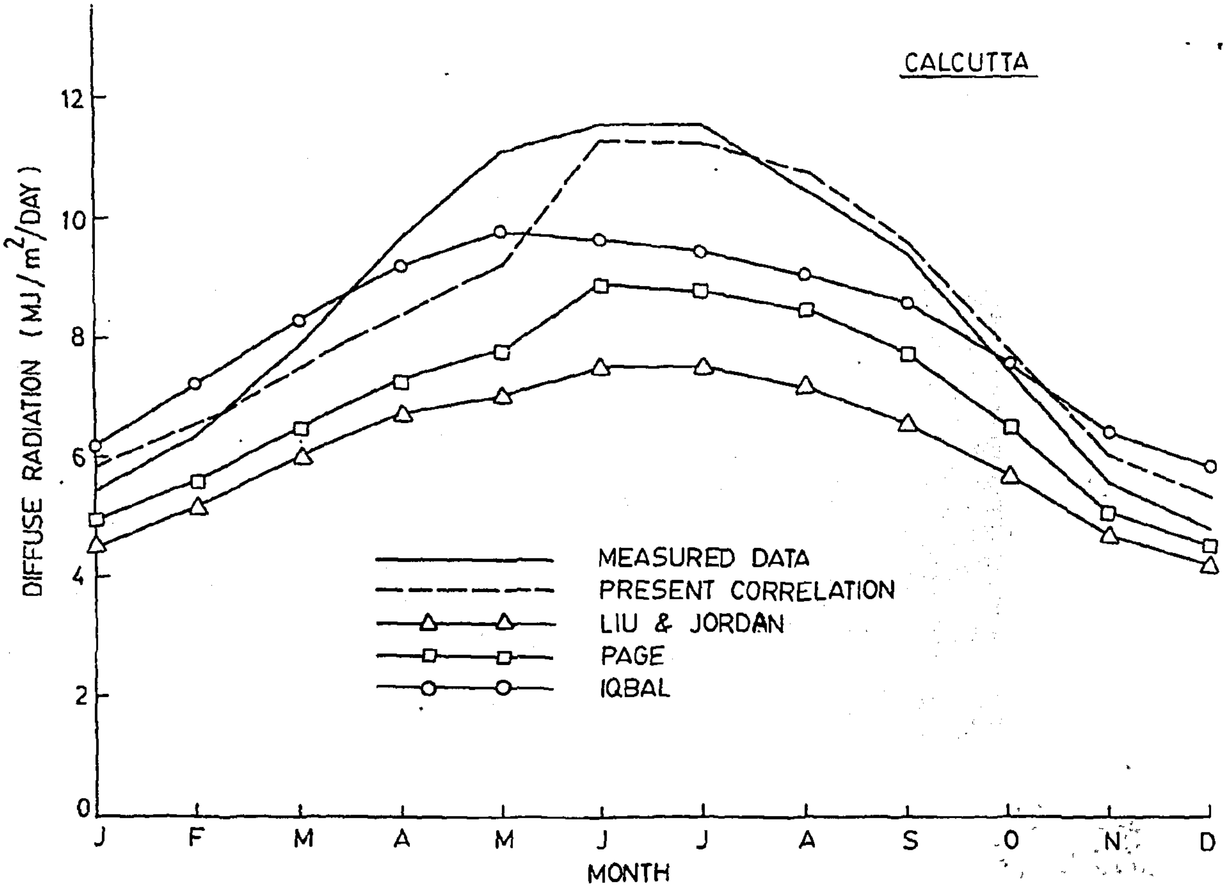

Fig. 6 – Comparison of measured and estimated diffuse radiation for Calcutta

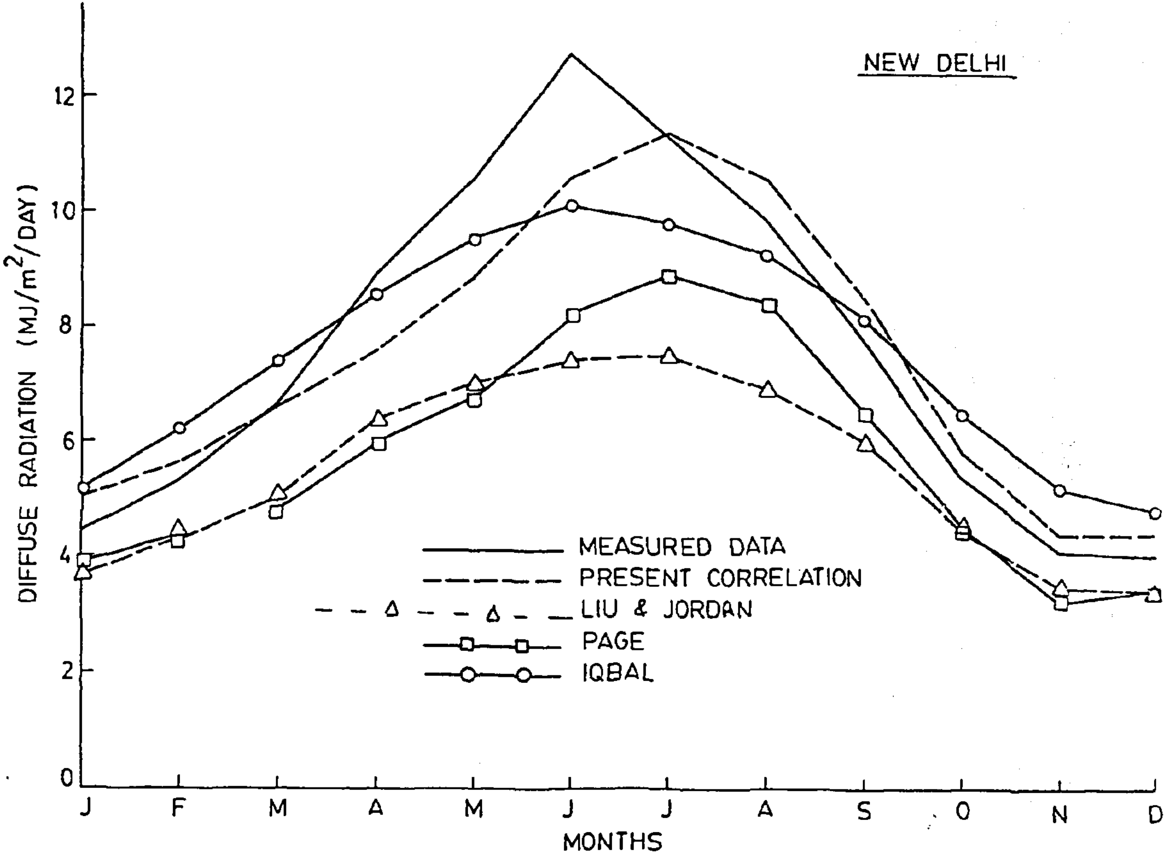

