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Studies on the estimation of Pan Evaporation from meteorological parameters

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ABSTRACT. The study reveals that in the computation of pan evaporation the use of the energy term becomes very important under conditions of high evaporation.

A procedure for computation of solar radiation for a close network of stations from the percentage hours of sunshine has been outlined.

Kohler's technique for deriving pan evaporation using solar radiation, total wind run, average air temperature and vapour pressure data has been found to yield good results under Indian conditions. Monthly normal evaporation maps using Kohler's technique have been prepared and discussed.

1. Introduction

Evaporation data recorded with the help of evaporimeters is a very important meteorological parameter, the need for which is being increasingly felt in many diverse fields of science such as climatology, agriculture, hydrology, micro-meteorology, botany etc.

This importance is reflected in the efforts that are being made by W.M.O. to reduce the evaporation data now being recorded with evaporimeters varying in size, shape, metal of construction, manner of mounting, maintenance etc to a standard datum. The following gives a bird's eye-view of the various uses to which these data are being or can be put —

(1) When measured from small size evaporimeters it gives a measure of the daily march of the evaporating power of the air and leads to a better understanding of the various forces tending to subject a plant to a water stress.

(2) When corrected for the heat flow through the sides and bottom the evaporation value could be used in the energy budget method of estimation of evaporation.

(3) When corrected for the diameter effect in addition to that of heat flow, it is a measure of the maximum possible evaporation from shallow extensive water surfaces. The latter, variously designated as potential transpiration, potential evaporation and potential evapotranspiration, is an important parameter in the classification of climates with particular reference to the relative water requirements.

(4) Evaporation data are also required for the extrapolation in time and space of the experimentally determined irrigation requirements estimates, when the latter are available only for a few places in a grid.

Need for obtaining computed values

In India observations on evaporation have been recorded with standard U.S.A. open pan evaporimeters made of 20 SWG copper sheets painted white outside and tinned inside and kept above ground on wooden grills with water surface about 1 ft above ground and between 1 and 2 inches from the rim of the pan. However, a large amount of these data have had to be rejected because of errors due to bird visitations. From 1961, evaporation data are being recorded by covering the U.S.A. evaporimeter with 3/4″ wire mesh cover. Studies to derive a conversion factor for obtaining open pan data from mesh covered one are in progress. Thus it will take some time before reliable climatological records of pan evaporation are built up in the country.

For carrying out specific studies, directly measured pan values are necessary and cannot be superceded by indirect estimates. However, there are many problems connected with the optimum utilisation of natural water resources which require climatological information on evaporation. One, therefore, naturally becomes interested in the possibility of obtaining evaporation data from readily available climatological information.

2. Computation of pan evaporation from meteorological parameters

Many attempts have been made in the past to obtain empirical formulae for determining pan evaporation. Most of these formulae are of the Daltonian form

$$E = (e_0 - e_a) f (u)$$

where E is evaporation in unit time, e_0 the saturation vapour pressure at the water surface temperature, e_a is equal to vapour pressure of air and $f(u)$ is a function of the horizontal wind at pan level. These formulae requiring the use of water surface temperature data would appear to be of little practical value since where this information is available pan evaporation data are usually available. Further when the hours of observations do not coincide with the X and N epochs of the water temperature as is the case in most countries it is not possible to obtain the correct mean water surface temperature. Raman and Satakopan (1934) used Rohwer's (1931) expression for computing pan evaporation by assuming the mean daily air temperature to be equal to that of the mean daily temperature of water surface. In Table 1 are presented the observed and computed values of evaporation as per Raman and Satakopan. This reveals that this assumption fails under conditions of high evaporation.

Penman (1948) through a simultaneous solution of an aerodynamic equation of the Daltonian form and the energy balance method, eliminated the need for water temperature observations and derived the equation —

$$E = \frac{1}{\triangle + \nu} (Q_n \triangle + \nu E_a) \qquad (1)$$

where ν is defined by the equation

$$R = \nu \left(\frac{T_0 - T_a}{e_0 - e_d} \right) \qquad (1a)$$

$$\text{and } E_a = (e_a - e_d) \quad A + B_W) \qquad (1b)$$

In these expressions $\triangle$ is the slope of the saturation vapour pressure *vs* temperature curve at air temperature, Q_n is the net radiant energy expressed in the same units as E, R the dimensionless Bowen's ratio, T_0 and T_a the mean water surface and air temperatures, e_0 and e_a the saturation vapour pressure corresponding to the air and water temperatures, e_d is the mean vapour pressure of air, W is the total wind run at pan level, and A and B are constants.

A similar formula has also been derived by Ferguson (1952). During the water loss investigations at Lake Hefner, this formula has been tested extensively by Kohler and co-workers (1954, 1955, 1959). They found that if in the Penman equation E_a was taken as

$$(e_a - e_d)^{\cdot 88} (\cdot 37 + \cdot 0041\, W)$$

and a value of ·025 was used for ν it gave reliable values of pan evaporation. As a result of these and other extensive studies these workers have presented a coaxial graphical technique for determination of pan evaporation. As net radiation values are relatively scarce compared to those of solar radiation, these workers adopted the following technique to incorporate the solar radiation term in the coaxial graph. The solar radiation value corresponding to any given $Q_n \triangle$ and air temperature value was marked in the graph and lines of equal solar radiation values were connected up. Thus computation of pan evaporation by this technique requires the use of following parameters, namely,

(*i*) Mean dry bulb and dew point temperature of air,

(*ii*) Total wind run at pan level and

(*iii*) Total solar radiation received.

For estimating wind speed at pan level Kohler *et al.* (1959) suggest the use of the formula —

$$\frac{U_1}{U_2} = \left(\frac{Z_1}{Z_2}\right)^{0.3} \tag{2}$$

In the United States, this formula has been tested by Kohler *et al.* (1955) in different climatic regimes ranging from Alaska to Florida and it has been found to give good results.

3. Preliminary studies on the validity of Kohler's method

Under the circumstances there is a very great need to verify the applicability of this approach for India for computing pan evaporation by carrying out such studies at places having records of all the required parameters.

Fortunately due to the IGY and IGC programmes evaporation data with wire mesh cover have been recorded at a few stations in India from 1958 onwards. At these stations records of radiation are also available.

