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Relation between the incident solar radiation and the duration of bright sunshine at Madras

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ABSTRACT. From the daily, weekly and monthly values of Q/Q_A and n/N the least square regression constants, a and b in the equation, $Q/Q_A = a + b\,(n/N)$, have been calculated for Madras, Q and Q_A being radiations on one square centimetre of horizontal surface at the surface of the earth and at the top of the atmosphere respectively, n and N being the actual and the maximum possible durations of bright sunshine respectively. Daily data have also been grouped season-wise for the dry and the monsoon seasons and the values of a and b have been calculated for the two seasons. Correlation coefficients between Q/Q_A and n/N have also been calculated.

The values of a and b for Madras have been compared with those obtained by different workers in other parts of the world.

The mean monthly incident radiation at a few places on the east coast having the same cloud regime as at Madras has also been worked out.

1. Introduction

Total solar radiation incident on the surface of the earth is a parameter of considerable significance. Apart from its importance in the study of radiation balance of the atmosphere, special mention may be made of the fact that it is being recognised that solar radiation received by the plant prominently governs its rate of transpiration and as such it has to be taken into account in estimating the water needs of the plant. It is, therefore, necessary that a good network of stations with radiation instruments is available. Unfortunately, the existing network of radiation stations over the surface of the earth is meagre and it is very much so for the tropics. The network is gradually improving but it would take a considerably long time before a satisfactory network is established within the tropics. Till that time, the incident solar radiation has to be obtained by indirect means. There are two indirect ways of estimating the radiation : (*i*) To obtain the relationship between solar radiation and duration of bright sunshine for existing radiation stations and to apply this relationship to locations where data relating to duration of sunshine are available. Sunshine data are available for a large number of stations extending over long periods. (*ii*) To calculate from the known amount of solar radiation incident at the top of the atmosphere after allowing for reflection at the top of the atmosphere, molecular and non-molecular scattering, absorption by the solid and liquid particles, absorption by water vapour and other gases and reflection and absorption by different types of cloud. Many of these quantities to be allowed for, are difficult of estimation and as such this method of obtaining the solar radiation is of little use. It is felt that the first method which is very simple can be used by applying the relation between radiation and duration of sunshine to locations where sunshine data are available and where moisture conditions of the atmosphere and cloud regimes are generally similar.

Angstrom (1924) first suggested the relation $Q/Q_0 = a' + (1{\cdot}00 - a')\, n/N$, where Q and Q_0 are radiations incident on one square centimetre of horizontal surface of the earth on any day and on a cloudless day respectively, n, the actual duration of bright sunshine and N, the maximum possible duration of bright sunshine and a' is the mean

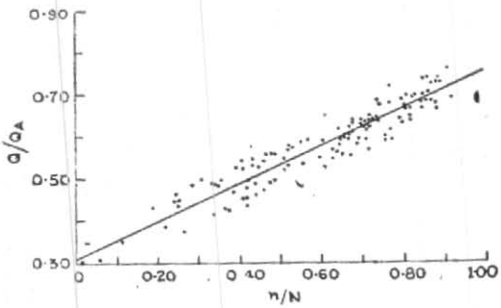

Fig. 1. Weekly values

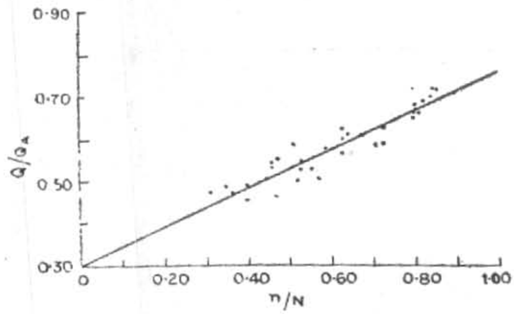

Fig. 2. Monthly values

Scatter diagrams of Q/Q_A and n/N

Straight line shown is the least square regression equation

proportion of radiation received on a completely overcast day. a' would primarily depend upon the type and thickness of cloud. Even Q_0 would not be constant but would depend on the moisture and scattering nuclei in the atmosphere. It would, therefore, be better to relate Q to Q_A, the radiation incident on one square centimetre of horizontal surface at the top of the atmosphere, as has been done by some workers. This relation is, $Q/Q_A = a + b\ (n/N)$, where a and b are the regression constants. It is proposed to study this relationship for Madras.

