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Global and diffuse solar radiant exposures at Pune

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सार — पुणे में विकिरण मापन का कार्य वर्ष 1957 से किया जा रहा है। आकाश की सामान्य स्थिति और वर्षा वितरण से संबंधित 1986-90 की अवधि के विकिरण आँकड़ों का इस शोध पत्र में अध्ययन किया गया है। पिछले चार दशकों में भूमंडलीय विकिरण में लगभग 5 प्रतिशत की कमी आई है। सर्दी के महीनों में सम्पूर्ण भूमंडलीय विकिरण में विसरित विकिरण का लगभग 23 प्रतिशत भाग होता है। मानसून ऋतु में इसका अनुपात 70 प्रतिशत से भी ज्यादा बढ़ जाता है। विशिष्ट वर्षा वितरण भूमंडलीय और विसरित विकिरण दोनों ही को प्रभावित करता है परन्तु यह प्रभाव विपरीत रूप में होता है। वायुमंडलीय परिसंचरण में कमी होने पर विसरित विकिरण में वृद्धि होती है। तथापि, जो परिवर्तन देखे गए हैं वे अभी तक सांख्यिकीय रूप से अधिक महत्व के साबित नहीं हुए हैं।

ABSTRACT. Radiation measurements are being carried out at Pune since 1957. The radiation data for the period 1986-90 are studied here with reference to general sky condition and rainfall distribution. Global irradiances show a decrease of about 5 per cent over the last four decades. The diffuse irradiation contributes about 23 per cent to the global irradiance during winter months. Its proportion increases to more than 70 per cent during the monsoon period. The specific rainfall distribution affects both global and diffuse irradiances but in opposite directions. The diffuse irradiance shows increases as the atmospheric transmission decreases. However, the changes found have not become statistically highly significant as yet.

Key words — Global and diffuse Irradiation Variations over years. Effect of rainfall distribution.

1. Introduction

The magnitude of the global radiant exposure (H_g) and of the diffuse radiant exposure (H_d) depend on the angle of incident irradiation and on the then prevailing atmospheric condition. Besides the clouding - the extent and type of clouds - the atmospheric transmission very much depends on the type and distribution of atmospheric pollutants. The clouds and the pollutants effectively attenuate the irradiation by selective absorption and by scattering. The scattering media themselves become a secondary source of radiation and this energy reaches the earth's surface diffusedly (H_d). The direct beam irradiation and the scattered incident irradiation together irradiates the earth surface and the combined energy is termed the global radiant exposure (H_g).

A network of radiation measuring stations has been in operation in India. Several attempts have been made to analyse the network data to present a climatological picture of the radiation field. Mani *et al.*, (1962) were the first to study the data. Since then Mani and Chacko, (1963, 1973), Rao and Ganesan (1972), Chacko *et al.*, (1968) and Desikan *et al.*, (1968), had dealt with these data. India Meteorological Department (1980, 1985) has published the climatologial aspects of these data. Mani (1980); Mani and Rangarajan (1982) again has broughtout publications covering the entire country based on the measured data and on the data derived from sunshine duration. The present attempt is to study the global (H_g) and diffuse (H_d) radiant exposures at Pune obtained over a recent period of five years (1986-90). Pune located as it is on the lee side of the Western Ghats has seen a sudden explosion of industrial development during the mid seventies and during the eighties. This developmental activities together with the consequent and unavoidable urbanisation will have profound effect immediately on the radiation field which may alter the climatic conditions after several decades. Of the various radiation parameters that react to the changes in the environment, the global irradiation is the main input energy and the diffuse component is a direct indicator of the environmental conditions at a place. The radiation field under cloud free conditions would give a better indication of the atmospheric conditions due to the developmental activities. However, the distribution of the dust particles does not remain constant. It changes constantly due to changes in the temperature, humidity and wind fields and by growth in size of the particles by accretion and coalescence processes and possible subsequent cloud formation. It is, therefore, more appropriate to study the radiation data pertaining to H_g and H_d under normal conditions,

TABLE 1

Annual mean values of daily global & diffuse radiant exposures in MJm^{-2}

	1986	1987	1988	1989	1990	Mean
Global	19.85	19.86	19.39	19.60	19.02	19.56
Diffuse	7.45	7.57	7.49	7.80	7.43	7.54
Ratio	0.38	0.38	0.39	0.40	0.39	0.39
Departure (%) from mean						
Global	+1.5	+1.5	-0.9	+0.2	-2.8	
Diffuse	-1.2	+0.4	-0.7	+3.4	-1.5	
Rainfall (mm)	572.7	718.9	944.8	668.6	902.7	
Departure percentage	-15	+7	+41	-1	+34	

TABLE 2

Monthly rainfall (mm) at Pune

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Normal	2.0	0.9	3.3	14.9	31.5	104.2	178.4	102.2	121.8	78.0	29.9	5.0	672.1
1986	0.0	0.0	0.0	0.0	35.0	264.1	63.9	99.9	71.4	0.6	2.3	35.5	572.7
1987	5.2	2.5	0.0	4.5	116.6	72.7	61.0	223.6	23.1	166.4	8.3	35.3	718.9
1988	0.0	tr.	0.0	4.8	15.6	67.0	299.0	84.1	431.1	0.3	0.0	0.0	944.8
1989	0.0	0.0	7.7	24.7	27.0	170.1	187.7	74.9	154.8	21.5	0.0	0.2	668.6
1990	0.0	0.0	0.0	0.0	81.2	173.3	248.6	197.6	37.9	125.4	38.2	0.0	902.7

irrespective of cloud-free or cloudy conditions, as this is the energy input for all subsequent energy management by natural processes.

2. The data

Pune has been measuring global radiant exposure since 1955. But it was during the IGY period in 1957 that the measurements of global and diffuse radiant exposures are being carried out systematically. The site of the data collection has remained the same with almost negligible change in the exposure conditions as well. Systematic calibration of regular intervals are also being carried out. Thermoelectric pyranometers with potentiometric recorders have been in use since 1957. The data pertaining to the period 1986-90 are dealt here.

