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Total Solar Radiation in relation to duration of sunshine

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ABSTRACT. An attempt has been made to establish a relation between the total radiation from sun and sky and the duration of bright sunshine based on the formula, $Q/Q_A = a+b(n/N)$, Q and Q_A being the radiation amounts on one square centimeter of horizontal surface at the surface of the earth and at the top of the atmosphere respectively and n and N being the actual and the maximum possible hours of bright sunshine respectively. The values of the regression constants a and b have been computed for daily, weekly and monthly data. Data from daily observations have been grouped for the dry and the monsoon seasons, and the constants a and b calculated and compared with those obtained by others.

Mean monthly total radiation at a few places in north India, having the same cloud regime as at Delhi, has also been computed and discussed.

1. Introduction

Apart from the fact that the solar radiation is a major control in all atmospheric processes, the duration and intensity of radiation are important for photosynthesis which plays a vital role in plant growth. A detailed investigation into the processes which control the thermal balance at the ground surface is necessary for an understanding of the physics of air and soil layers near the ground. In turn, this thermal balance of the ground surface is controlled by the incoming solar radiation and the downward heat radiation from the absorbing gases like water vapour, carbondioxide and ozone in the atmosphere. It is, therefore, necessary that the radiant energy measurements be made at a number of stations. Unfortunately, the network of stations recording solar radiation income is very meagre and it will take much time to establish a wide network of stations. Angström (1924) suggested a relation $Q/Q_0 = a'+(1\cdot00-a')\ n/N$, where Q and Q_0 are radiations actually received on any day and on a clear sky day respectively, n and N the actual and the maximum possible duration of sunshine respectively and a' is the mean proportion of radiation received on a completely overcast day. Thus a' is dependent on the type and thickness of clouds. Moreover, Q_0 instead of being a constant quantity would vary with moisture contents and would depend on scattering nuclei in the atmosphere. It is, therefore, better to use here the relation $Q/Q_A = a+b(n/N)$, where Q_A is the radiation at the top of the atmosphere and a and b are constants.

2. Brief description of the instruments

For the measurement of total solar radiation at Delhi a Moll-Gorczynski solarimeter with a recording millivoltmeter having a range of 0-15 mV is used.

The solarimeter is installed on the roof of the observatory at New Delhi where an unobstructed view of the whole sky is available. Hourly and daily values of total radiation are evaluated from the solarimeter records. Duration of bright sunshine is recorded with a Campbell-Stokes sunshine recorder.

3. Analysis of records

Table 1 gives the mean values of the possible and actual hours of sunshine in each month. The percentage of possible sunshine in different months has also been calculated. The data used here is from 1959 to 1962. It is noteworthy that these figures

TABLE 1

	Hours of possible sunshine per day	Hours of actual bright sunshine per day	Percentage of possible sunshine
Jan	10·52	7·63	72·5
Feb	11·57	8·48	73·3
Mar	11·96	8·40	70·2
Apr	12·87	9·45	73·4
May	13·58	9·53	70·2
Jun	13·97	7·63	54·6
Jul	13·81	6·02	43·6
Aug	13·19	4·93	37·4
Sep	12·37	7·20	58·2
Oct	11·48	8·85	77·1
Nov	10·73	9·18	85·5
Dec	10·32	8·02	77·7

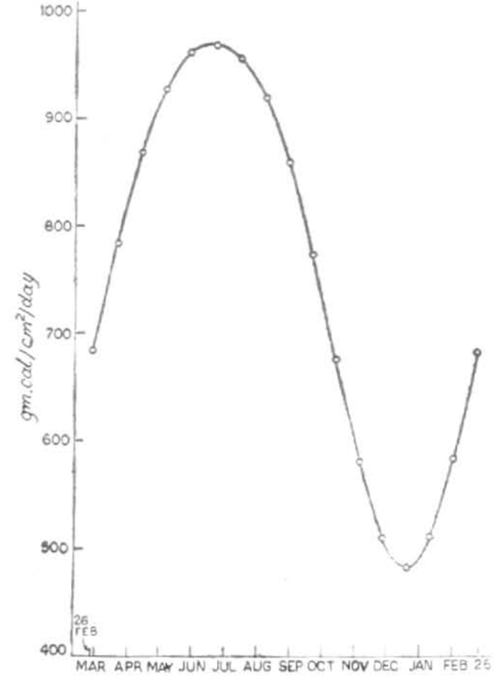

Fig. 1. Q_A curve for Delhi (Lat. 28.6°)