Thus the data at these stations afford us an opportunity to test the formulation of Kohler *et al.* However, at these stations the wind speed is recorded at heights of nearly 30 ft except at Poona where records are available at 2 and 6 ft also. A preliminary study was, therefore, carried out to find out the magnitude of the error of estimated evaporation that is likely to arise due to errors in the determination of pan level wind by the formula of Kohler, Nordenson and Baker (1959). These results have shown that errors on this score are negligible, as in the formulation of Kohler *et al.* the contribution of the wind term is small.

The values obtained by the use of the coaxial graph (Fig. 1) were also extensively compared with the values actually computed by the use of the basic equation and it was found that the differences between the two rarely exceeded $\pm$ ·01 of an inch.

To verify how far the daily values of evaporation estimated by the method of Kohler *et al.* differ from the actual, for Poona, four typical fortnights in the year 1960 were chosen. The results presented in Table 2 show excellent agreement between the computed and measured values even on a daily basis. These studies were then extended to cover the other IGY stations. During the course of these studies it was found that there were many months with only a few days of observations on radiation as recorded with Moll's solarimeter. Fortunately as these stations were also recording lucimeter observations recourse was taken to obtain the Moll's radiation values from the lucimeter observations through the use of the month-wise, station-wise conversion factors determined by Hariharan (1961). The results of these studies are presented in Table 3.

From Table 3 it was seen that at Dum Dum the computed values were consistently higher for all the months except May to September. It was thought that this might be due to the deposition of industrial smoke on the water surface during the stable months. To test this, evaporation data recorded at Chinsurah (a crop weather station situated about 20 miles from Calcutta) in 1962, with standard mesh covered U.S.A. pan were compared with those computed from the prevalent meteorological parameters at the station and by assuming the radiation receipt at Chinsurah to be the same as at Dum Dum. The results presented in Table 4 show excellent agreement between the observed and computed values and this is a major point regarding the location of evaporimeters at or near industrial cities.

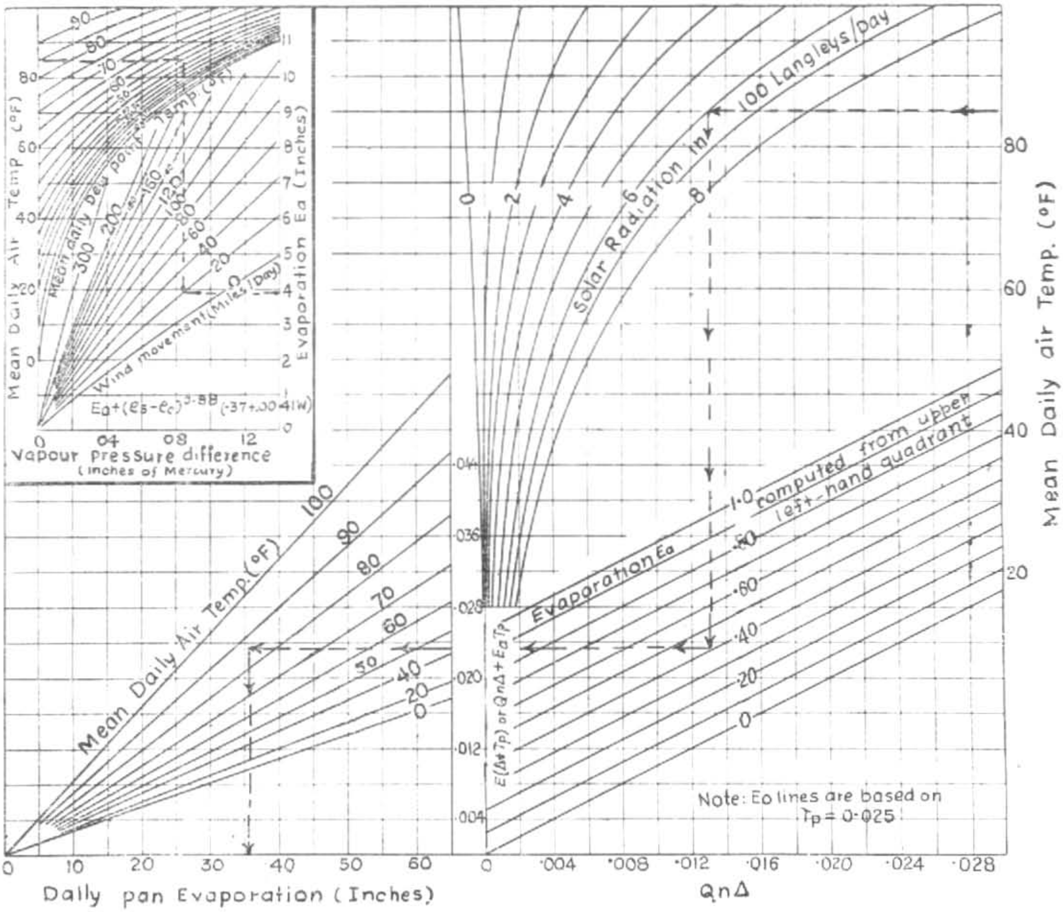

Fig. 1. Revised class A pan relation of Kohler, Nordenson and Fox: $E(\triangle+\tau_p)$ **or** $Q_n\triangle+E_a\tau_p$

At Jodhpur the agreement is not good in the months of January, February, November and December when the mean dew point temperature is near about 35°F. The formula would appear to become not so reliable under these conditions. However since the absolute amount of evaporation is very small in these months the total contribution of any error in the estimates for the winter months would have only a negligible effect on the annual water loss. These studies would appear to indicate that Kohler's method can be used to obtain reliable climatological normals of mean annual evaporation and its monthly distribution.

Use of mean of spot readings in lieu of 24-hr means

In the use of Kohler's method it would be ideal to have the means of air temperature and dew point based on autographic records. The number of stations with autographic data of these elements is still small. However, there are many stations having records of maximum, minimum temperatures and the dew point of the air for two specified hours (0300 and 1200 GMT for synoptic stations and 0700 and 1400 LMT for Agricultural meteorological stations). Therefore at stations having autographic records, a study was undertaken to find out the effects of using the mean of maximum, minimum and the mean of the two dew point observations in the place of the 24-hr means of air temperature and dew point respectively. A sample computation presented in Table 5 shows that there is no loss in accuracy due to the use of the mean values as described above instead of the 24-hr means. This technique, therefore, becomes applicable also to stations having records of maximum and minimum and dew point temperatures for specified hours, radiation and total wind run.

