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# A comparative study of observed and estimated values of evaporation in India

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ABSTRACT. The evaporation losses for water yield studies are being estimated by extrapolation from evaporation charts based on Rowher's empirical formulae. Since these charts were prepared using the old meteorological normals, these have been revised using the latest 1960 normals of 216 stations. These values are compared with evaporation charts based on observed pan evaporimeter losses at 80 stations. Monthly and annual charts showing the anomalies between the observed and empirically estimated Rowher's values are presented and the significant features described with an explanation of the anomalies. A comparison of spot values of evaporation by both these methods has also been made and results discussed.

## 1. Introduction

During the post independence period, a large number of multipurpose projects have been undertaken for river valley development. In all these cases whether it is for irrigation or hydro-electric projects, it is essential to estimate accurately the dependable water yield and thence determine the losses due to evaporation. With this information it is possible to prepare the working table for reservoir operations. These estimates are critical specially in the summer months when the reservoir level is the lowest but losses due to evaporation is highest over parts of India like Rajasthan and Bihar. At present monthly and annual evaporation charts based on the Rowher's formula as modified by Raman and Satakopan (1948)* have been in use for the purpose of estimating evaporation losses from the reservoirs. The annual values together with their monthly break up are determined by interpolation from the charts on which the isopleths have been drawn. These charts were based on evaporation calculated from climatological normals of observatories upto 1940. Reduction coefficients for reducing evaporation losses from large reservoirs were applied to the values read from these charts. During the last four or five years the evaporation charts (Venkataraman and Krishnamurthy 1965) based on the Kohler's technique were also being referred to and a comparison of the evaporation values obtained by the Rowher's and the Kohler's charts were made before actually determining the evaporation losses. Recently observed values of evaporation were also available from a few isolated observations with pan evaporimeter set up either by the India Meteorological Department or the various projects authorities. All the three sets of evaporation values from Rowher's and Kohler's charts and observed data wherever it was available were compared. In some cases there were large divergences of the values by the different methods and hence mean figures for annual evaporation with appropriate monthly break up were decided upon by judgement of the general climatological conditions and at times comparison of the values accepted for projects undertaken earlier in the neighbourhood of the region in question.

## 2. Need for comparison and revision of the charts

With more and more observed pan evaporimeter data available during the recent years the India Meteorological Department has published evaporation charts (K. N. Rao *et al.* 1971) based on the observed values of evaporation over about 80 stations with the data calculated for a period of five to ten years (India met. Dep. 1970). A comparison of the values obtained from the observed evaporation charts based on the Rowher's and Kohler's techniques showed abnormal deviation of the observed values which was found to be higher than the values derived from the empirical estimates. In the case of one or two projects the situation was anomalous since the evaporation losses accepted earlier for projects in the neighbourhood were significantly lower than the observed data. A detailed examination and comparison of the values became necessary so that errors, if any, could be eliminated and large deviation could be explained.

As already mentioned the evaporation charts based on Rowher's formula were prepared using

*$E=0\cdot 7\,(1\cdot 465-0\cdot 0186\,B)\,(0\cdot 44+0\cdot 118\,W)(100/H-1)e$ where, $E$=Evaporation, $B$=Atmospheric pressure, $W$=Wind speed, $h$=Humidity, $e$=Vapour pressure