Fig. 5 - Comparison of measured and estimated diffuse radiation for New Delhi

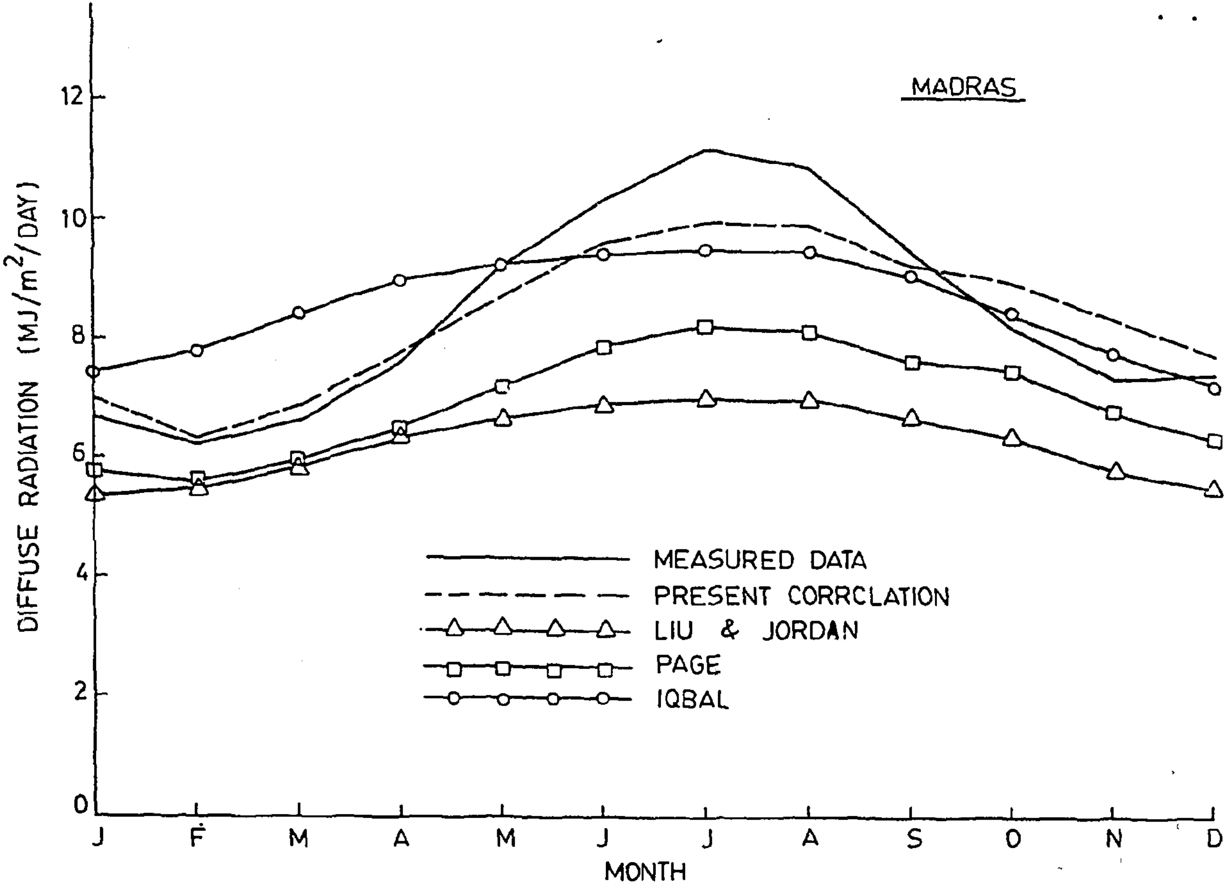