4. Importance of the Energy term

Penman's formula (equation 1) contains the aerodynamic term E_a which gives the evaporation computed in terms of vapour pressure deficit and wind speed. In the same formula E gives the evaporation after providing for the energy term. Under conditions of equal air and water temperatures the aerodynamic term must itself give the value of evaporation, very close to that of E. It was considered desirable to find the limiting value of evaporation up to which the assumption of the air temperature being equal to water temperature, would remain valid. Fig. 2 was, therefore, prepared with the X-axis being E_a and the Y-axis being E of the Penman equation. All the computed monthly values of E_a and E for Delhi, Poona and Madras for the period 1958-61 were used in the figure. An examination of Fig. 2 with the 45° straight line, which is shown as a broken line, shows that for evaporation values above 1/4″ the inclusion of the energy term becomes imperative.

5. Computation of solar radiation received on earth's surface

As radiation data available for India are rather meagre at present one has to see if these could be indirectly estimated. The starting point of all computation attempts is the fact that the amount of solar radiation received at any place on the earth, after passing through a cloud free atmosphere containing given amounts of precipitable water and suspended particles, could be fairly accurately derived. When clouds are present, the radiation reaching a surface is less than the clear sky radiation. The extent of depletion due to clouds will vary with the opacity of the cloud, which in turn is dependent on the cloud types. The percentage attenuation for different cloud forms are given by Haurwitz (1948). Since the hours of bright sunshine as recorded with a sunshine recorder give an estimate of the hours of cloud cut-off many attempts have been made to obtain solar radiation estimates from precipitable water content, aerosol content and percentage hours of bright sunshine data.

Ramdas and Yegnanarayanan (1954) initiated studies on the estimation of solar radiation in India in 1954 when Poona was the only station recording radiation observations. Faced with the lack of information on the precipitable water content and dust content data they obtained estimates of clear sky radiation by ignoring the influence of the dust content on depletion and by assuming the total precipitable water to be equal to $2{\cdot}1\times e$ where e is the vapour pressure at the ground level expressed in centimetres. Then using the equation of Fritz and Mcdonald (1949), *viz.*,

$$Q_c = Q_0\,(\,0{\cdot}61S + 0{\cdot}35\,) \qquad (3)$$

where Q_c = actual radiation received, Q_0 = the radiation expected with clear skies and S = the percentage hours of bright sunshine, they worked out radiation receipt at 22 stations for which adequate sunshine hours data were available.

Since 1957 radiation observations have been recorded systematically at Poona, Madras, Calcutta and Delhi by means of the Moll's solarimeter. It was, therefore, decided to compute for these stations the mean monthly clear day *Surface radiation ratios* which can be defined as the ratio of the amount of radiation received from sun

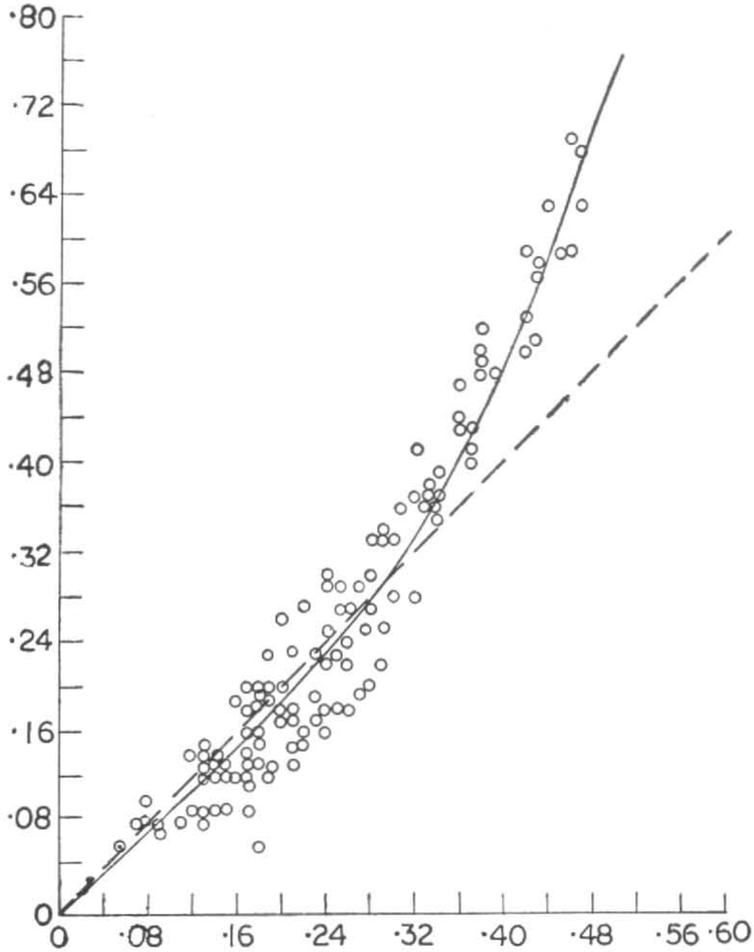

Fig. 2

and sky to the solar radiation at the top of the atmosphere and to compare them with the ratios based on the clear day radiation estimates of Ramdas and Yegnanarayanan. The comparison presented in Table 7 shows that the clear day radiation estimates of Ramdas and Yegnanarayanan are about 15 per cent greater than the actual observed values except at Dum Dum where the over-estimation is about 30 per cent, due to the presence of greater amount of suspended particles there.