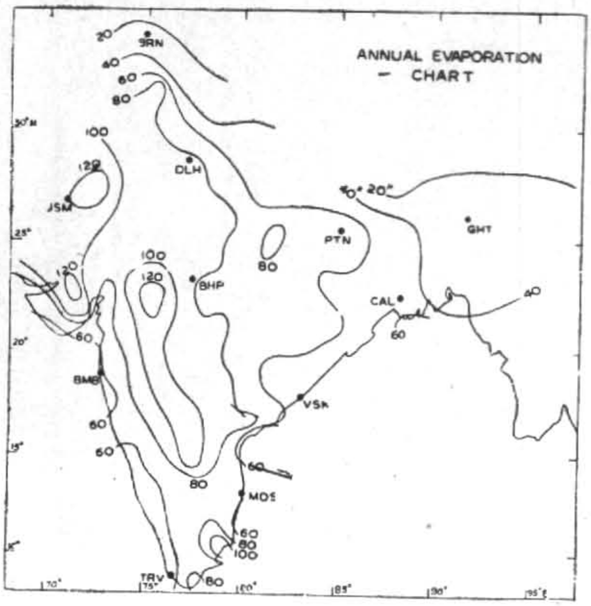


Fig. 1

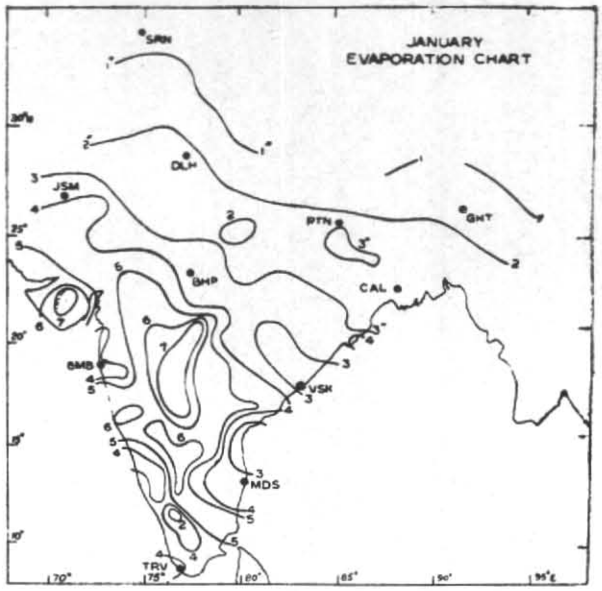


Fig. 2

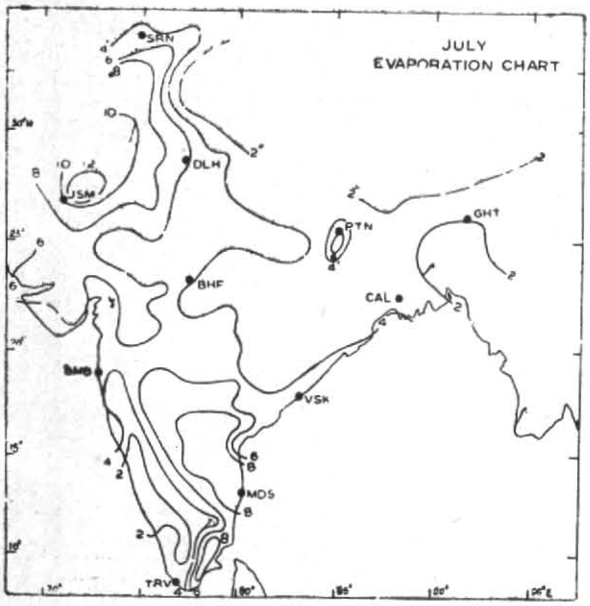


Fig. 3

the old normals of meteorological elements based on data upto 1940. These climatological normals have been revised using recent data upto 1960 and also with the additional data from the observatories set up during the recent period (India met. Dep. 1967). Hence, the first step was to revise the evaporation charts using the new normals. To facilitate computation a suitable Fortan programme was prepared for estimating monthly evaporation values based on the Rowher's formula as adopted by Raman and Satakopan for all 216 observatory stations in India. A fresh set of revised charts of monthly and annual evaporation was prepared. In the following section an attempt has been made to compare the evaporation values obtained from these charts with that of the observed values from pan evaporimeter, both by the grid values obtained from the charts and representative spot values measured at few stations.

Figs. 1 to 3 are the annual and monthly charts of January and July showing the isopleths of evaporation losses determined by the Rowher's formula using the revised 1960 meteorological normals of all available stations. At the outset it may be mentioned that although the general pattern of isopleths agree with that of the earlies set of charts, there are a few changes in the centres of maximum and minimum losses both in their location and the absolute values. Some significant features of these revised charts with the evaporation charts based on observations are given below.