2. Instruments and records

A radiation station was started at Madras (Lat. 13·0°N, Long. 80·2°E and height 15m a.s.l.) in October 1957 as a part of the IGY programme. Total daily solar radiation (direct radiation + diffuse sky radiation) on a horizontal surface is obtained from the records of the Moll-Gorczynski solarigraph. Duration of bright sunshine was obtained from the records of the Campbell stokes sunshine recorder. Data for the period 1 October 1957 to 30 September 1960 have been used in the present study.

3. Analysis of records and results

The values of Q_A were obtained for Madras latitude for each day of the year by interpolation from the values given for specific latitudes and dates by List (1958). These are based on the value 1·94 cal cm^{-2} min^{-1} of the solar constant. Daily values of N were obtained from the times of sunrise and sunset for Madras given in the *Indian Ephemeris and Nautical Almanac.* The ratios Q/Q_A and n/N were calculated for each day, each week and each month. While calculating the ratios for the week and the month the days on which only sunshine record was available were not taken into account. No two weeks had any overlapping days and thus the ratios are independent of each other.

For daily values, n/N ranged from 0 to 0·96, while for the weekly and the monthly values it ranged from 0·03 to 0·91 and 0·35 to 0·85 respectively. Scatter diagrams for the weekly and the monthly ratios have been given in Figs. 1 and 2. Since the number of daily ratios is very large, a frequency distribution table (Table 1) has been given for these instead of the scatter diagram.

From the daily, weekly and monthly ratios, least square regression constants a and b and correlation coefficients between Q/Q_A and n/N were calculated. Lines representing the least square regression equations for the week and the month have been drawn on Figs. 1 and 2 respectively. The daily data were grouped separately for the two periods January to May and June to December which correspond to the clear and dry season and cloudy and wet season (*i.e.*, the monsoon season) at Madras and the least square

TABLE 1

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	Total
·000— ·100	6	18	38	46	15				123
·100— ·200			1	10	18	2			31
·200— ·300			1	4	20	6			31
·300— ·400			1	3	15	21	1		41
·400— ·500			1		16	37	4		58
·500— ·600					9	44	23		76
·600— ·700					7	40	54		101
·700— ·800						22	101	13	136
·800— ·900						5	160	120	285
·900—1·000						2	27	50	79
Total	6	18	41	64	100	179	370	183	961

TABLE 2

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

	a	b	a_0	b_0	r
Daily (clear and dry season)	0·27	0·50	0·35	0·65	0·83
Daily (cloudy and wet, *i.e.*, monsoon season)	0·32	0·41	0·44	0·56	0·78
Daily (irrespective of season)	0·31	0·44	0·41	0·59	0·83
Weekly	0·31	0·45	0·41	0·59	0·95
Monthly	0·30	0·46	0·39	0·61	0·93

regression constants a and b and correlation coefficients between Q/Q_A and n/N were also calculated for the two seasons. The values of a and b and of r, the correlation coefficients are given in Table 2. Some workers have calculated the constants a_0, b_0 in the relation

$$Q/Q_0 = a_0 + b_0\,(n/N)$$

$$Q/Q_A = a + b\,(n/N) \qquad (1)$$

when sky is clear n/N is nearly 1 and Q becomes Q_0. Hence,

$$Q_0/Q_A = a+b \qquad (2)$$

Dividing equation (1) by (2),

$$Q/Q_0 = \frac{a}{a+b} + \frac{b}{a+b}\left(\frac{n}{N}\right)$$
$$= a_0 + b_0\,(n/N)$$

Thus, $a_0 = \dfrac{a}{a+b}$ and $b_0 = \dfrac{b}{a+b}$

From these relations a and b were converted into a_0 and b_0 for the purpose of comparison. The values of a_0 and b_0 for Madras are also shown in Table 2.

4. Discussion of the results

Regression constants from daily (irrespective of season), weekly and monthly values differ very little from each other. The values of a and b from the daily data for monsoon season (northeast and southwest) differ appreciably from those for the clear dry season. The value of $(a+b)$ for clear and dry season is 0·77, while that for the monsoon season is 0·73. This would be due to the greater moisture content of the

TABLE 3

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 (East Africa)	1·3° S	0·26	0·57			0·92
Glover and McCulloch* (1958)	Windhoek (S. Africa)	22·6°S	0·26	0·52			
	Pretoria (S. Africa)	25·6°S	0·25	0·50			
	Bloemfontein (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			
Smith (1959, 1960)	Trinidad (West 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	
Angstrom	Stockholm (Sweden)	59·4°N			0·23	0·77	
		MONTHLY					
Glover and McCulloch (1958)	Kabete (East 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)	Rothamstead (England)	51·8°N	0·18	0·55			0·79
	Gembloux (Belgium)	50·6°N	0·15	0·54			0·83
	Varsailles (France)	48·8°N	0·23	0·50			0·90
	Mt. Stromlo (Australia)	35·3°S	0·25	0·54			0·89
	Dry Creek (Australia)	34·8°S	0·30	0·50			0·95
	32 stations within latitudinal belt 7°S to 65°N		0·23	0·48			