Now substituting the relation $Q_c = 1{\cdot}15 \times Q_{0A}$ where Q_{0A} is the actual observed clear day radiation in Fritz and Mcdonald's expression, equation (3) can be written as —

$$Q_c = Q_{0A}\ (\ {\cdot}7S + {\cdot}4\ ) \qquad (4)$$

As no sunshine recorder gives a value of S greater than $0{\cdot}95$ on clear days use of the above relation will overestimate the clear day radiation by 7 per cent. Now on overcast days the formula would give an estimate equal to 40 per cent of the expected clear sky radiation. Considering the monsoon cloud types of India a reference to Haurwitz's Table would appear to justify the figure. This is also supported by the findings of Mani, Chacko and Venkiteshwaran (1962). Thus formula 3 was expected to function well on clear and overcast days. However it was thought that on partly cloudy days correct estimates can be obtained by using hourly percentage of bright sunshine and hourly percentage of extra-terrestrial radiation in the following formula, *viz.*,

$$Q_c = \Sigma xy.\ K + [X - (\Sigma xy)]\ 0{\cdot}4\ K$$
$$= K(\cdot 6\Sigma xy + 0{\cdot}4\ X) \qquad (5)$$

where Q_c is the radiation received, x is the extra-terrestrial radiation pertaining to an hour as given in Table 6, y the percentage bright hours of sunshine for that hour, X the total extra-terrestrial radiation for the whole day, Σxy the total radation received during the bright hours and K the correct clear sky surface radiation ratio. Table 6 was prepared from the relation —

$$I = (\sin\phi \sin\delta + \cos\phi \cos\delta \cos h) \times$$
$$\times (1{\cdot}94 \times 60 \times 1/r^2) \qquad (6)$$

where I is the hourly radiation in cal/cm^2/m received on a horizontal surface at the top of the atmosphere, ϕ is the latitude, δ the declination and r earth's radius vector for the middle of each month and h the hour angle of the sun.

For stations Poona, Madras, New Delhi, Dum Dum and Trivandrum the radiation values were computed by means of the above formula. The percentage deviations of the computed values from the observed are presented in Table 8. This shows an excellent agreement between the computed and measured values with only 21 of the 192 values exceeding a variation of $\pm$ 8 per cent. A majority of the 21 values is confined to the monsoon months at Poona, Trivandrum and Madras.

Since the use of formula (5) required elaborate computation it was decided to compare the estimates based on equation (4) which requires the use of only daily percentage hours of bright sunshine.

In Table 9 are presented the average monthly percentage deviations from the observed values of the estimates based on equations (4) and (5).

This shows that the use of hourly values does not very greatly improve the accuracy of the computed values with only 5 values exceeding a variation of $\pm$ 8 per cent.

Thus for obtaining climatological normals of radiation the formula of Fritz and Mcdonald using Q_0 values as reported by Ramdas and Yegnanarayanan would suffice.

6. Preparation of Pan Evaporation Maps

As pointed out earlier computation of pan evaporation necessitates collection of climatological normals of (*i*) Dry bulb temperature, (*ii*) Dew point temperature, (*iii*) Total wind run at pan level and (*iv*) Percentage hours of bright sunshine.

The climatological data of all the synoptic and Agricultural meteorological stations were used for the purpose. For this purpose the mean dry bulb was taken as the mean of the maximum and minimum. The mean of the two vapour pressure readings were taken and the corresponding dew point was worked out. The wind run at pan level was computed by use of formula (2), *viz.*,

$$\frac{U_1}{U_2} = \left(\frac{Z_1}{Z_2}\right)^{0.3}$$

For all the Agricultural meteorological stations and for the synoptic stations for which published climatological normals are not available these were worked out making use of a minimum of 10-year data.

Regarding the percentage of hours of sunshine (needed for the computation of radiation value in the formula 3), the means based on a maximum of 10-year data were worked out for the synoptic and Agricultural meteorological stations.

Monthly evaporation values were arrived making use of Kohler's coaxial graphs (Fig. 1).

Difficulties were envisaged in preparation of evaporation maps due to gaps in Rajasthan and Uttar Pradesh and Orissa stations, wherein climatological data for 10 years were not available.

At these stations normals were prepared with the data for a minimum period of 7 years and evaporation calculated was interpolated in the evaporation maps.

7. Discussions

The monthly and annual computed evaporation data for different Agricultural meteorological and synoptic stations have been plotted on charts and lines of equal evaporation drawn. These are given in Figs. 3 to 15.

The general features brought about by these charts are given below —

January — The evaporation is generally high over the peninsula except for a narrow belt below the Mysore plateau. The evaporation gradually decreases as we proceed north of the Vindhyas with evaporation in Bengal, Assam and Himalayan region being very low. The maximum evaporation occurs in the south Maharashtra Deccan.

February — The chart during this month is more or less similar to that of January. The evaporation is generally higher than that in January.

The region of maximum evaporation is more diffusive and occurs in the Maharashtra region.

March — All over the country there is an increase of evaporation. The low evaporation in the Himalayas still persists.

April — There is a considerable increase in evaporation all over the country except at the SE corner of India. The rate of evaporation in the Maharashtra Deccan increases sharply as we proceed to the interior from the coast.

May — Evaporation continues to be high during this month also. The belt of high evaporation gets extended northwestwards towards Rajasthan. The areas in Assam continue to be regions of low evaporation. There is a decrease in evaporation in the coastal areas of western India, probably due to premonsoon thundershowers. A slight increase is noticed in the Coromandal Coast.

June — With the onset of monsoon there is a general decrease in the rate of evaporation. However the rate of evaporation continues to be high over the Madras State and the belt of high evaporation gets shifted northwestwards to Rajasthan.

July — The chart is similar to that of June but there is a conspicuous fall of evaporation over the whole country.

August — There is a further fall in northern parts of India. The comparatively high rate of evaporation over Madras persists. The evaporation is very low in the Bombay and Malabar coasts.

September—This does not differ much from the map for August.

October — An increase is noted over Rajasthan, while a fall occurs in Madras. The former is due to the withdrawal of southwest monsoon and the latter due to the setting in of the northeast monsoon.

November — The area of high evaporation lies over Gujarat. With the advance of northeast monsoon, the evaporation decreases further over Madras. The low evaporation over south Kerala persists.

December — Conditions similar to that in January appear.

Annual — As is to be expected, the annual evaporation is high in the Maharashtra, Deccan and Rajasthan and Madras.

8. Conclusion

(1) Use of Rohwer's formula assuming water temperature equal to air temperature will fail under conditions when pan evaporation is 1/4″ or more.

(2) Where data of average air temperature and vapour pressure, wind run at pan level and solar radiation are available Kohler's method gives reliable estimates of pan evaporation.

In the use of this method errors in the value of pan level wind derived by means of the formula $(U_1/U_2) = (Z_1/Z_2)^{0 \cdot 3}$ do not influence the accuracy of the computations.