### 3. Annual charts

High evaporation loss of more than 80 inches (200 cm) exists over the arid regions of western India and central Peninsula forming an extensive belt north to south upto the Rayalaseema district of Andhra Pradesh. The centres of high are located over west Rajasthan, north Gujarat and Madhya Pradesh around Jalgaon and Indore. The extreme value of 125 inches is over Phalodi (Rajasthan) and Indore (Madhya Pradesh). Almost equally high values are indicated at Trichinapaly in the south-east Peninsula and Rajkot in Gujarat, *viz.*, 122·6 and 124·9 inches respectively. Assam and the sub-mountain Himalayan region record the lowest values in the range of 20 to 60 inches. Evaporation losses of the order of 40 inches are also seen along the west coast of the Peninsular India.

#### 4. Monthly features

By and large the monthly charts, also show similar trends of spatial distribution of losses due to evaporation. The monthly charts of January and February show the maximum evaporation loss occurring over interior Gujarat and the central parts of southern Peninsula with the values decreasing towards the coastal regions in the east and west and also the sub-mountain Himalayan belt in the north. The rate of evaporation show an increasing tendency in March and the trend continues to persist in the succeeding months of April and also in May when the highest monthly loss of 22 inches is recorded over the arid regions of Rajasthan and Maharashtra. The decrease of evaporation over the coast is not of the same magnitude as in the interior. Hence there is a steep gradient towards the east and west coasts and the north towards the hills.

With the onset of the monsoon in June, there is a marked fall in the evaporation loss over the coastal region but not so in the interior parts. The centre of maximum values persists in Rajasthan while the high over Marathwada is less pronounced. A new centre of high evaporation appears over interior Mysore, Andhra Pradesh and adjoining Tamil Nadu. When the monsoon is well established in July, there is a sharp fall in the evaporation losses in Rajasthan. The area of high evaporation in the south is well marked over extreme south Tamil Nadu and it coincides with the rain-shadow area of the southwest monsoon winds. The remaining months of August and September during monsoon show similar features. The lowest evaporation is recorded along the west coast and Assam where the rainfall is heavy. In the extreme north, Leh and Srinagar record the highest evaporation during the monsoon season.

With the retreating monsoon in October and November changes are significant. The evaporation losses decrease further. The transition to the winter pattern is marked with scattered centres of high and low evaporation and weak gradient. The chart for December is similar to that for January and February.

It may be mentioned that in all these charts, the evaporation estimates for high level stations have also been made and the isopleths have been drawn to fit in with neighbouring values. This has been done to facilitate extrapolation of evaporation losses in the hilly catchments where generally a large number of the hydel irrigation projects are undertaken.

#### 5. Comparison with the observed evaporation values

The charts showing the estimated evaporation losses have been compared with the charts based on the observed values prepared by the India Meteorological Department. For this purpose 51 grid points for every $2\frac{1}{2}$-degree square over the whole country were marked and the evaporation figures interpolated from the two sets of charts. The observed values were based on pan evaporation with mesh covered instruments.

Hence these were converted to open pan losses by multiplying with the factor 1·144. To obtain the lake evaporation these were again multiplied by the reduction factor 0·7. The algebraic difference between the observed pan evaporimeter losses and estimated values for every one of grid points is again plotted and isopleths drawn. Thus a set of anomaly charts of monthly and annual evaporation were obtained. Figs. 4-7 show the charts for all the months along with the annual chart.

Some of the significant and interesting features of these anomaly charts are described below.

#### 6. Annual chart

The anomalies in the annual values vary generally within the range of $\pm$ 10 inches. There are a few extremely high departures of the order of $\pm$ 20 inches. In Jammu & Kashmir and Assam where the evaporation losses are comparatively low, the observed values are higher than the empirical estimates. Over west Rajasthan and neighbourhood, the area recording maximum evaporation in the country, the observed values are lower than the estimated loss. By and large the coastal belt shows positive anomalies with a reversal of the sign in the interior regions.