are almost the same as calculated by Mani, *et al.* (1962) in respect of data of Delhi for 1958. It can be seen from the table, that (*i*) July and August are the months of maximum cloudiness or the minimum duration of sunshine, (*ii*) May has the maximum duration of sunshine hours, (*iii*) August has the minimum number of sunshine hours and (*iv*) November is the clearest month.

The daily, weekly and monthly values of Q, Q_A, n and N were calculated in order to determine the ratios Q/Q_A and n/N. In all these computations the average values for 1959-62 were used. The daily values of Q_A were interpolated for New Delhi latitude (28° 35′ N) from the values given for specific latitudes and dates by List (1958). The values of N were determined from the *Indian Ephemeris and Nautical Almanac* considering the daily duration of sunshine from the time of sunrise to sunset. The Q_A curve for New Delhi is shown in Fig. 1. Scatter diagrams for the weekly and the monthly ratios Q/Q_A and n/N have been shown in Figs. 2 and 3 respectively. Lines representing the best fits for the least square regression equations for the weekly values and the monthly values were drawn and the least square regression constants d and b and r—the correlation coefficient between Q/Q_A and n/N have been calculated. On similar lines the values of Q/Q_A and n/N were computed for daily data and from their scatter diagrams the constants a and b and the coefficient of correlation have been calculated. For daily values, n/N ranged from 0 to 0·96 while for the weekly and the monthly values n/N ranged from 0·23 to 0·92 and 0·30 to 0·96 respectively. Since the number of daily ratios is very large a frequency distribution (Table 2) has been given instead of the scatter diagram. In order to analyse the daily data seasonwise these were grouped separately into (*i*) clear and dry season (October to May) and (*ii*) cloudy and wet season (June to September). Table 3 shows the different values of a, b, a_0 and b_0 and also r, the coefficient of correlation between Q/Q_A and

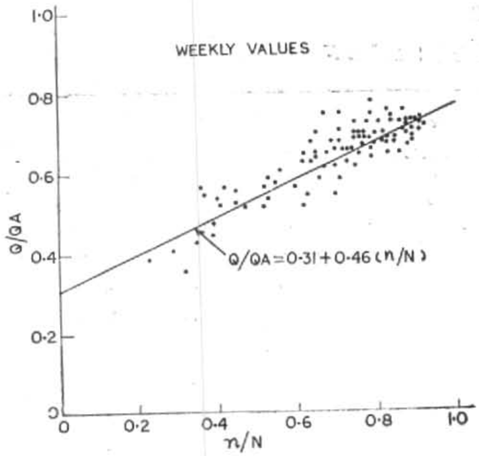

Fig. 2

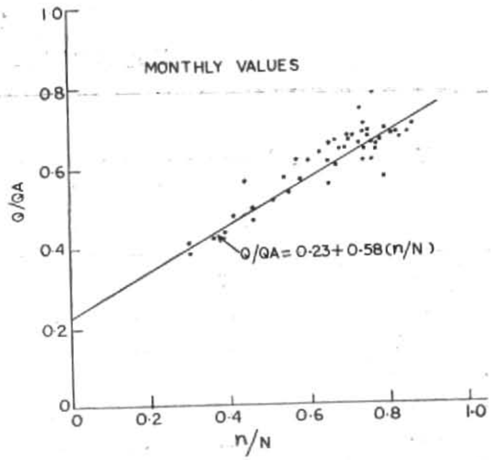

Fig. 3

Scatter diagrams of Q/Q_A and n/N

n/N. The constants a_0 and b_0 were determined since some workers have calculated them by the relations, $Q/Q_0 = a_0 + b_0\ (n/N)$, which, when compared with $Q/Q_A = a + b\ (n/N)$ used here, gives the relations $a_0 = a/(a+b)$ and $b_0 = b/(a+b)$. Since in the case of clear sky, *i.e.*, when n/N is nearly unity, $Q=Q_0$ and $Q_0/Q_A = a+b$. Table 4 shows the comparative study of a, b, a_0 , b_0 and r, calculated for Delhi with those worked out by others for different parts of the world.