3. Results & discussions

On an annual scale, Pune receives about 19.6 MJm^{-2} of global solar radiant exposure in a day. The mean daily diffuse value is about 7.5 MJm^{-2}, about 39% of the global value. Desikan *et al.*, (1994) reported a mean value of 21.8 MJm^{-2} on a cloudless day at Pune for global radiant exposure and only a value of about 4 MJm^{-2} for diffuse component, just 19% of the global value. The stark difference in H_d is mainly due to the cloud effects, particularly during cloudy monsoon months, though the steadily increasing atmospheric pollutants have their own contribution. The normal value (1957-85), according to IMD's Atlas is 20.32 MJm^{-2} and 7.45 MJm^{-2} for H_g and H_d respectively. Thus a reduction by 3.7% in H_g and an increase of 1.2% in H_d seems to have occured during 1986-90 period. However 1958 had a daily global irradiation of 22.18 MJm^{-2}, about 14% higher than that received during 1990 (19.02 MJm^{-2}). The corresponding diffuse irradiation was 7.66 MJm^{-2}, about the same that prevailed during 1990 (7.43 MJm^{-2}). The trend in

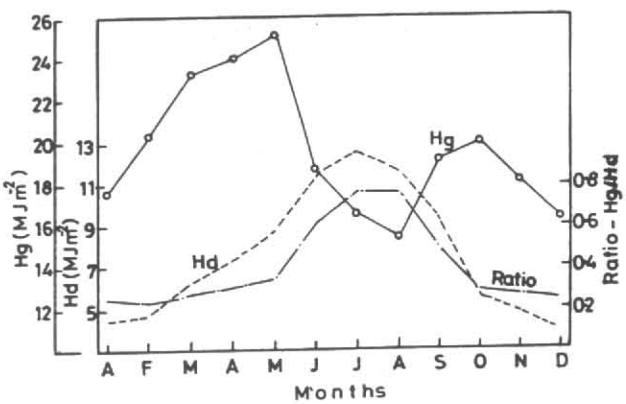

Fig.1. Variations (Mean for 1986-90) of global and diffuse solar radiant exposures at Pune

the changes are evident, though the actual magnitude is likely to be less, as the field is very much influenced by the highly variable cloud cover that prevailed during the specific years. The pollutants due to industrialisation and consequent urbanisation also contribute to the decreases in H_g and increases seen in H_d, though they are not as dominant as those due to cloud effects.

Table 1 gives the mean daily values of H_g and H_d together with the total rainfall during each year during the period 1986-90. No specific effect due to rains can be seen on an annual scale. The ratio H_d / H_g shows a slight increase of 5% from the normal 0.37 to the mean 0.39 for the period 1986-87.

Fig.1 gives the mean monthly values of daily global and diffuse irradiances and their ratio for the period 1986 - 90.

The amount of global irradiance of 16.37 MJm^{-2} is received during December when the sun's elevation angle at noon hardly reaches 48°. This is 16% lower than the annual mean value of 19.56 MJm^{-2}. As the sun traverses to