#### 7. Monthy features

*January* — A detailed examination of the monthly anomaly charts also broadly show similar significant characteristics. In January the anomalies are the lowest and lie within the range of

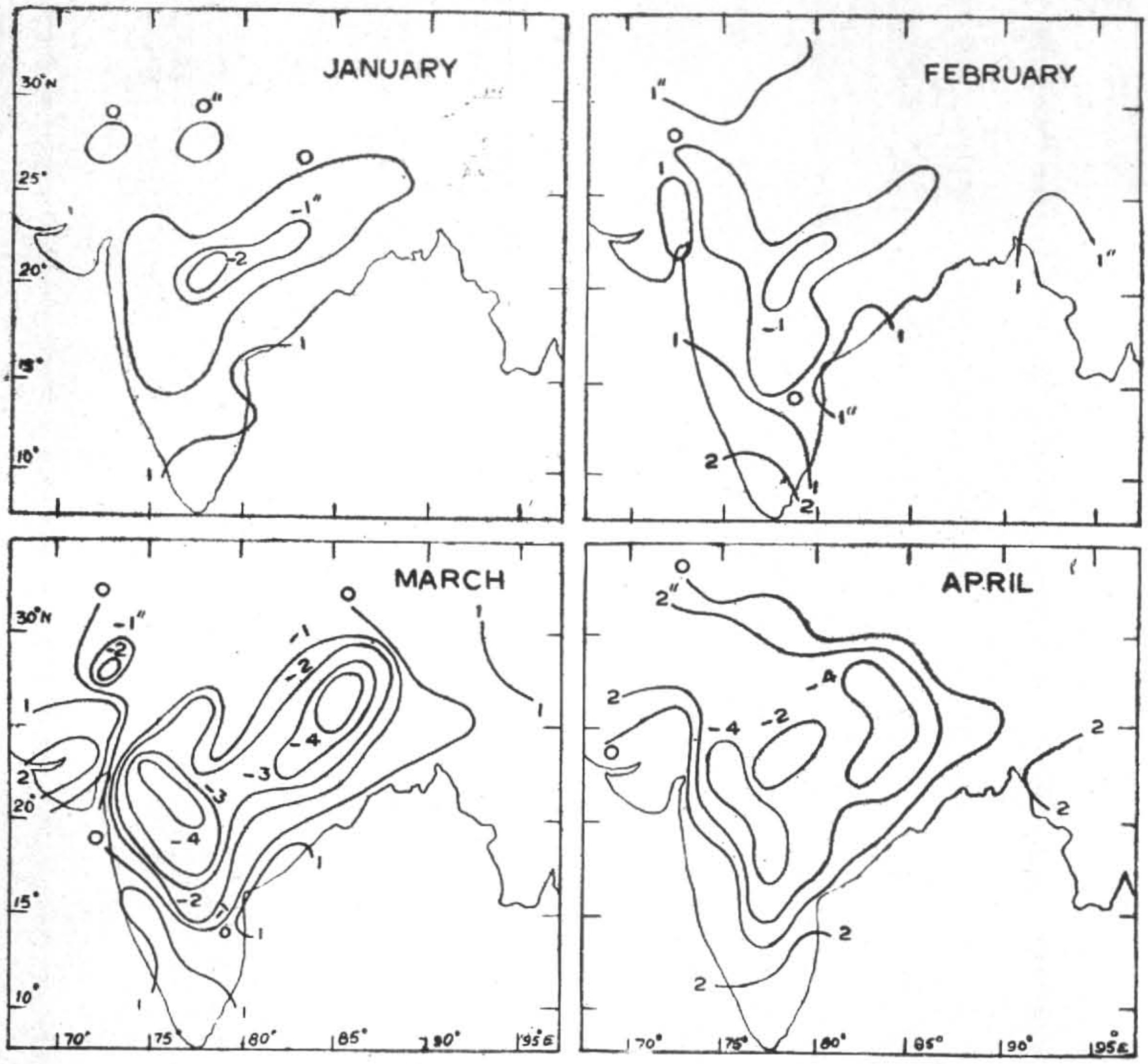


Fig. 4

Anomaly chart of evaporations (in inches)

±0·5 inch. The highest negative anomaly is observed in the central Peninsula decreasing towards the coast and becoming positive in the extreme northeast and towards south of the country. The computed evaporation loss over Rajasthan agrees well with the observed data in this month.