* Mean of the values given for the different years † Quoted by Smith (1959, 1960)

‡ Correlation is between Q/Q_0 and n/N

atmosphere during the monsoon season which causes greater absorption of the radiation in the atmosphere. The value of $a+b$ when the regression constants are calculated from the daily data irrespective of the seasons is 0·75 which is midway between those for the two seasons.

In Table 3 are given the values of a, b, a_0, b_0 obtained by other workers from the daily and monthly data. Correlation coefficients between Q/Q_A or Q/Q_0 and n/N, wherever available, have also been given in Table 3.

TABLE 4

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

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calculated	441	498	556	588	579	419	413	414	402	427	444	464
Actual from solarimeter data	435	507	567	586	587	427	417	417	378	382	439	460

TABLE 5

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

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Samalkot	472	525	567	586	556	461	411	419	443	421	432	448
Tiruchirapalli	473	551	585	570	538	477	446	474	516	458	433	419
Aduthurai	488	544	594	570	547	495	472	495	529	458	398	419
Kovilpatti	486	534	580	537	504	478	466	499	510	450	409	437

Comparing the regression constants obtained from daily data, it is seen that there is a very good agreement between the values of a and b for Madras for the clear dry season and those for Windhock, Pretoria, Bloemfontein, Durban, Wingfield, Trinidad and Jamaica. In the case of Kabete, the regression constant, a, is practically the same but b differs appreciably.

The values of a_0, b_0 and r obtained from monthly data for Madras agree very well with those for the stations in U.S.A. given by Fritz and McDonald (1958).

5. Values of mean monthly radiation at a few places in Madras State and coastal Andhra Pradesh

Cloud regimes at places in the coastal belt of Madras State and Andhra Pradesh can be considered similar, these being generally in the same air mass flow. It was therefore felt that the monthly values of a and b for Madras can be used for calculating the mean monthly radiation for places in the coastal belt.

In order to see how far the assumption of similarity of cloud regimes is valid, mean daily radiation for different months was calculated for Visakhapatnam by using the relation derived for Madras and the values compared with the actual mean daily values obtained from the available records (*i.e.*, for 1961) of the solarimeter. These values are given in Table 4. The agreement is generally good. The relation can, therefore, be used for calculating the incident radiation at any place in the coastal belt of Madras and of Andhra Pradesh.

As sunshine data for places Kovilpatti, Aduthurai, Tiruchirapalli and Samalkot in the coastal belt of Madras State and of Andhra Pradesh were available, the values of mean monthly radiation at these places have been worked out taking into account sunshine data for the last 6 years. The mean daily values for different months are given in Table 5.

The values of the total solar and sky radiation at the four places given in Table 5 will prove useful in the near future due to the fact that big industrial undertakings and other ancillary developments are coming up in the regions where these stations are

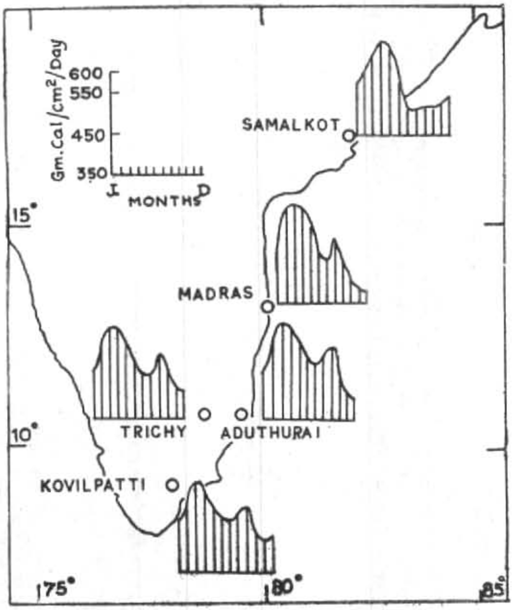

Fig. 3

situated. The actual positions of these stations *vis-a-vis* Madras are shown in the map (Fig. 3). The mean monthly variation of the total incident radiation is also shown graphically close to each station.

6. Acknowledgements

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