4. Discussion of the results

The values of the coefficient of correlation in the different cases of grouping the data range from $+0{\cdot}83$ to $+0{\cdot}95$. The values of the regression constants for weekly and daily data are quite close to each other but for a little difference with the monthly values. It can also be seen that the constants when compared in the seasonwise groups of daily values an appreciable difference is noted. In which case these differences in the values of a, b, $(a+b)$ would be due to greater moisture content of the atmosphere during the wet season which causes greater absorption of the radiation in the atmosphere. The values of the constants in the case of daily data, irrespective of season, are midway between those for the clear and dry and cloudy and wet seasons. A similar trend of the values of these constants was found earlier by Mooley *et al.* (1962) for Madras.

It is interesting to compare the values of these constants found for Delhi with those found by other workers given in Table 4. It can be easily concluded that the regression constants a and b for clear and dry season of Delhi have very good agreement with those for Wingfield, Trinidad, Jamaica, Windhock, Pretoria, Blomfontein and Durban and that there is a slight difference when compared with those for Kabete. In the case of monthly values, it is seen that the constant a for Delhi is exactly the same as that for Kabete, Varsailles, and 32 stations within latitudinal belt 7°S to 65°N and practically same as for Mt. Stromlo, and the constant b for Delhi is in very good agreement with those for Kabete and Rothamstead. There is a very good agreement between the values of r for Delhi and almost all the stations shown in Table 4. It is also noteworthy that the constants a, b, a_0 , b_0 and r for monthly data of Delhi have marked difference with those for Madras. While for daily and weekly data there is very good agreement between the values of a, b, a_0 , b_0 and r for Madras and Delhi.

TABLE 2

Frequency distribution of Q/Q_A and n/N

n/N	Q/Q_A									
	·000 to ·100	·100 to ·200	·200 to ·300	·300 to ·400	·400 to ·500	·500 to ·600	·600 to ·700	·700 to ·800	·800 to ·900	Total
·000 — ·100	7	16	28	15	9	2	..	..	..	77
·100 — ·200	..	..	2	7	7	6	..	..	..	22
·200 — ·300	..	..	1	7	13	5	..	..	..	26
·300 — ·400	..	..	..	5	20	16	1	..	..	42
·400 — ·500	..	..	..	..	11	31	6	4	..	52
·500 — ·600	..	..	..	..	3	29	15	5	..	52
·600 — ·700	..	..	..	..	2	33	59	7	..	101
·700 — ·800	..	..	..	..	..	12	124	50	1	187
·800 — ·900	..	..	..	..	..	7	122	139	8	276
·900 — 1·000	..	..	..	..	..	..	20	102	6	128
Total	7	16	31	34	65	141	347	307	15	963

TABLE 3

Regression constants and correlation coefficient r, between Q/Q_A and n/N for Delhi

	a	b	a_0	b_0	r
Monthly	0·23	0·58	0·28	0·71	0·86
Weekly	0·31	0·46	0·40	0·60	0·95
Daily					
(*i*) Clear and dry season	0·29	0·52	0·35	0·64	0·83
(*ii*) Cloudy and wet season	0·32	0·43	0·40	0·57	0·90
(*iii*) Irrespective of season	0·31	0·48	0·39	0·60	0·87

TABLE 4

Values of a, b, a_0, b_0 and r obtained by different workers

	Location	Latitude	a	b	a_0	b_0	r
	DAILY						
Glover and McCulloch (1958)	Kabete (E. Africa)	1·3°S	0·26	0·57			0·92
Glover and McCulloch (1958)*	Windhock (S. Africa)	22·6°S	0·26	0·52			
	Pretoria (S. Africa)	25·6°S	0·25	0·50			
	Blomfontein (S. Africa)	29·1°S	0·26	0·49			
	Durban (S. Africa)	29·8°S	0·26	0·51			
	Wingfield (S. Africa)	33·9°S	0·29	0·50			