*February* — In February, the same tendency can be noticed. With the increasing temperatures, the anomalies also increase without any change of sign. The estimated evaporation continues to be higher in the central India and central Peninsula and lower along the coast and north of the country where cloudiness is present and rainfall occurs due to the passage of western disturbances.

*March* — With further rise of temperature in March, the anomalies increase. There are two centres of high negative values of 4 inches, one over Madhya Maharashtra and the second over Bihar. The observed values are lower than the computed figures by as much as 3 to 4 inches in these areas. Along the coastal region and extreme north, the anomalies are positive and not high.

*April* — Similar pattern persists during April with further increase in the anomalies. Over Bihar the negative values are marked. At one of the grid point $27\frac{1}{2}$°N and 82°E, the computed value is of the order of 11·00 inches is nearly double the observed evaporation loss of 5·67 inches. It is interesting to note that over the central parts of Indo-Gangetic

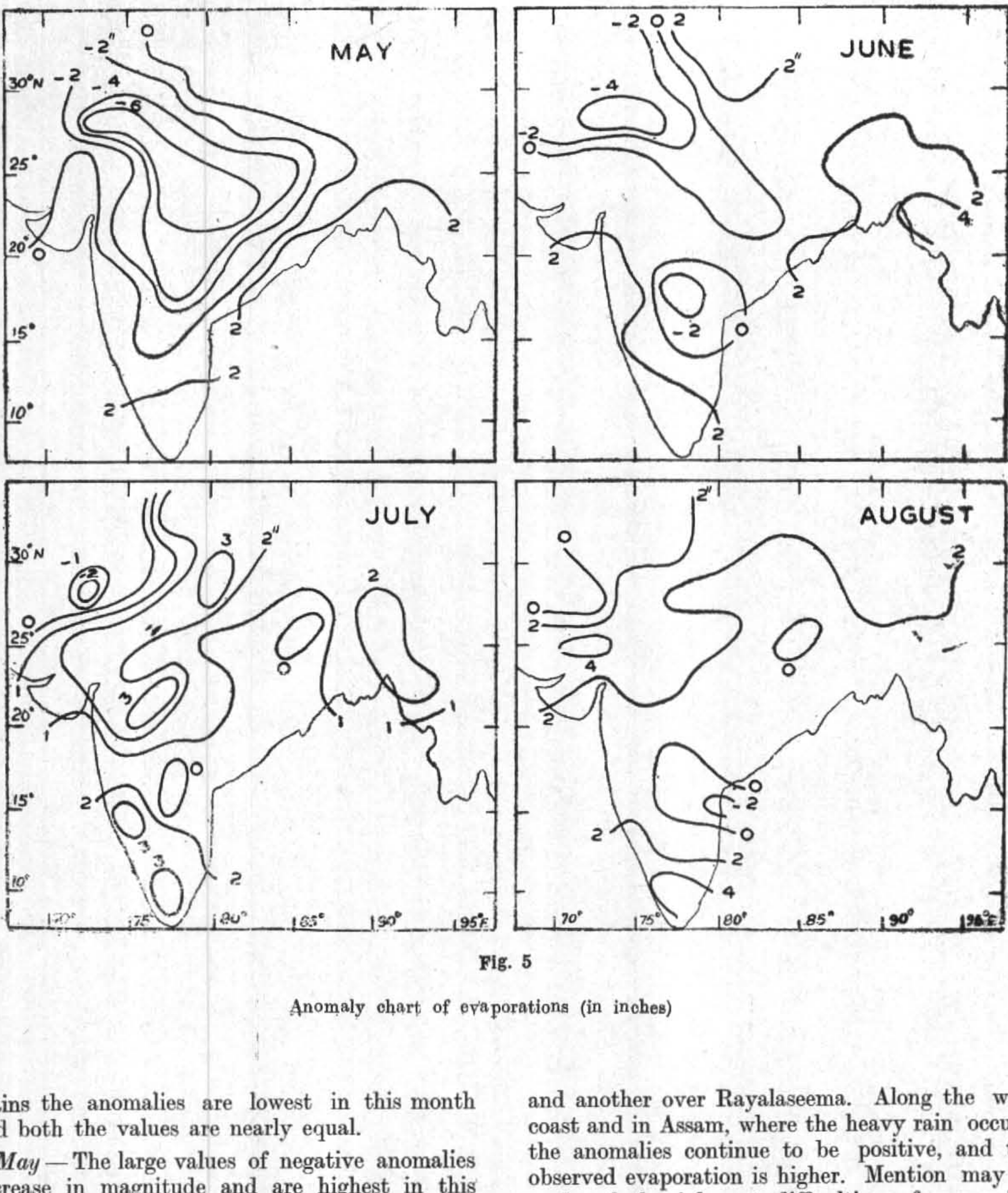


Fig. 5

Anomaly chart of evaporations (in inches)

plains the anomalies are lowest in this month and both the values are nearly equal.

*May* — The large values of negative anomalies increase in magnitude and are highest in this month. They cover extended areas over the whole of interior. The computed values are higher than the observed data by about 4 to 6 inches over Rajasthan, U.P., M.P. and Bihar. The positive anomalies over Assam and extreme south Peninsula are generally of the order of 2 inches.

*June* — With the advance of monsoon and heavy rains over most parts in this month, the earlier trend is reversed. The differences between the two sets of values are decreased. The two centres of high negative anomalies are confined to Rajasthan and another over Rayalaseema. Along the west coast and in Assam, where the heavy rain occurs, the anomalies continue to be positive, and the observed evaporation is higher. Mention may be made of the inherent difficulties of measuring evaporation on rainy days with evaporimeter.

*July* — The anomalies continue to decrease in this month. The area of negative anomalies are replaced by positive values. Northwest Rajasthan and Bihar form the centres of comparatively high negative anomalies. There are a large number of centres of positive anomalies and these coincide with the heavy rainfall zones of west coast, Assam and sub-mountain hills of U.P. and the Punjab.