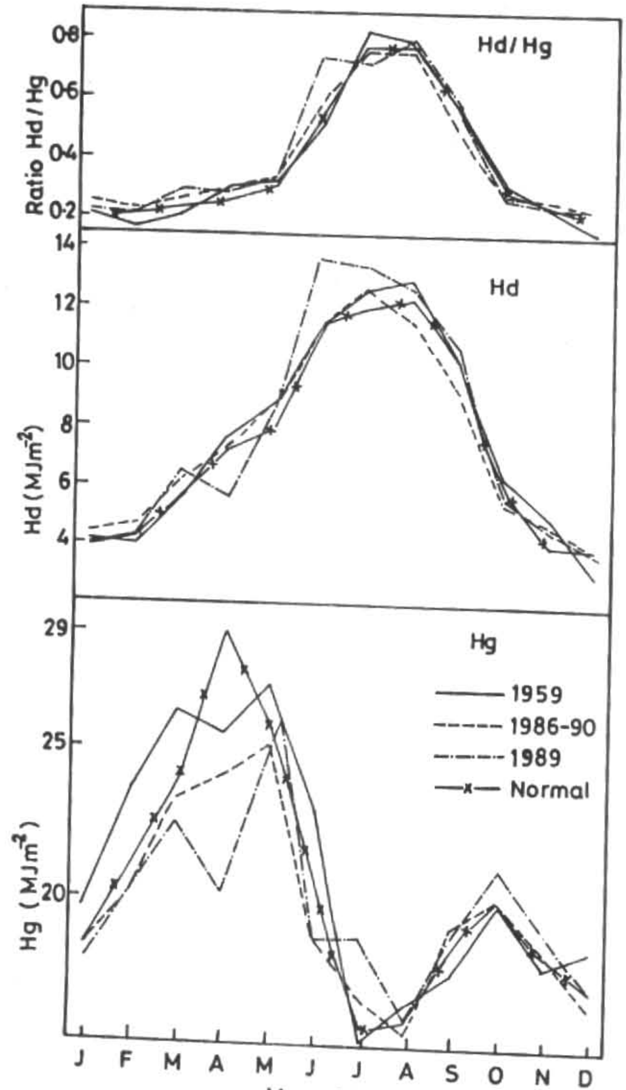

Fig.2. Variations (normal) of global & diffuse solar radiant exposures at Pune

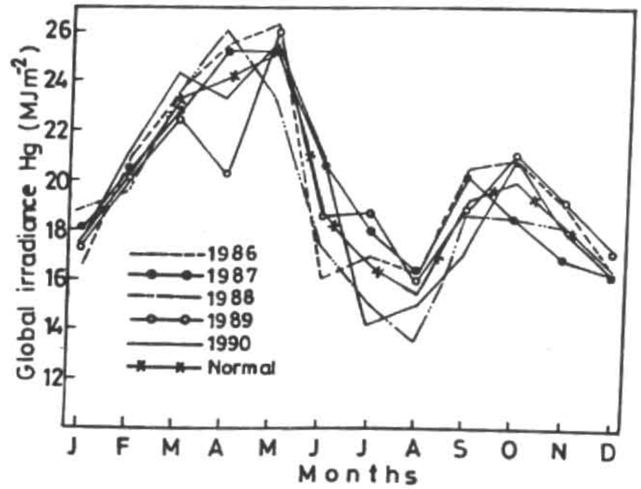

Fig.3. Variations in global solar radiant exposures at Pune during 1986-90

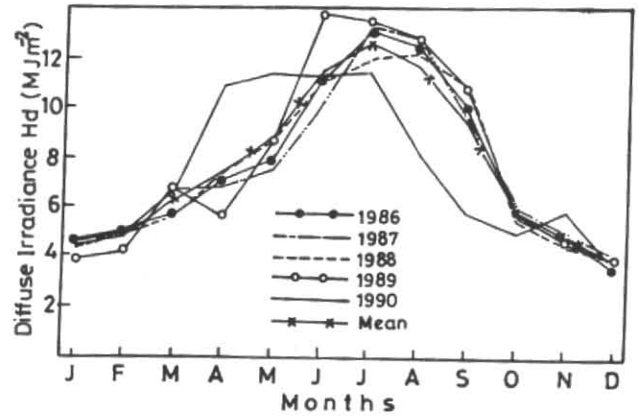

Fig.4. Variations in diffuse solar radiant exposures at Pune during 1986-90

the north reaching higher elevations at the noon time, the irradiance values also record steady increases, 15% more in February over that in January and again 15% more during March to reach a high value of 23.27 MJm^{-2}. The highest recorded is 25.20 MJm^{-2} in May which is 29% more than the annual mean and about 54% more than the December value. With the onset of the cloudy monsoon season, the global irradiances drop by 26% to 18.67 MJm^{-2} in June and reach a minimum of 15.40 MJm^{-2} in August, which is 21% lower than the annual mean. With decreasing cloudy conditions in September, H_g sharply increases by 24% to 19.15 MJm^{-2} and then to 19.97 MJm^{-2} in October. The values steadily decrease thereafter as the winter sun irradiates at larger zenith angles.

The diffuse irradiance at the earth's surface is entirely due to the scattering and reflection processes that occur as the solar irradiation passes through the atmosphere and its suspended particles and the clouds. Under cloudfree conditions, the scattering is restricted to the air molecules and the suspended aerosol particles. The lowest value of H_d recorded on an average is 3.85 MJm^{-2} in December which is 49% lower than the annual mean of 7.54 MJm^{-2}.

This low incidence is mostly due to cloudfree conditions common during the month. With the moisture incursion in March and consequent clouding, the diffuse irradiance registers a sharp increase by 32% to 6.19 MJm^{-2}. April records a 7.31 MJm^{-2} of irradiation an 18% increase over that of March. The steady increasing cloud coverage in May increases the diffuse component to increase to 8.76 MJm^{-2} (an increase of 20%). The onset of monsoon in June causes extensive clouding making H_d to jump to 11.40 MJm^{-2}. The maximum diffuse value recorded is in July with 12.57 MJm^{-2} which is 69% more than the annual mean.

The ratios of the diffuse to the global irradiances (H_d/H_g) is 0.39 (annual mean). The values are quite low during the winter months at around 0.24. As the clouding

TABLE 3

Seasonal variations in Hg and H_d (MJm^{-2})

	H_g				H_d			
Seasons	Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Monsoon	Post-monsoon	Winter
1986	25.12	17.39	18.93	18.08	6.50	11.60	5.24	4.33
1987	24.39	18.85	17.66	18.04	6.97	11.41	5.40	4.41
1988	24.25	16.79	19.40	17.77	7.15	11.43	4.83	4.01
1989	22.90	18.00	20.09	18.43	6.91	12.64	5.17	4.48
1990	24.28	16.15	18.24	18.07	9.57	9.13	5.37	4.42
Mean	24.19	17.44	18.86	18.08	7.42	11.24	5.20	4.33
H_d/H_g ratio	0.31	0.64	0.28	0.24				

increases from March onwards the ratio also starts increasing. The maximum percentage of 76 of diffuse component occurs in July and August. The post monsoon season has a ratio of about 0.28 much of the dust load having been washed down by the rains earlier. Mani and Chacko (1963) report as low as 0.16 in 1959 during the winter. They found that under cloudless sky conditions, the ratio can be quite low at 0.12, which gradually increases to more than 0.22 as winter gives place to the pre-monsoon season. May had 32% of its global irradiance in the form of diffuse irradiance. The high ratio in May is to be ascribed to the increased dust load and large sized particulate matter. Desikan *et al.* (1994) also report high value of Angström turbidity coefficient in May. Srivastava *et al.* (1992) also from the sun photometric measurements report a high turbidity in the pre-monsoon period.

Fig.2 depicts the monthly variation of H_g, H_d and H_d/H_g based on the normal values of global and diffuse radiant exposure. Also the mean values of the period 1986-90 are included. The data for both sets are for days - clear and cloudy ones. The general trend that one can easily note is that the values of H_g for the period 1986-90 are lower while H_d values are higher in this period than the normal ones. Similarly the ratios of H_d to H_g for the period 1986-90 are generally more than the normals. This only indicates the general trend that the atmosphere is getting more of dust load than the earlier epochs. H_g values are lower by about 4% during the period 1986-90. H_d values are higher by more than 10% during the months when the clouding is minimal. The ratios H_d/H_g are also consistently high during this period.

It will be of interest to have a comparison of the values and the two parameters that were obtainable at two different periods widely separated in time. Fig.2 also gives the comparative variations in 1959 and in 1989. The winter months show a strong decrease in H_g in 1989, by about 15% while H_d shows a definite increase of more than 10% . On an annual scale, H_g in 1989 is lower by 6% whereas H_d is higher by 2%.

While there have been large variations between the normal values and the 1986-90 period, there is little variation from year to year during the later period, particularly in the winter season. The activities of the pre-monsoon thunderstorm activities affect the irradiances very widely. This comes out clearly (Figs. 3 & 4) in May 1987 when the global and diffuse values register low values. The heavy rains in May 1987 (117 mm) as against the normal value of 31.5 mm have washed the dust load down. The corresponding diffuse value is 7.46 MJm^{-2}, about 15 MJm^{-2} lower than the average for May. Similar effect can be seen in April 1989 which had a rainfall of 25 mm. The values of H_g and H_d are 20.22 MJm^{-2} and 5.62 MJm^{-2} respectively as against the average 24.05 MJm^{-2} (-16%) and 7.31 MJm^{-2} (-23%).

The variations in the post-monsoon period although the conditions are somewhat similar in the persistence of clouding and the moisture, the diffuse irradiances do not exactly follow the field of H_g. For instance, September and October in 1987 and again in 1990 show the variations in opposite directions as given below :

	September			October		
Irradiance (MJm^{-2})	Avrg	1987	Change (%)	Avrg	1987	Change (%)
H_g	19.15	20.43	+6.7	19.9	8.46	-7.6
H_d	9.35	9.66	+3.3	5.55	5.90	+6.3
Rainfall (mm)	121.80	23.10	-81	78.00	166.40	+113

	September			October		
Irradiance (MJm^{-2})	Avrg	1990	Change (%)	Avrg	1990	Change (%)
H_g	19.15	18.50	-2.6	19.97	18.43	-7.7
H_d	9.35	5.73	-38.7	5.55	4.95	-10.8
Rainfall (mm)	121.80	37.90	-69	78.00	125.40	+61

September 1988 however shows an interesting effect due to the heavy rains and heavy clouding with high moisture contents. Under such conditions, H_g shows a sharp drop of 11% over the average value of 19.15 MJm^{-2} whereas H_d shows a high value of 5.90 MJm^{-2}, about 6.3% more than the average value.