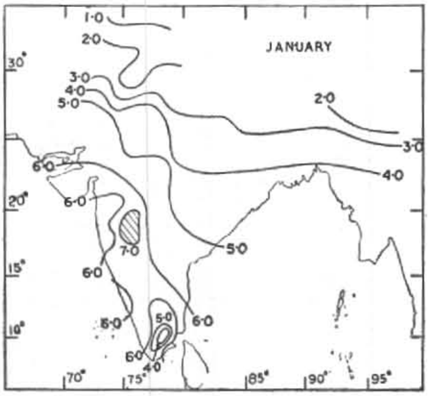

Fig. 3

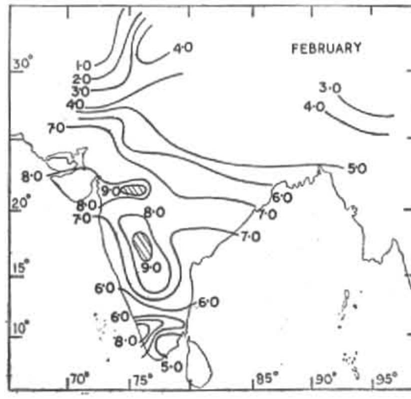

Fig. 4

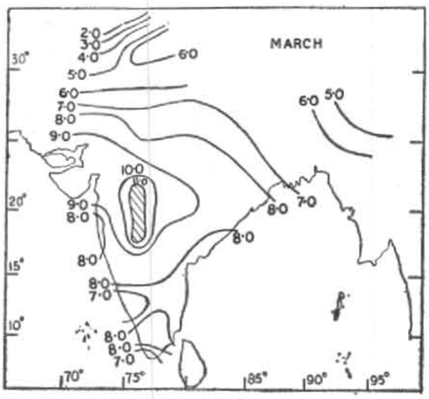

Fig. 5

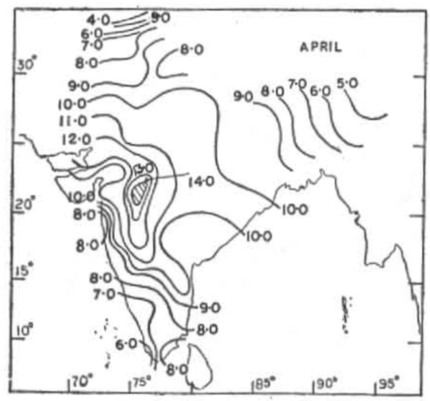

Fig. 6

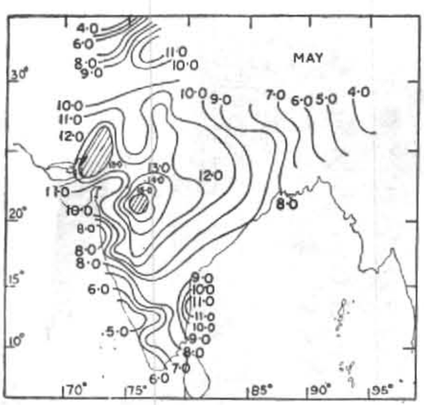

Fig 7

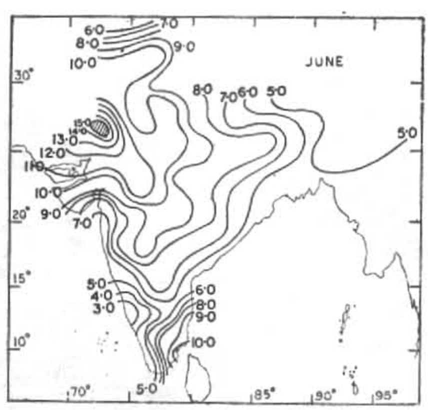

Fig. 8

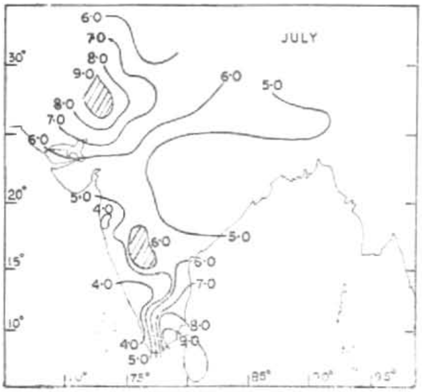

Fig. 9

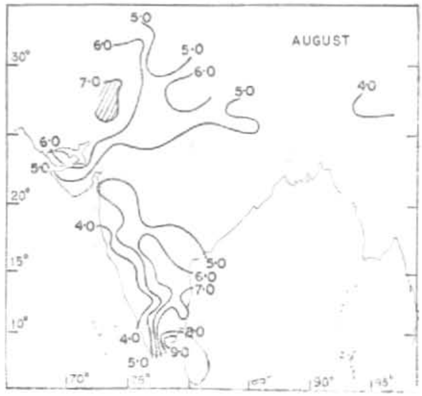

Fig. 10

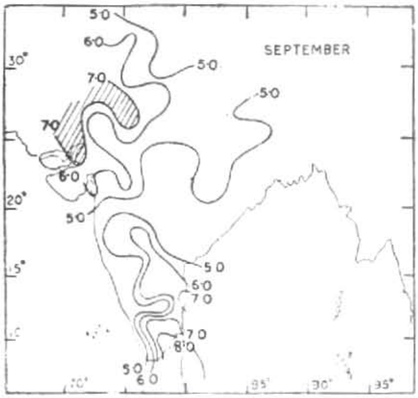

Fig. 11

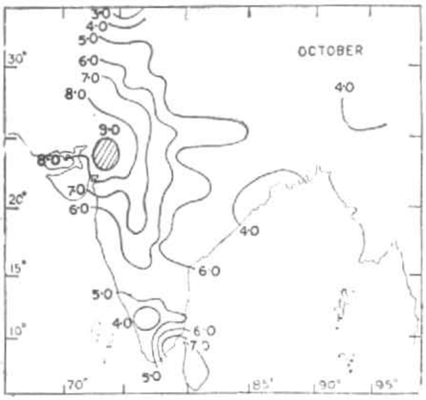

Fig. 12

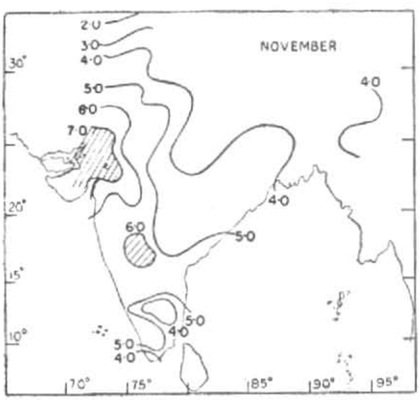

Fig. 13

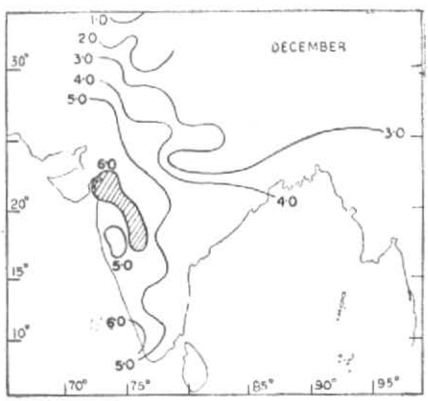

Fig. 14

(3) Evaporimeters placed in industrial cities (like Calcutta) will not give values of evaporation representative of the region. In such regions the evaporimeters will have to be located in the open country side.

(4) Means of maximum and minimum and mean of dew point recorded at 0300 and 1200 GMT could be used respectively in place of 24-hr means of air temperature and dew point without any loss of accuracy in the computed value of pan evaporation.

(5) For obtaining the values of solar radiation on clear days the values published by Ramdas and Yegnanarayanan will have to be reduced by 1/8.

(6) Use of the hourly distribution of the clear sky radiation and bright hours of sunshine and assumption of only 40 per cent transmission of radiation during the non-bright hours yield good estimates of solar radiation received at the earth's surface.

(7) Use of daily values of clear sky radiation and percentage hours of sunshine in place of their hourly distribution does not substantially affect the accuracy of the computed solar radiation values.

(8) Broadly speaking spatial patterns of evaporation revealed by the new maps are more or less the same as those of Raman and Satakopan. However, there are significant quantitative differences in magnitude of the evaporation values and also some differences with regard to the location of centres of maximum and minimum evaporation.