Fig. 8 - Comparison of measured and estimated diffuse radiation for Madras

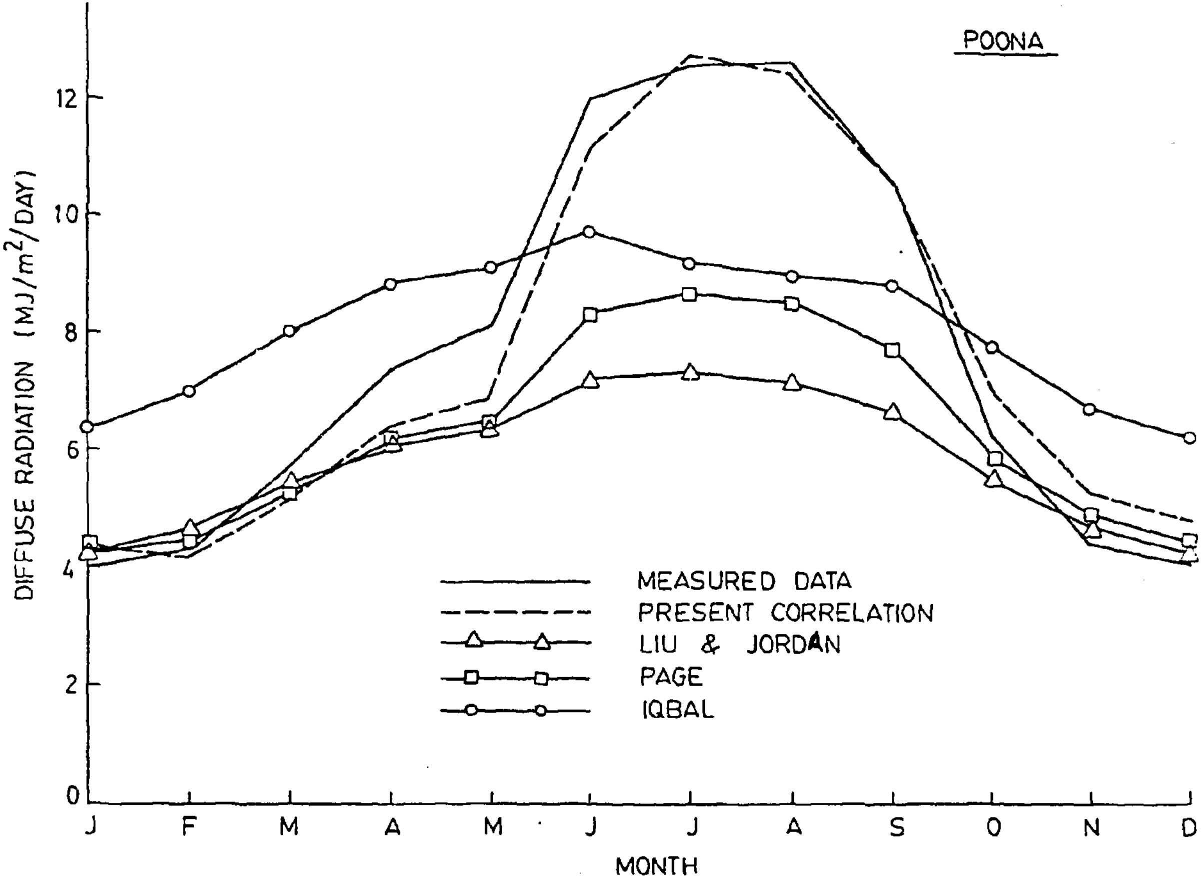

Fig. 7 - Comparison of