The solar irradiation as it passes through, gets scattered and the scattered beam reaches the earth's surface in a diffuse fashion. Thus the direct beam irradiation suffers a reduction in its energy level depending on the prevailing conditions of the atmospheric constituents. In other words,

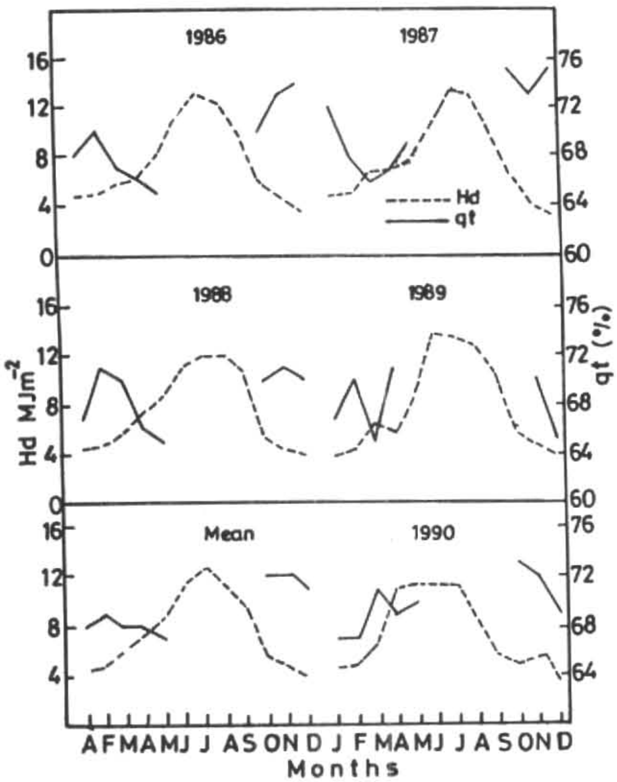

Fig.5. Diffuse irradiance & atmospheric transparency at Pune

the direct beam irradiation and the diffuse irradiation depend on the atmospheric transmission characteristics at a given instant. The transmission of the irradiation or the atmospheric transparency depends to very great extent on the path length through which the irradiation passes. The convenient method to obtain this transmission factor is to measure the direct solar irradiance in the solar irradiance received by a surface held normal to it and compare the irradiance with the extra-terrestrial value taking the optical path length at the time of measurement into account. If $S_{0\lambda}$ is the extraterristrial direct solar irradiance and S_λ is the direct solar irradiance as measured for a known optical path length (m), the atmospheric transmission coefficient q_λ for the wavelength band λ is then given by

$$S_\lambda = S_0 \, q_\lambda^m$$

When the measurement is made over the entire solar radiation wavelength range, the relationship then is written as

$$S_t = S_{0t} \, q_t^m$$

Direct solar irradiance measurements are regularly made at Pune. Fig.4 gives the mean transmission coefficient (for eight months when the measurements are possible) and

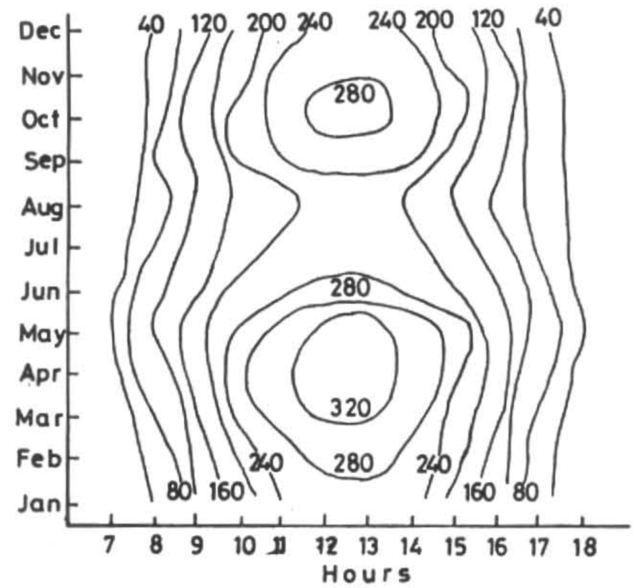

Fig.6. Mean diurnal variations in global solar radiant exposure

the diffuse solar irradiance H_d. The transmission coefficient and the diffuse irradiances should naturally change in opposite sense. When H_d is higher, the atmosphere should be more opaque. This is clearly broughtout in Fig.5. On an average the Pune skies have a transparency of about 69%. The actual value will vary widely depending on the prevailing concentrations of dust particles and moisture in the atmosphere. The effect of rainfall can also be clearly seen. Rains in December 1986 has increased the transparency to 74% while reducing the value of H_d to 3.57 MJm^{-2}. Though 1988 had very good rains, the absence of it in October - December has caused q_t to remain around 70%. The near dry conditions of November - December 1989 with poor rains in October has caused a sharp decrease in q_t to 6.5% in December and the change in H_d is not that characteristic. Again in 1990, the rains in October and November have perhaps kept the air clean to give a value of more than 72% and in December it drops to 69%.

Table 3 gives the seasonal global and diffuse solar irradiances and the corresponding rainfall. The global irradiance in pre-monsoon season is the highest registering 24.19 MJm^{-2} and H_d is 7.42 MJm^{-2}, which amounts to 31% of the global value. The lowest H_g is in the monsoon season (17.44 MJm^{-2}) while H_d records highest (11.24 MJm^{-2}) during this heavily clouded season, making H_d to contribute as high as 64% to the total incident irradiation. The lowest diffuse irradiances occur during the nearly cloudfree winter months (4.33 MJm^{-2}) which amounts to 24% of the global irradiances. The post-monsoon season in particular responds well to the monsoon activity. H_g values are high whenever the rainfall deficiency during the post-monsoon is very high as in the 1987-89. The very heavy rains during