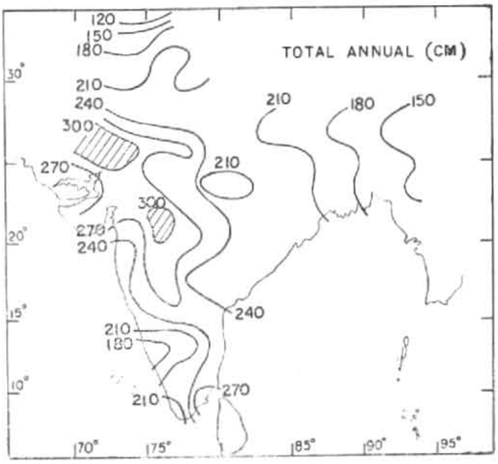

Fig. 15

9. Acknowledgements

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TABLE 1

Mean daily evaporation (in inches) as computed from Raman and Satakopan's formula and as observed

	1958				1959					
	Madras		New Delhi		Madras		Poona		New Delhi	
	C	A	C	A	C	A	C	A	C	A
January	·15	·17	·09	·09	·12	·16	·18	·17	·07	·08
February	·19	·21	·16	·15	·14	·19	·24	·24	·16	·13
March	·21	·25	·30	·26	·18	·22	·40	·34	·29	·27
April	·24	·27	·55	·32	·20	·27	·43	·38	·47	·32
May	·28	·28	·73	·47	·29	·34	·45	·37	·55	·41
June	·56	·41	·77	·52	·28	·29	·27	·30	·63	·40
July	·35	·28	·17	·27	·25	·23	·13	·14	·31	·26
August	·22	·20	·15	·18	·23	·28	·14	·14	·18	·19
September	·24	·26	·14	·17	·20	·23	·11	·15	·19	·19
October	·07	·16	·18	·15	·18	·18	·15	·17	·18	·18
November	·10	·13	·13	·11	·11	·15	·11	·12	·15	·13
December	·11	·13	·08	·07	·11	·12	·18	·15	·10	·10

	1960						1961			
	Madras		Poona		New Delhi		Poona		New Delhi	
	C	A	C	A	C	A	C	A	C	A
January	·14	·15	·11	·11	·07	·09	·21	·17	·08	·08
February	·11	·20	·28	·22	·18	·17	·25	·21	·11	·16
March	·23	·24	·39	·31	·23	·20	·45	·35	·28	·23
April	·23	·25	·57	·38	·49	·34	·55	·41	·46	·35
May	·40	·35	·41	·32	*	—	·37	·33	·61	·41
June	·45	·34	·26	·23	·73	·48	·31	·30	·58	·48
July	·24	·26	·16	·15	·19	·21	·11	·11	—	—
August	·42	·33	·11	·13	·12	·16	·13	·13	—	*
September	·17	·19	·14	·14	·23	·22	·15	·16	·16	·15
October	·17	·17	·22	·20	·16	·15	·16	·19	·12	·17
November	·08	·11	·18	·15	·13	·12	·19	·17	·08	·09
December	·08	·13	·17	·15	·10	·09	·19	·18	·06	·07

C=Computed, A=Actual, *Values doubtful

TABLE 2

Daily pan evaporation (in inches) as observed and as computed by Kohler's method during four typical fortnights at Poona in 1960