measured and estimated diffuse radiation for Poona

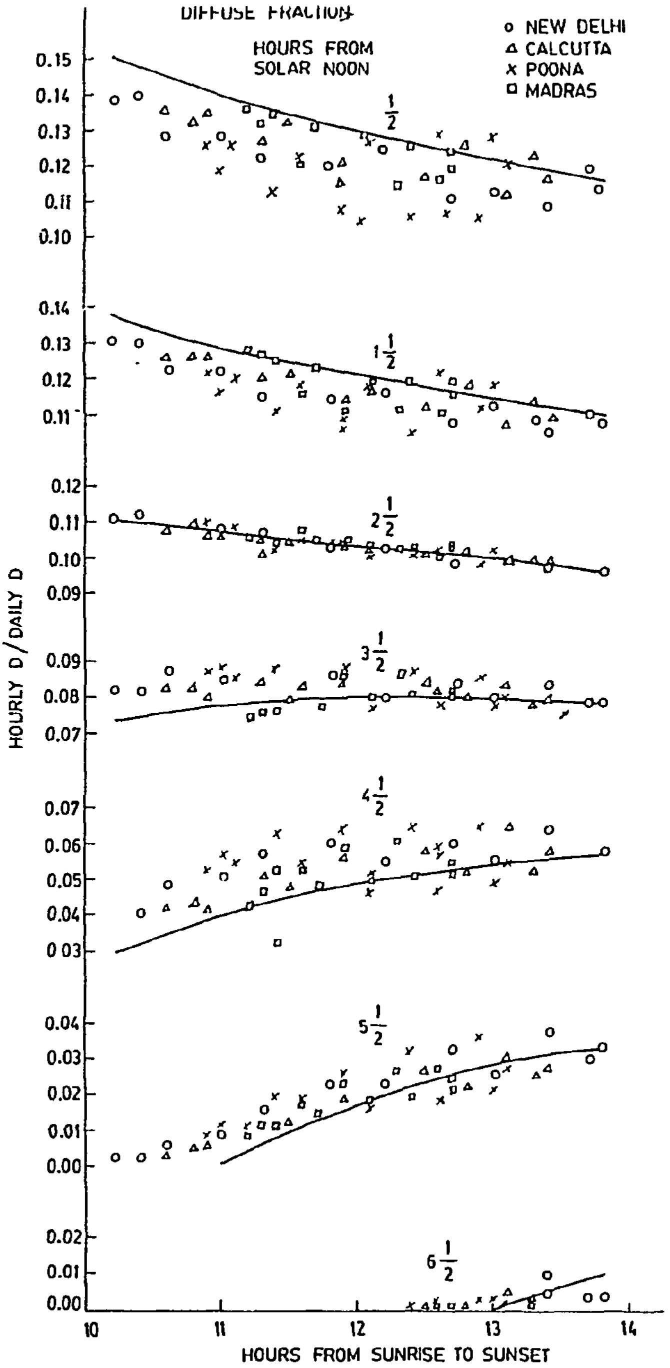

Fig 9 Eq13-(Continuous line) versus observed diffuse