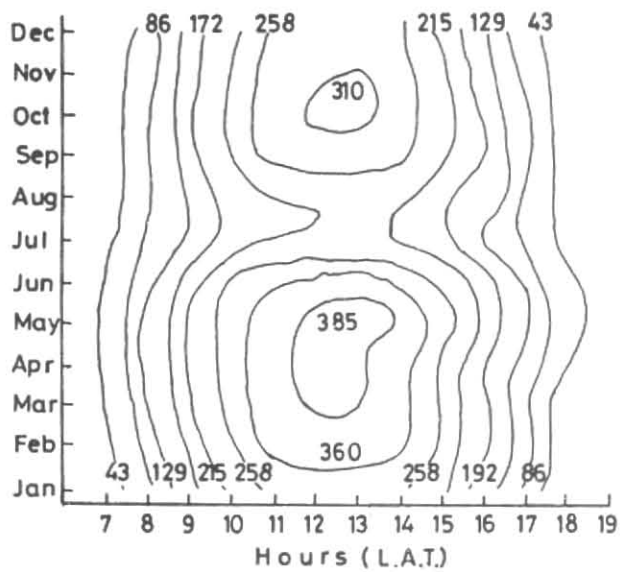

Fig.7. Diurnal variations in global solar radiant exposure during 1958

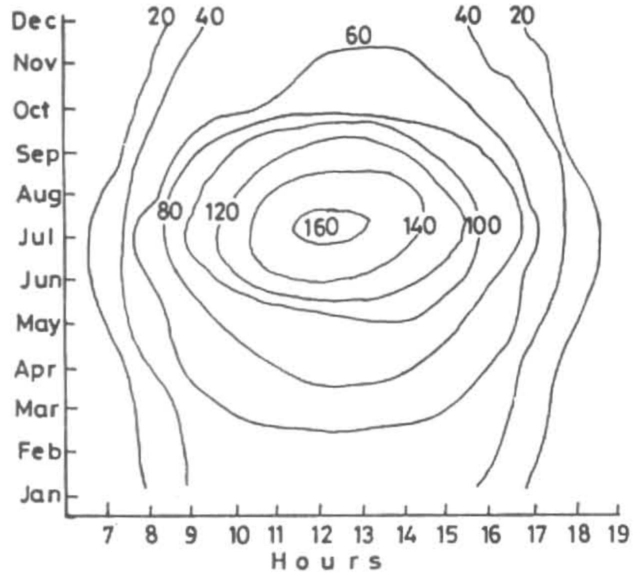

Fig.9. Mean diurnal variations in diffuse solar radiant exposure

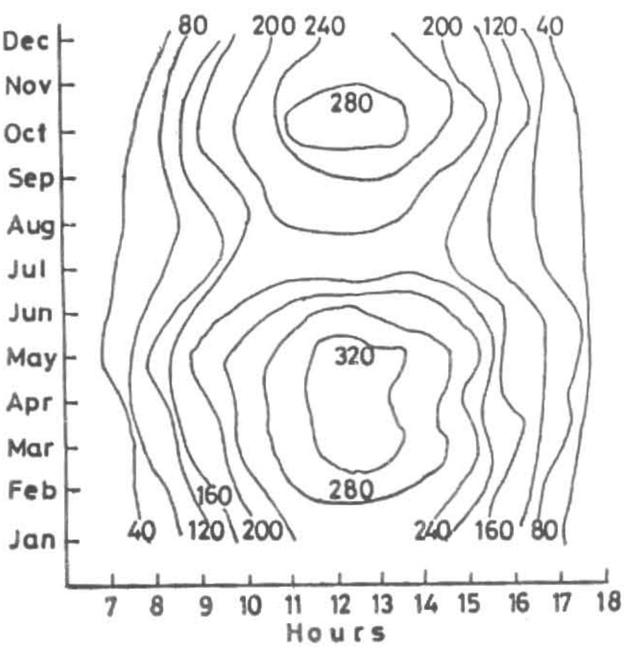

Fig.8. Diurnal variations in global solar radiant exposure during 1988

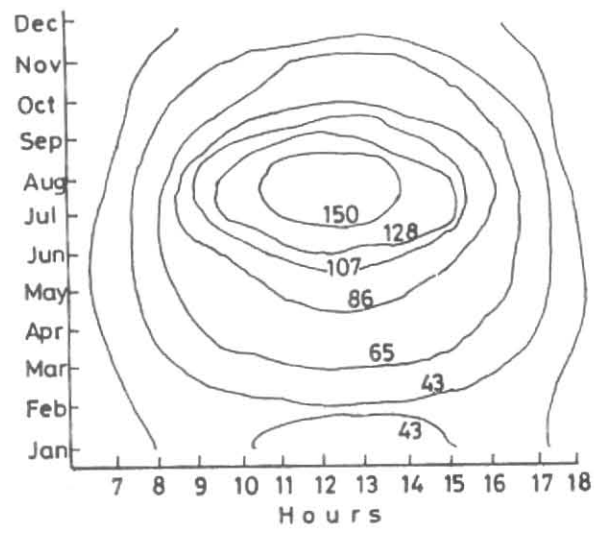

Fig.10. Diurnal variations in diffuse solar radiant exposure during 1959

1988 monsoon gives H_d a low value of 16.79 MJm^{-2} for H_g. There was no rain in October and November that year which increases H_g to 19.40 MJm^{-2} and gives the lowest H_d (4.83 MJm^{-2}).

Diurnal variations

The hourly values of global and diffuse irradiation show gradual increase from the sunrise to noon and a gradual fall thereafter as expected. The magnitudes of H_g and H_d are controlled by the atmospheric conditions and its clouding. The values register increases as the solar altitude increases with the season from winter to pre-monsoon period. The magnitudes in the pre-monsoon season are however governed more by the prevailing clouds of the season.

Fig.6 gives the isopleths of the average hourly global irradiances over a year. 5-6 hours in a day receive more than 2.80 MJm^{-2} during the pre-monsoon period March to May. The secondary maximum of 2.80 MJm^{-2} occurs only for 2 hours around the noon in October after the cleansing of the skies by the monsoon rains. However more than 2.00 MJm^{-2} of energy is being received at Pune for more than four hours