Date	Computed	Actual	Date	Computed	Actual
17-4-60	·38	·40	25-10-60	·22	·22
18-4-60	·43	·41	26-10-60	·22	·20
19-4-60	·43	·43	27-10-60	·23	·22
20-4-60	·42	·42	28-10-60	·23	·23
21-4-60	·46	·43	29-10-60	·24	·20
22-4-60	·43	·40	30-10-60	26	·26
23-4-60	·48	·48	31-10-60	·25	·26
24-4-60	·47	·46	1-11-60	·23	·19
25-4-60	·43	·43	2-11-60	·13	·14
26-4-60	·41	·40	3-11-60	·21	·24
27-4-60	·39	·41	4-11-60	·21	·21
28-4-60	·31	·36	5-11-60	·22	·21
29-4-60	·33	·33	6-11-60	08	·08
30-4-60	·32	·32	7-11-60	·08	·07
1-8-60	·07	·07	25-12-60	·16	·16
2-8-60	·07	·09	26-12-60	·17	·16
3-8-60	·14	·16	27-12-60	·21	·19
4-8-60	·14	·12	28-12-60	·19	·18
5-8-60	·09	·09	29-12-60	·19	·19
6-8-60	·16	·16	30-12-60	·17	·16
7-8-60	·17	·17	31-12-60	·15	·13
8-8-60	·13	·16	1-1-61	·17	·14
9-8-60	·10	·12	2-1-61	·17	·13
10-8-60	·16	·18	3-1-61	·16	·15
11-8-60	·11	·12	4-1-61	·19	·17
12-8-60	·14	·15	5-1-61	·17	·15
13-8-60	·14	·15	6-1-61	·19	·18
14-8-60	·14	·13	7-1-61	·18	·15

TABLE 3

Mean daily evaporation (in mm) as computed by Kohler's method and as observed

	Madras (Mean of 1958-1960)		Poona (Mean of 1958-1961)		Dum Dum (Mean of 1958-1961)		New Delhi (Mean of 1958-1961)		Nagpur (Mean of 1960-1961)		Trivandrum (Mean of 1960 only)		Jodhpur (Mean of 1960-1962)	
	C	A	C	A	C	A	C	A	C	A	C	A	C	A
Jan	4·5	4·1	4·6	4·2	3·2	2·2	2·2	2·2	4·8	4·2	5·3	4·5	4·5	2·8
Feb	5·7	5·1	6·3	5·9	4·3	3·3	4·0	3·9	7·1	5·9	5·3	5·0	5·7	4·3
Mar	6·7	6·0	8·5	8·6	5·8	4·6	6·8	6·1	9·7	9·4	6·1	5·4	8·6	7·7
Apr	6·9	6·7	9·4	10·0	7·2	6·0	9·3	8·5	10·9	10·4	4·8	4·2	10·7	10·5
May	8·0	8·3	9·3	9·1	6·7	6·3	11·2	11·1	11·8	12·4	3·3	3·4	12·9	13·5
Jun	8·0	8·7	7·2	7·5	5·1	4·8	10·9	11·7	8·0	8·7	4·3	4·1	11·2	11·9
Jul	6·3	6·6	3·9	3·6	4·3	3·9	5·4	6·2	4·5	4·3	3·8	3·6	7·0	7·3
Aug	6·2	6·8	3·6	3·3	4·2	3·8	4·5	4·2	3·2	3·6	4·8	4·9	6·3	6·6
Sep	5·7	5·7	4·5	3·9	3·8	3·0	5·5	4·7	3·8	3·8	4·3	3·5	6·9	6·7
Oct	4·7	4·5	5·0	4·7	3·7	2·3	4·6	4·0	4·8	4·5	4·3	4·0	7·3	6·6
Nov	3·5	3·3	4·6	3·9	3·5	2·8	3·1	2·9	4·5	4·4	2·8	2·4	5·9	4·2
Dec	3·4	3·2	4·5	3·9	2·5	2·2	2·4	2·2	4·3	4·5	4·6	3·9	4·5	3·0

C=Computed, A=Actual

TABLE 4

Mean daily evaporation at Chinsurah during 1962 as computed by Kohler's method and as observed

	Computed (mm)	Actual (mm)
January	3·3	3·8
February	4·1	4·3
March	7·1	7·9
April	7·9	8·2
May	8·4	8·6
June	4·3	4·7
July	4·6	5·4
August	—	—
September	4·6	4·1
October	3·8	3·7
November	3·8	3·3
December	3·3	2·8

TABLE 5

Mean daily evaporation (in inches) computed by using (*a*) 24-hr means of dry bulb and dew point and (*b*) mean of spot readings of dry bulb and dew point in Kohler's method

	Dum Dum		Poona		Madras		New Delhi	
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*a*)
January	·13	·12	·21	·21	·22	·20	·12	·12
February	·15	·14	·26	·27	·26	·25	·20	·17
March	·26	·24	·33	·34	·28	·26	·32	·30
April	·27	·27	·39	·38	·30	·27	·42	·42
May	·26	·28	·42	·43	·32	·27	·50	·49
June	·23	·22	·38	·35	·39	·36	·49	·49
July	—	—	·18	·17	·28	·27	—	—
August	—	—	·16	·14	·22	·18	·24	·21
September	·20	·17	·21	·22	·28	·25	—	—
October	·17	·16	·22	·24	·16	·13	·27	·24
November	·16	·17	·18	·22	·15	·13	·19	·17
December	·12	·12	·17	·18	—	—	·13	·10

(*a*) Based on 24-hr mean, (*b*) Based on spot readings

TABLE 6

Radiation (in cal/cm² /hr) received on a horizontal surface at the top of the atmosphere

Latitude (°N)	Hours of the day (Local Apparent Time)						
	5-6 and 18-19	6-7 and 17-18	7-8 and 16-17	8-9 and 15-16	9-10 and 14-15	10-11 and 13-14	11-12 and 12-13
			JANUARY				
5	0	11	39	64	85	100	107
10	0	7	35	60	81	95	102
15	0	3	30	55	75	89	96
20	0	0	26	49	69	83	90
25	0	0	21	44	62	76	83
30	0	0	16	39	57	70	77
			FEBRUARY				
5	0	13	42	68	90	105	113
10	0	11	39	65	86	101	111
15	0	8	36	62	83	97	105
20	0	5	33	58	78	92	99
25	0	3	29	53	73	86	94
30	0	1	27	50	69	82	89
			MARCH				
5	0	15	45	71	93	108	116
10	0	14	44	70	91	106	114
15	0	13	42	68	89	104	111
20	0	13	41	66	86	101	108
25	0	12	39	63	83	97	104
30	0	11	37	60	79	92	99

TABLE 6 (*contd*)