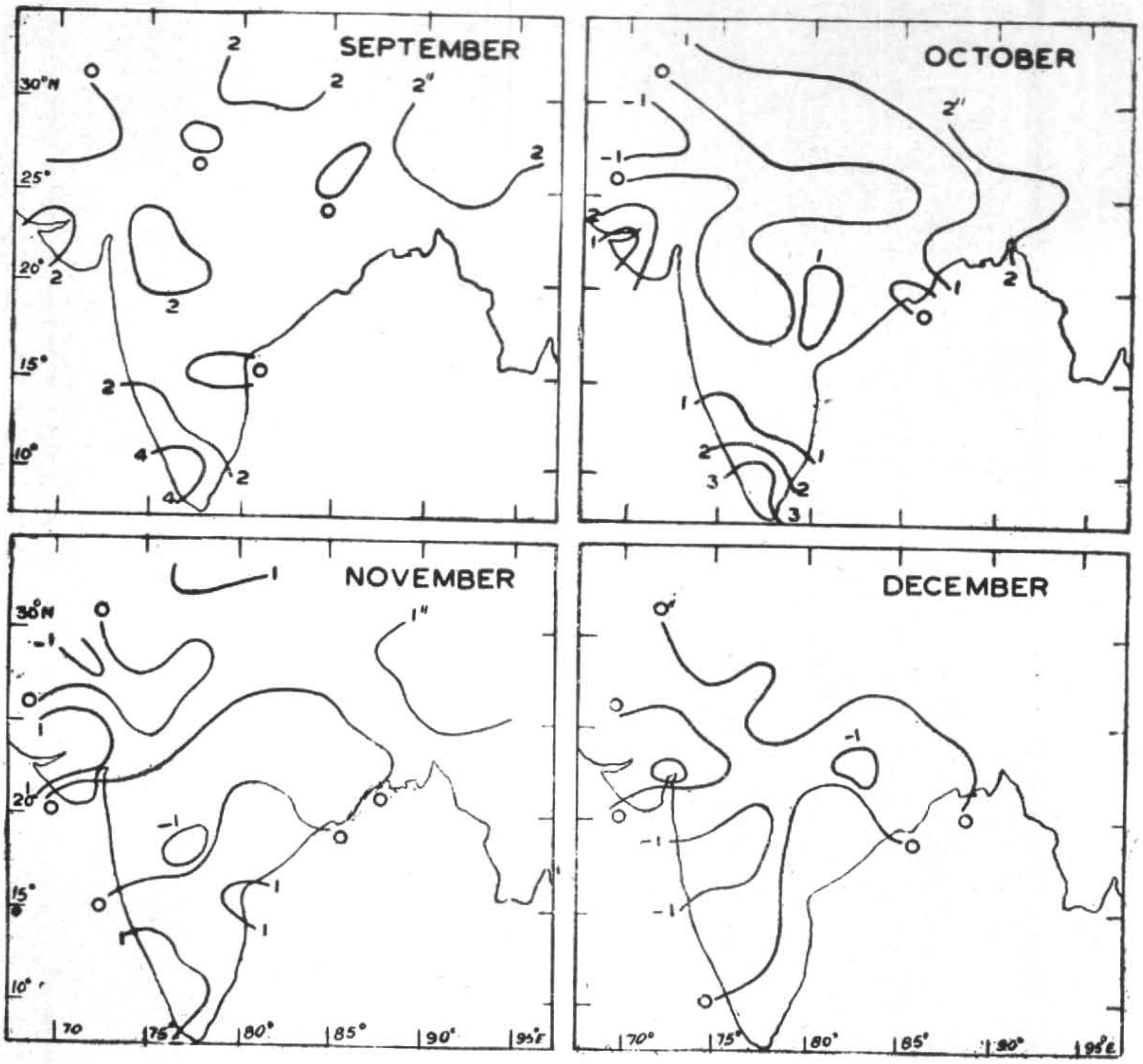


Fig. 6

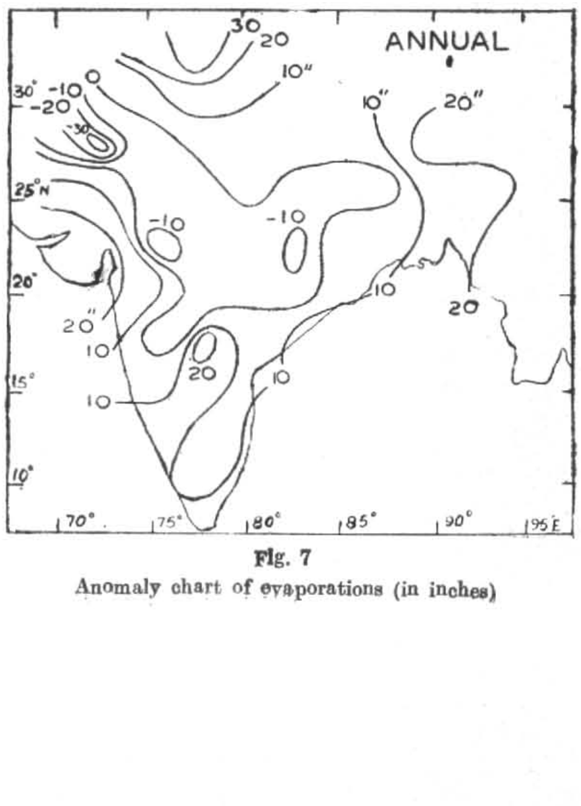


Fig. 7

Anomaly chart of evaporations (in inches)