fraction (marked points)

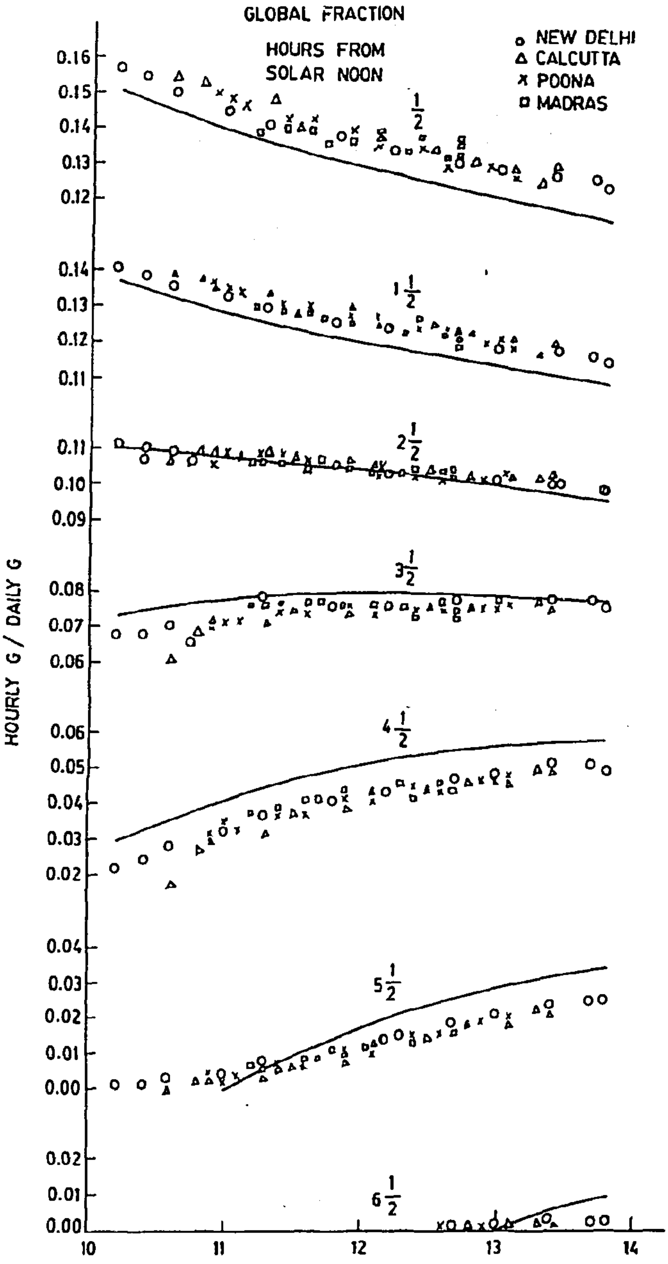

Fig 10. Eq 13 - (Continuous line) versus observed fraction (marked points)