Latitude (°N)	Hours of the day (Local Apparent Time)						
	5–6 and 18–19	6–7 and 17–18	7–8 and 16–17	8–9 and 15–16	9–10 and 14–15	10–11 and 13–14	11–12 and 12–13
			APRIL				
5	0	17	45	71	92	107	114
10	0	18	44	72	92	107	115
15	0	19	47	72	92	107	114
20	0	21	48	72	92	105	113
25	0	22	48	71	90	104	112
30	0	23	48	70	88	101	108
			MAY				
5	0	17	44	69	88	102	110
10	0	20	47	71	91	104	112
15	0	23	49	73	92	106	113
20	0	26	51	74	94	106	113
25	3	28	53	75	93	106	112
30	6	31	54	75	93	105	111
			JUNE				
5	0	17	43	67	86	99	106
10	0	21	47	70	89	102	109
15	0	25	50	72	91	103	111
20	3	28	53	75	93	105	112
25	7	31	55	76	93	105	112
30	11	34	57	77	93	105	111
			JULY				
5	0	17	44	69	89	104	111
10	0	21	47	71	90	103	110
15	0	25	50	73	92	105	112
20	3	28	53	75	93	106	113
25	7	31	55	77	94	106	113
30	13	34	57	78	95	106	113
			AUGUST				
5	0	17	44	69	89	104	111
10	0	19	46	71	91	105	112
15	0	21	48	72	91	105	113
20	0	23	49	72	91	105	112
25	0	25	50	72	91	104	111
30	1	26	50	72	89	102	108
			SEPTEMBER				
5	0	15	44	70	92	106	114
10	0	16	44	70	91	105	113
15	0	16	44	69	90	104	112
20	0	16	43	68	88	102	109
25	0	16	42	66	85	99	106
30	0	16	41	64	82	95	102

TABLE 6 *(contd)*

Latitude (°N)	Hours of the day (Local Apparent Time) 5–6 and 18–19	6–7 and 17–18	7–8 and 16–17	8–9 and 15–16	9–10 and 14–15	10–11 and 13–14	11–12 and 12–13
			OCTOBER				
5	0	13	43	69	90	104	113
10	0	12	41	66	87	102	110
15	0	10	28	64	84	99	106
20	0	8	36	60	80	95	102
25	0	6	33	57	76	89	97
30	0	4	30	52	71	84	91
			NOVEMBER				
5	0	11	40	65	86	101	108
10	0	8	36	61	82	96	104
15	0	5	32	57	77	91	98
20	0	1	28	52	71	85	92
25	0	0	23	46	65	79	85
30	0	0	19	41	59	71	78
			DECEMBER				
5	0	10	39	63	83	97	105
10	0	6	33	58	78	92	99
15	0	2	29	53	72	86	93
20	0	0	23	47	66	79	87
25	0	0	18	41	59	72	79
30	0	0	13	34	52	64	71

TABLE 7

Clear sky surface radiation ratios (A) as computed after Ramdas and Yegnanarayanan and (B) as observed

	POONA		DUM DUM		TRIVANDRUM		DELHI		MADRAS	
	A	B	A	B	A	B	A	B	A	B
January	·860	·756	·886	·676	·833	·708	·854	·746	·901	·753
February	·849	·734	·879	·664	·822	·688	·855	·760	·888	·745
March	·877	·742	·859	·655	·847	·704	·866	·772	·865	·727
April	·838	·728	·870	·646	·867	·696	·884	·746	·849	·720
May	·830	·740	·839	·641	·872	—	·849	·747	·846	·726
June	·797	—	·864	—	·871	—	·851	·672	·841	·721
July	·807	—	·857	—	·865	—	·815	—	·832	·698
August	·814	—	·885	—	·871	·711	·846	·701	·854	·732
September	·817	·701	·766	—	·856	—	·860	·684	·862	·742
October	·821	·701	·843	·651	·839	·744	·926	·714	·869	·712
November	·839	·730	·890	·695	·810	—	·881	·753	·916	·753
December	·868	·742	·876	·618	·826	·718	·873	·763	·867	·743

TABLE 8

Percentage deviation of values of radiation estimated by equation (5) from the observed

	Dum Dum				Poona				Madras			New Delhi				Trivan-drum
	1958	59	60	61	58	59	60	61	58	59	60	58	59	60	61	1960
January	–6	7	3	–3	0	–3	–10	–7	–5	–8	–8	–2	–1	–3	–4	–1
February	–1	2	–8	–2	2	0	–5	–3	–2	–5	–6	0	–1	–5	0	–6
March	0	–2	3	–3	0	2	0	–5	–1	–4	–4	–6	–8	–11	–5	–3
April	0	–2	–5	–1	0	–5	0	–5	–5	–8	–4	–2	–2	–1	–2	–3
May	5	–10	3	1	4	1	10	3	–6	–7	–3	–2	–1	–1	–3	0
June	1	5	3	4	5	–7	18	–4	–4	–7	0	2	–6	–2	–7	15
July	–3	–3	–6	–4	15	20	11	6	–1	–5	–2	12	–3	–4	–6	7
August	1	0	4	3	14	3	–9	9	–4	–2	–7	–4	–3	1	–7	6
September	0	–2	–6	3	8	3	–10	5	3	–3	–4	3	–5	–5	1	16
October	–3	–12	–2	–1	7	–2	–8	0	–10	–8	–10	2	–2	–2	–2	10
November	5	–5	–3	2	4	–8	–5	–6	–12	–8	–22	–1	0	–3	–7	5
December	–2	2	–4	2	0	–8	–6	–6	–8	–5	–12	–1	0	–5	–5	4

TABLE 9

Mean percentage deviation of estimated values of radiation as obtained by the use of (a) daily and (b) hourly values of bright hours of sunshine

	Poona		Madras		New Delhi		Trivandrum	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
January	–9	–5	–15	–7	–4	–2	–2	–1
February	–5	–2	–12	–4	–4	–1	–1	–6
March	–6	–1	–5	–3	7	–8	0	–3
April	–4	–2	–6	–6	–2	–2	–3	–3
May	–4	5	–3	–5	3	–2	–10	0
June	1	3	–2	–4	0	–3	–10	15
July	6	13	–1	–3	–6	–4	3	7
August	8	4	0	–4	–7	–4	–1	6
September	5	1	–3	–1	–5	–1	16	16
October	2	–1	–6	–9	–10	–1	15	10
November	–4	–4	–15	–8	–6	–3	5	5
December	–12	–5	–12	–8	–7	–3	0	4