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Effect of air pollution on radiation and human comfort over six Indian stations*

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ABSTRACT. Using the theoretical values of the total solar radiation received at the top of the atmosphere an attempt has been made to find out, for six Indian stations, the depletion of radiation by the atmospheric particulate matter, by determining the reduction due to the presence of precipitable water vapour content and the cloudiness in the atmosphere. The effect of pollutants on solar radiation at these six stations are computed and discussed in comparison with the others results.

Using solar radiation values received at the surface, with pollutants (R_{t_1}) and without pollutants (Rt_2) in the atmosphere, radiation discomfort indices are calculated and discussed.

1. Introduction

Atmospheric pollution is becoming an increasingly serious problem to human health and welfare. Considerable work has been done on atmospheric pollution using meteorological parameters like temperature and wind. Comparatively less work has been done on the effects of pollution on radiation. Both natural and man-made aerosols forced into the atmosphere from the various sources, decrease the atmospheric transparency with consequent alteration in the solar radiation reaching the ground. Some workers (Ganesan 1972, Mani *et al.* 1968) used turbidity coefficient as a measure of air polluton. But, this parameter reflects not only the particulate matter but also water vapour content of the atmosphere to some extent. This can be seen from the mean monthly turbidity coefficient values presented by Ganesan (*loc. cit*) for some Indian stations, where high turbidity values are seen in May to July months; which suggests that the use of this parameter as an index of air pollution is not justifiable, as precipitation washes out the pollutants in the atmosphere (*vide* infra). Raghavan and Yadav (1966) computed theoretically, the depletion of the total solar radiaton due to water vapour and other constituents of the atmosphere.

Therefore, in the present study, an attempt has been made to find out the depletion of the incoming solar radiation by the pollutants present in the atmosphere. Also the modification made by the pollutants of the atmosphere in the radiation discomfort indices is studied.

2. Method

Total solar radiation at the top of the atmosphere (R^T) can be calculated from Smithsonian tables. Part of R_T is depleted due to absorption and scattering by the intervening atmosphere, mainly by clouds, precipitable water vapour and pollutants in the atmosphere.

The present study is limited to derive a simple method of estimating the amount of solar radiation depleted by the aerosols present in the atmosphere. For this purpose, first, following a simple approach the effect of clouds (c) and precipitable water vapour (w) on incoming shortwave solar radiation (R) are determined as follows :

The depletion effect of precipitable water vapour (w) on R is given as—

$$D_w = R_T\,(100 - \beta)\,(1 - s) \qquad (1)$$

where D_w=depletion of R due to w, in cal/cm^2/day,

R_T=solar radiation received at the top of the atmosphere in cal/cm^2/day,

β=transparency coefficient of w (estimated from Smithsonian tables for the total precipitable water vapour in the atmosphere from surface to 200-mb level),

and $s=n/N$ (n=hours of bright sunshine, and N=length of the day in hours).

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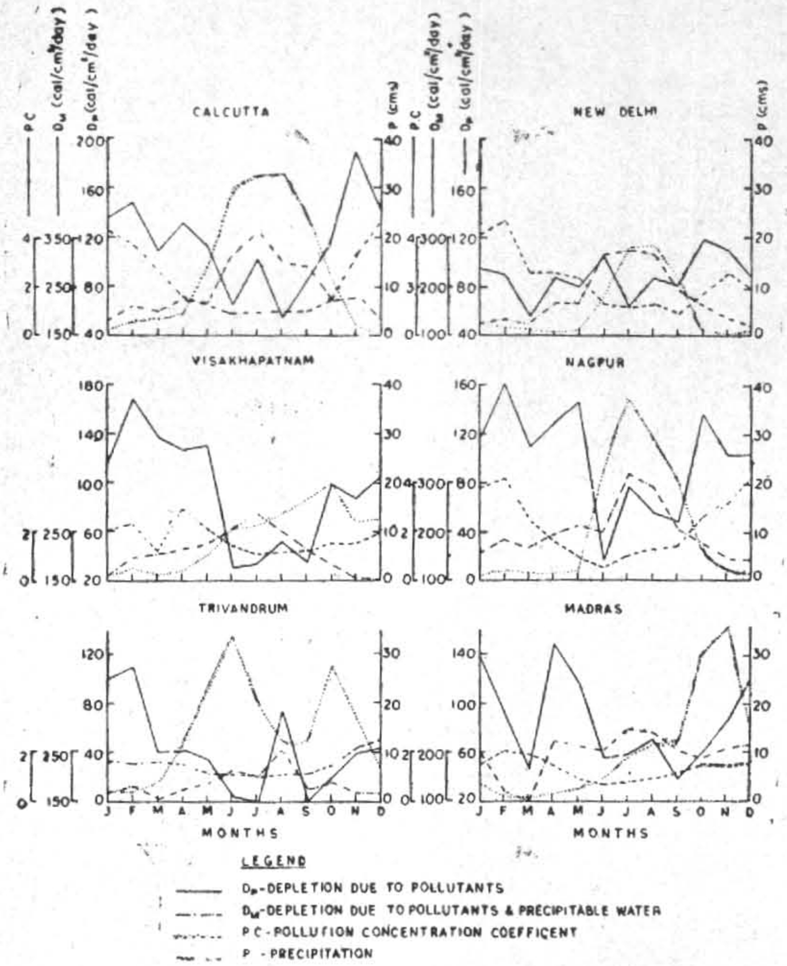

Fig 1. Variation of D_P, D_w, P_M and P at different stations

The depletion due to cloudiness (c) is given as :

$$D_c = R_0 \ (1 - s) \quad (2)$$

where, D_c=depletion of R due to cloudiness, in cal/cm^2/day, and R_0=observed total solar radiation at the surface on clear days, in cal/cm^2/day.