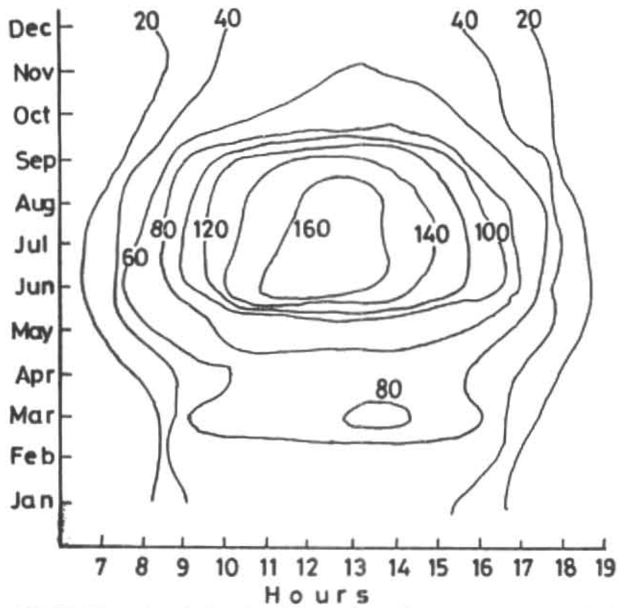

Fig.11. Diurnal variations in diffuse solar radiant exposure during 1989

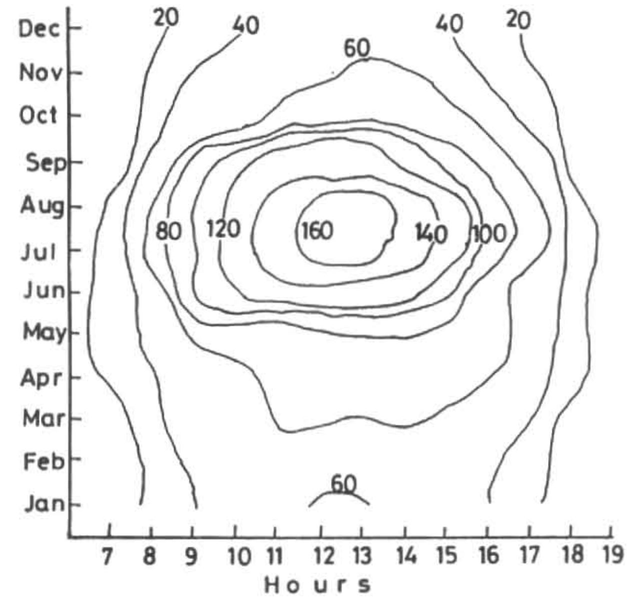

Fig.13. Diurnal variations in diffuse solar radiant exposure during 1986

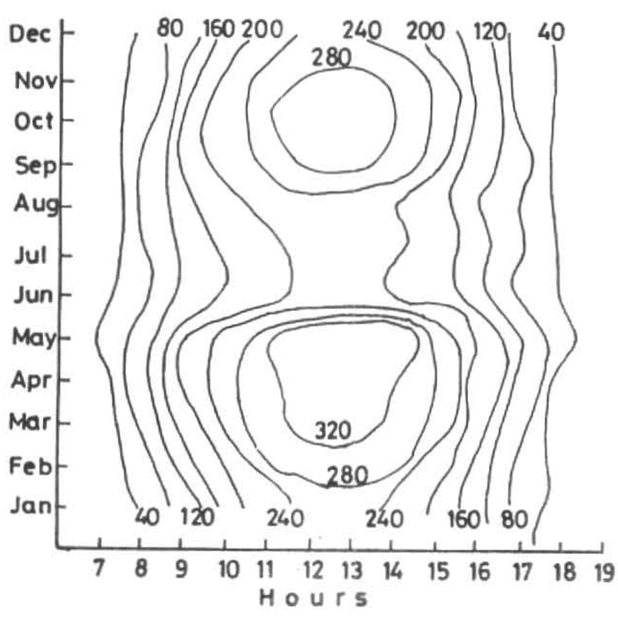

Fig.12. Diurnal variations in global solar radiant exposure during 1986

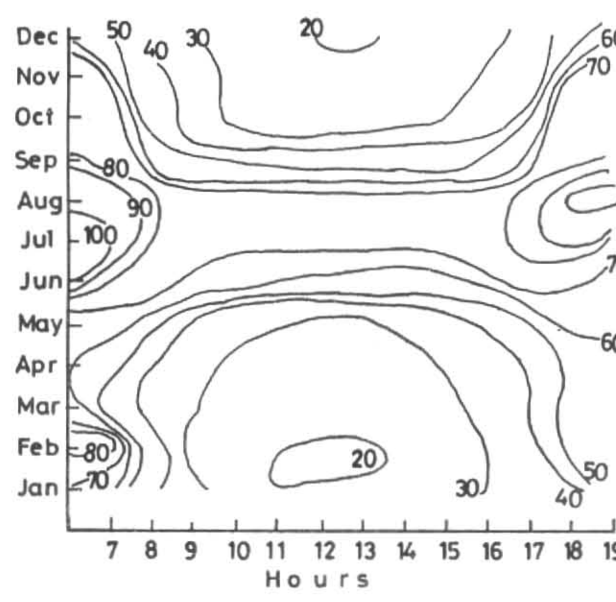

Fig.14. Mean diurnal variations in the ratio H_d/H_g

every day of the year. The actual pattern however changes from year to year depending on the then prevailing weather conditions.

Fig.7 gives the global irradiance field at Pune during 1958. The maximum occurs during the pre-monsoon with a value higher than 3.40 MJm^{-2} as against 3.20 MJm^{-2} during the period 1986-90. The secondary maximum in October has however remained nearly at 3.00 MJm^{-2} even after the 4 decades. The 1988 values (Fig.8) however remain almost the same as that of 1958.

Fig.9 gives the hourly isopleths of diffuse solar irradiances. Being controlled and affected by the clouds, the diffuse irradiance field is highly variable and does not depict the symmetry seen in the case of global irradiances. Expectedly the maximum H_d is recorded around the noon during July. 3-4 hours of the monsoon months receive more than 1.40 MJm^{-2} as diffuse irradiation. H_d never reaches even 0.60 MJm^{-2} in any hour during the winter months due to low incidence of cloudy and dry atmospheric conditions.

Fig.10 shows the isopleths of diffuse radiation during 1959. The shape of the isopleths remains nearly the same though the 1986-90 values are slightly higher. The 0.60 MJm^{-2} isopleths covers the entire year except the winter during 1986-90 whereas the energy level is 0.54 MJm^{-2}

during 1959. (Fig.10). The 1.60 MJm^{-2} isopleth is expanded to three month period June-August of 1989 (Fig.11) and for three hours the unlike the 1959 isopleth of 1.50 MJm^{-2} which is limited to July-August.

1986 had deficit rains 29.6% in the pre-monsoon season, 1.4% during the monsoon and 97% during the post-monsoon season. The resultant radiant field is seen (Fig.12) to have a sudden fall in the noon peak from about 3.50 MJm^{-2} in May to 2.25 MJm^{-2} in June, a decrease by 36%. Similarly the increase from the cloudy August (2.15 MJm^{-2}) which had near normal rains (99.9 mm) to a high 2.90 MJm^{-2} in September (deficit in rain by more than 40%) is of the order of 35%. The effect of persisting moisture, inspite of lower angle of solar elevation during September can be seen. The noon maximum in September is of the order of 2.90 MJm^{-2}, when compared with 3.50 MJm^{-2} of the May noon the difference being of the order of 17% with respect to May. The isopleths are also less crowded in the post-monsoon season. When compared with the global irradiance distribution over 1986 at Pune, the diffuse irradiation field (Fig.13) maintains a symmetry about the July noon in its hourly values.