*Mean of the values given for the different years

TABLE 4 *(contd)*

	Location	Latitude	a	b	a_0	b_0	r
			DAILY				
Smith (1959, 1960)	Trinidad (W. Indies)	10·6°N	0·27	0·49			
Cowan**	Jamaica	18 °N	0·31	0·49			
Kimball	Washington D. C. (U. S. A.)	47·3°N	..	..	0·22	0·78	..
Angström	Stockholm (Sweden)	59·4°N	..	..	0·23	0·77	..
Mooley, *et al.* (1962)	Madras (India)	13·0°N	0·31	0·44	0·41	0·59	0·83
Mani, *et al.* (1962)	New Delhi (India)	28·6°N	..	..	0·38	0·57	0·90
			MONTHLY				
Glover and McCulloch (1958)	Kabete (E. Africa)	1·3°S	0·23	0·62	..	..	0·97
Fritz and McDonald	11 stations in U.S.A.	..	..	..	0·35	0·61	0·88†
Black, *et al.* (1954)	Varsailles (France)	48·8°N	0·23	0·50	..	..	0·90
	Mt. Stromlo (Australia)	35·3°S	0·25	0·54	..	..	0·89
	32 stations within latitudinal belt 7°S to 65°N		0·23	0·48	..	..	..
Mooley, *et al.* (1962)	Madras (India)	13·0°N	0·30	0·46	0·39	0·61	0·93

**Quoted by Smith (1959, 1960)

†Correlation is between Q/Q_0 and n/N

TABLE 5

Incident solar and sky radiation in gm. cal/cm²/day at Jullundur

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Computed by Ramdas and Yegnanarayanan (1954)	321	420	457	569	644	634	546	486	458	459	375	309
Computed by using the formula $Q/Q_A = 0{\cdot}23 + 0{\cdot}58\ (n/N)$	314	421	473	627	679	641	528	535	509	524	374	323

TABLE 6

Incident solar and sky radiation in gm. cal/cm²/day

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aligarh	376	475	536	621	651	598	513	414	500	481	443	357
Gorakhpur	355	456	509	596	639	539	484	433	454	445	416	339
Muzaffarnagar	349	447	514	611	652	584	507	441	497	475	409	335
Nagina	338	435	514	593	633	565	488	450	481	469	392	340
Saharanpur	329	431	509	591	654	604	499	423	511	458	389	321

5. Estimation of solar radiation at a few places in northern India

Table 5 shows the computed mean daily values of the total radiation for different months by Ramdas and Yegnanarayanan (1954) and by the present author using the relation $Q/Q_A = 0 \cdot 23 + 0 \cdot 58\ n/N$ for Jullundur (Lat. 31°25′ N, Long. 75°35′ E). The ratio n/N was calculated by taking the average monthly values of the duration of sunshine data (1959-62). It is interesting to note that the values compare favourably. The above relation can, therefore, be used for calculating the approximate total radiation at places in northern part of India having the same cloud conditions as at Delhi. The data of the duration of sunshine were available for five selected stations, *viz.*, Sugarcane Research Station, Gorakhpur (Lat. 27°00′N, Long. 83°27′ E), Government Agriculture Farm, Aligarh (Lat. 27°00′ N, Long. 78°10′E), Government Rice Research Station, Nagina (Lat. 29°28′N, Long. 78°32′E), Sugarcane Research Station, Muzaffarnagar (Lat. 29°28′ N, Long. 77°44′E) and Government Horticulture Research Institute, Saharanpur (Lat. 29°58′N, Long 77°33′E). The values of Q_A and n/N for these stations were computed and using the formula $Q/Q_A = 0 \cdot 23 + 0 \cdot 58 n/N$, the values of Q, the total solar radiation received during the day for the different months were calculated as given in Table 6. These values will prove useful for agricultural and various other practical purposes.

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