Thus, the depletion due to particulate matter (P) present in the atmosphere is given as :

$$D_P = R_T - R_{t1} - D_c - D_w \quad (3)$$

where D_P=depletion due to particulate matter, in cal/cm^2/day and R_{t1}=total solar radiation received at the surface in cal/cm^2/day. And the depletion due to w and P can be expressed as :

$$D_M = D_P + D_w \ \text{cal/cm}^2\text{/day.} \quad (4)$$

From recent work it is seen that the particulate matter present in the atmosphere reduces the incoming shortwave solar radiation (R_t) and outgoing radiation and increases the net radiation balance at the surface (R_N). This increase in R_N counteracts to compensate the decrease in R_N due to reduction of R_t by particulate matter in the atmosphere; the difference if any is negligible. Therefore, using the radiation discomfort index formula of Philip and Reddy (1974), modified discomfort indices are obtained taking R_N as unaltered and for R_{t2} as $R_{t1}+D_P$.

TABLE 1

Percentage amount of incoming radiation affected by pollutants

Station	Season			Annual
	Winter	Summer	Monsoon	
Trivandrum	9·2	3.4	2.5	4.9
Madras	14.9	10.4	6.2	10.2
Vishakhapatnam	17.0	11.4	6.2	11.1
Nagpur	18.1	10.7	9.0	12.0
Calcutta	23.5	18.8	10.2	14.0
New Delhi	16.6	8.8	10.1	11.2

TABLE 2

Radiation Discomfort Indices

Station	Winter		Summer		Monsoon		Annual	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
Trivandrum	0·95	0·93	1·03	1·03	0·93	0·93	0·97	0·96
Madras	0·86	0·81	1·17	1·13	1·03	1·00	1·02	0·98
Visakhapatnam	0·80	0·75	1·09	1·05	0·97	0·94	0·96	0·92
Nagpur	0·60	0·57	0·93	0·92	0·85	0·81	0·79	0·77
Calcutta	0·63	0·59	0·97	0·93	0·90	0·85	0·83	0·79
New Delhi	0·33	0·31	0·80	0·78	0·91	0·87	0·68	0·65

Comfort range: (0·60 to 0·95)

3. Data and Analysis

Ten-year monthly mean data of total solar radiation (R_0) and (R_{t1}) and observed bright hours of sunshine (n) recorded at the surface during the period 1960-1969 for six Indian cities listed in Table 1, are used in the analysis. Rawinsonde data for the same period are also utilized to calculate the precipitable water vapour content in gm/cm^2. Using this data from Eq. (3), D_P values are estimated at these six stations.

Table 1 gives the percentage depletion of incoming solar radiation due to particulate matter, in the three seasons: Winter (Nov to Feb), Summer (Mar to Jun) and Monsoon (Jul to Oct) and Annual. Fig. 1 depicts the variation, through the year, of the parameters D_P, D_M, P_c and P over the six Indian stations where D_P is the depletion of incoming solar radiation due to pollutants, D_M represents depletion due to P and w, P is total precipitation and the P_c is the pollution concentrations obtained by Jayanthi (1973) at twelve calendar months for six Indian stations. From the above computations, the discomfort indices over the six Indian stations are calculated in the following way (using the formula of Philip and Reddy 1974).

$R_{ID} = R_N\ (0 \cdot 003 + 0 \cdot 5/R_t)$ where R_{ID} is the radiation discomfort index, R_t and R_N respectively are total and net radiation intensities. $R_t = R_{t_1}$ with pollution and $R_t = R_{t_2}$ without pollution and correspondingly R_1 and R_2 are the discomfort indices. Table 2 gives the computed discomfort indices R_1 and R_2 (with and without pollution respectively).

4. Discussion

It is seen from Table 1 that in all the cases the percentage depletion is maximum in winter season and minimum in monsoon season. Heavy precipitation washes out the pollution concentration in the atmosphere and hence is the minimum in the monsoon months. Among the six Indian cities considered, the percentage depletion is maximum over Calcutta with its high industrialization and urban development. Trivandrum appears to be the least depleted station which is also seen in earlier studies (Jayanthi 1973, Reddy 1974). The depletion observed in the six cities at different months are also in agreement with the distribution of air pollution potential given by them. The percentage depletion due to pollutants is maximum in Calcutta, next in order come Nagpur, New Delhi Visakhapatnam, Madras and Trivandrum. It is interesting to note that all the months over Trivandrum (except Jan and Feb) are rainy months. Also the industrialisation and urban growth are less. These factors contribute generally to the low value of pollution over Trivandrum.

It is seen from Table 2, the change in comfort indices are not so pronounced in winter months, as expected. The modification in comfort index over Trivandrum is negligible with low pollution potential in the atmosphere. Calcutta with its maximum pollution potential has a higher order modification in winter. Next in the decreasing order are Visakhapatnam, Madras, New Delhi, Nagpur. It seems the modification in comfort indices due to the depletion of the radiation by pollutants is not as high as expected.

5. Conclusions

Percentage depletion in the total radiation is a measure of air pollution concentration. The effect of pollution over the alteration in radiation is appreciable in winter and summer seasons. For all the stations considered the effect is least in the monsoon season.

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