1988 had copius rains 944.8 mm as compared to the normal 672.1 mm. The pre-monsoon was in deficit by 59% the monsoon had a surplus of 74% and the post-monsoon had practically no rains (0.3 mm as against the normal of 107.9 mm). The noon maximum (Fig.8) in H_g in May has been reduced to 3.20 MJm^{-2} and restricted to just 2 hours as against the 4 hours of 1986. The isopleths are also more evenly placed indicating a reasonable symmetry in the diurnal and daily changes. Similarly is the case with the post-monsoon season. The absence of the post-monsoon rains has pushed the secondary maximum to over 3.00 MJm^{-2} in October, the increase being about 40% over the monsoon low values at noon. The secondary maximum occurs in October instead of September which received a very heavy rainfall of 431.1 mm. The normal rainfall is 121.8 mm in September. Despite this H_g at September noon (about 2.90 MJm^{-2}) is hardly 17% lower than the May value at the noon. Fig.13 shows the diurnal variations in the diffuse irradiance field. The symmetry that was seen in the normal values (Fig.9) or in 1986 (Fig.13) has been distorted by the uneven distribution of rainfall (Table 2). Even the May values during 1988 are higher by about 12% over 1986 values. The maximum has also shifted to August in 1988 as against July of 1986. July 1988 had 299.0 mm rain (normals 178.4 mm) and August had only 84.1 mm, lower by 18%. The heavy rains of September 1988 followed by clearer and rainfree conditions in October have caused a drop in H_d by about 58% from 1.55 MJm^{-2} to just 0.65 MJm^{-2}. This has caused the crowding of isopleths after August.

It is natural to expect the diffuse component to have a higher proportion at larger zenith angles than when the sun's elevations are higher. This is clearly brought out in Fig.14. The ratio H_d/H_g in the mean is more than 40% throughout the year near the sunrise and sunset timings. Of course one has to take note of the weak irradiances and the limitations of the sensitivity factor of the pyranometers to low level irradiances. The ratio remains lowest for higher solar elevations. February recording a very low value of 0.18. As the season advances into premonsoon, this ratio increases steadily, obviously with increasing dust load and the increasing cloud cover. The monsoon ushers in heavy clouding. In the process H_g falls drastically and H_d shows sharp increase. The resultant is the ratio doubles itself in June. The ratios are more than 0.70 in July and August throughout each day. With the weakening of the monsoon activity after September, the ratios in September decrease very sharply to 0.45, a drop of more than 37%. As the sky clears in October, H_g increases and H_d reduces further, resulting in a ratio H_d/H_g of the order of 0.22-0.23.

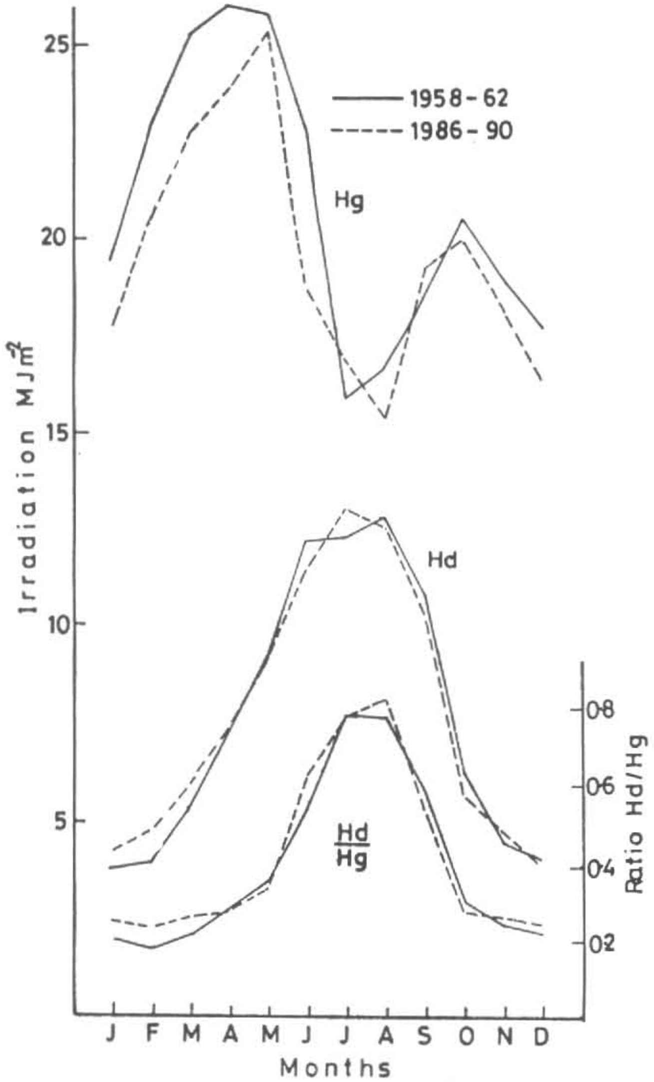

Fig.15. Annual March of in irradiation (MJm^{-2}) during 1958-62 and 1986-90 (all days)

TABLE 4

Seasonal rainfall (mm) at Pune

Seasons	Pre-monsoon (%)	Monsoon (%)	Post-monsoon (%)	Winter (%)
1986	35.0(-29.6)	499.3 (-1.4)	2.9 (-97)	35.0 (+343.0)
1987	121.1 (143.7)	380.4 (-24.9)	174.7 (+61.9)	430.0 (+444.3)
1988	20.4 (-59.0)	881.2 (+73.9)	0.3 (-99.7)	tr. (-100.0)
1989	59.4 (+19.5)	587.5 (+16.0)	21.5 (-80.1)	0.2 (-97.5)
1990	81.2 (+63.4)	657.4 (+29.8)	163.6 (+51.6)	0.0 (-100.0)
Normal	49.7	506.6	107.9	7.9

TABLE 5

Comparative values between the two periods

	H_g (MJm^{-2})			H_d (MJm^{-2})			H_d/H_g		
	Jan	Feb	Mar	Jan	Feb	March	Jan	Feb	Mar
All days									
1958-62	19.33	22.95	25.29	3.83	3.93	5.32	0.20	0.17	0.21
1986-90	17.61	20.50	22.74	4.30	4.76	5.90	0.24	0.23	0.26
Change %	-8.9	-10.6	-10.0	+ 12.9	+21.1	+11.5			
Clear days									
1958-62	19.88	23.22	25.88	3.03	3.60	4.27	0.15	0.16	0.16
1986-90	18.14	20.66	24.13	3.79	4.27	4.96	0.21	0.21	0.21
Change %	-8.8	-11.0	-6.8	+25.1	+18.6	+16.2			
Variation in Standard deviations									
All days									
1958-62	1.454	1.381	1.761	1.090	0.800	1.270			
1986.90	2.181	1.828	2.878	1.049	1.111	1.578			
Clear days									
1958-62	0.713	0.757	1.129	0.064	0.316	0.623			
1986-90	1.192	1.893	0.956	0.612	0.612	1.201			

Over the years, the noon ratio during the winter has substantially increased from about 0.13 in 1959 to 0.22 in 1986- 90.

Comparison with data of the period 1958-62

At the beginning of the discussions, it has been stated that values of H_g and H_d have shown marginal decreases in H_g and a marginal increase in H_d over the normal values. This would naturally be so since the higher irradiances of early sixties will be offset by the lower values during the last years which have been included in working out the normals. Hence a comparative study of the data for the period a 1958-62 and 1986- 90 is worth while. During sixties, Pune was still a small city with fewer vehicles on the road and a far less urban activity. By the end of eighties, it had become a highly industrialised and hence urbanised city with an uneven growth. Hence the pollution levels have also grown over the decades. The atmosphere has a very high resilience capability and does not easily undergo changes. Though there are large changes in H_g and H_d during the first epoch *viz.* 1958-62 and the second 1986-90 under consideration, it is found that the changes are not yet significant statistically.

On an annual basis, global irradiances H_d reduced by 6.3% from the 1958-62 base values of 20.91 MJm^{-2} whereas they were just lower by 3.7% only from the normal. Similarly the increase in diffuse irradiances is by 9.3% with reference to the 1958-62 values if 6.97 MJm^{-2} as compared to the nominal increase of 1.2% in the case of the normal value of H_d. The overall annual ratio 0.33 of H_d in H_g of 1958-62 has increased to 0.39 in 1986-90. The normal value of this ratio is 0.37 Fig.15 gives the annual March of the values of H_g and H_d for the two epochs. The global irradiances are almost always higher during 1958-62 whereas the diffuse irradiances are higher during the November - March period, a period with relatively cloud free/little cloud skies. The cloudy seasons however show longer fluctuations mainly due to the differing cloudings during the epochs. The higher values in the "non-cloudy" period must be attributed to the effect of pollution due to industrialisation and urbanisation during the intervening period.

Table 4 gives the mean monthly values of H_g and H_d for the three generally cloud-free months January. February and March during the two epochs. The ratio H_d/H_g shows increase from January to March during 1986-90. Table 5 also gives the mean H_g and H_d values under cloud-free sky conditions. The standard deviations worked out for the three months for both clean and general sky conditions are also included. It is seen that the scattering in the values are larger during 1986-90 period as compared to 1958- 62 even under clean sky conditions. This larger deviations during the later period is to be mainly ascribed to the atmospheric pollutants. Since the changes in the values of H_g and H_d during the period 1986-90 are not uniform with reference to the irradiances received during 1958-62. Student '*t*' test was carried out on the individual mean values for the three months *viz.*

TABLE 6

Results of student '*t*' test of significance on data for 1958-62 & 1986-90

	January				February				March			
	t	10%	5%	1%	*t*	10%	5%	1%	*t*	10%	5%	1%
Global all days	1.313	×	×	×	2.010	✓	×	×	1.512	×	×	×
Diffuse all days	-0.555	×	×	×	- 1.053	×	×	×	-0.886	×	×	×
Global cloud free days	2.506	✓	✓	×	2.511	✓	✓	×	2.000	✓	×	×
Diffuse cloud free days	1.861	×	×	×	1.271	×	×	×	0.897	×	×	×

Not significant– × Significant– ✓

January, February and March, the months with less cloud cover and relatively drier air conditions. The results are given in Table 6. It is seen that the changes are not significance as far as H_d is concerned for cloudless as well as for general conditions. H_g shows 10% significance in changes in its values from those of 1958-62 for cloudless condition during January, February & March. Changes are significant at 5% level only for January and February but only for cloudless skies. This would mean that the uncertainties arising out of the highly variable cloud cover mask the effects of atmospheric pollution to a great extent as far as the H_g and H_d are concerned.

4. Conclusion

The industrial advancement of the Pune region has shown its effect on the radiation field. Global solar radiant exposure H_g which had an annual value of 20.80 MJm^{-2} in 1959 has reduced to 19.56 MJm^{-2} during 1986-90 period. This amounts to 6% reduction in the energy received at the surface. The diffuse proportion however shows a marginal increase from 0.37 to 0.39 indicating an increase of 5%. The data presented in this paper pertain to the general sky conditions obtainable during a year. The diffuse irradiances are low in winter and maximum during the monsoons as they are more affected by the clouds. The irradiances change lastly from year-to-year depending on the washing down of particulate matter by the monsoon rains and the clouding activity. The daily totals range between 11.40 MJm^{-2} and 13.4 MJm^{-2} in July during 1986-90. During the transition month of September the fluctuations are more significant. H_d was as high as 10.75 MJm^{-2} during 1988 and 1989 when Pune had excess rains, whereas it was hardly 5.73 MJm^{-2} in 1990 when Pune had scanty rains. These are mainly due to the extent of clouding.

The atmospheric transparency has direct role on the diffuse irradiance field. For higher values of transmissions, the diffuse irradiation is lower and the global irradiation is higher. The diurnal variations in H_g, H_d and their ratio H_d/H_g are systematically disturbed by the rainfall distribution and clouding activity. The differences seen between the mean values of 1958-62 period and those of 1986-90 do not exhibit statistical significance when the data include those with cloud cover also. On the other hand only the global irradiance shows significant decrease at 5% level, when the data considered are for nearly cloud free conditions. This is naturally to be ascribed to the increase in the atmospheric pollutants caused by industrialisation and urbanisation at Pune. The clouds apparently play an important role in keeping the solar irradiance regime over place within certain limits. This requires a specific cloud-oriented studies in depth.

The changes in H_g and H_d have not yet become statistically significant, as pointed out by Desikan *et al.*, (1994). Thus it may yet possible to apply remedial measures in restricting the sources of pollutants like the industrial exhausts and vehicular emissions by enforcing modern techniques.

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