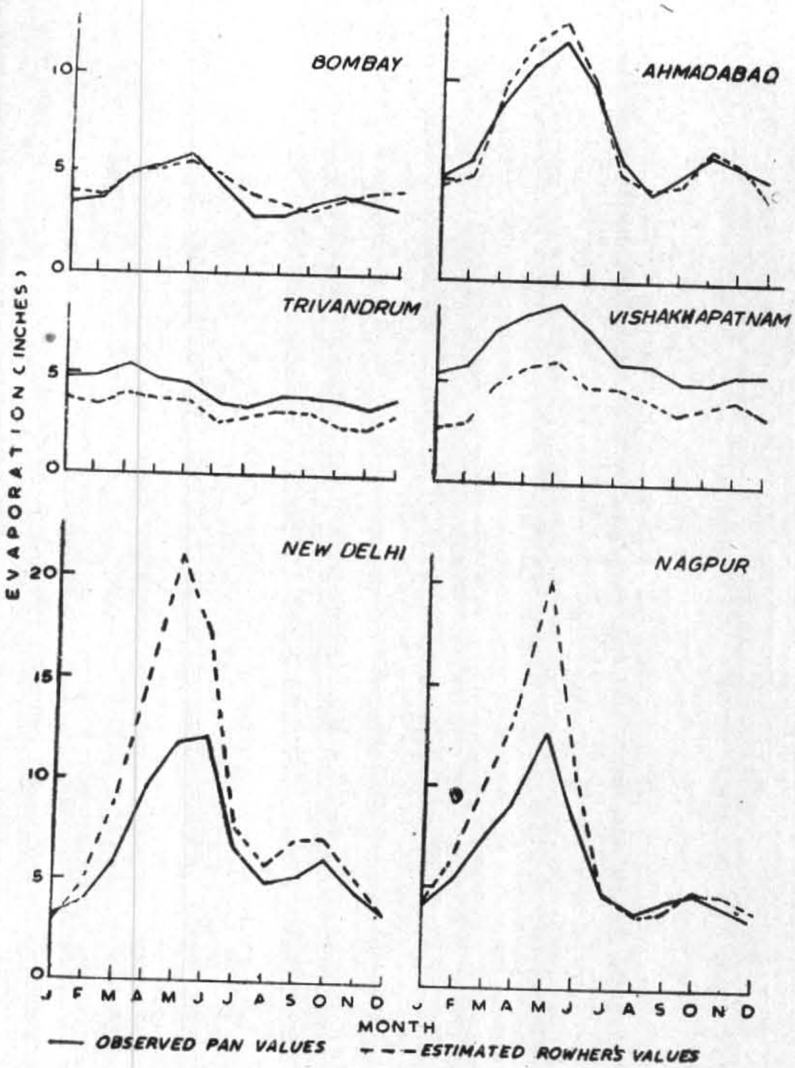


**Fig. 8**

Comparison of observed and estimated spot values

*August* — Similar features as exhibited in July can be seen in August. Over south coastal Andhra Pradesh and adjoining interior parts where the rainfall is scanty during the southwest monsoon, there is one more centre of negative anomalies. The anomalies are positive over the whole of the country and the observed values are higher than the estimates.

*September* — The anomalies distribution more or less shows the same pattern as in earlier month.

*October* — The withdrawal of monsoon and consequent decrease in rainfall over north and central parts of the country change the distribution pattern of the anomalies. The large negative anomalies with the central region over northwest Rajasthan extends to Bihar in the east and Rayalaseema in the south. In Assam and extreme south Peninsula where cloudiness persists the positive anomalies of the order of 2 inches are still recorded.

*November* — The anomalies and their areal distribution follows the same pattern as in October. The differences are reduced and the percentage of observed losses is also less.

*December* — During the month, the winter type as in the case of January and February can be again seen. The anomalies decrease further. They are negative over large areas along the west coast and central parts. The positive anomalies are confined to Jammu & Kashmir in the extreme north and Assam in the east.

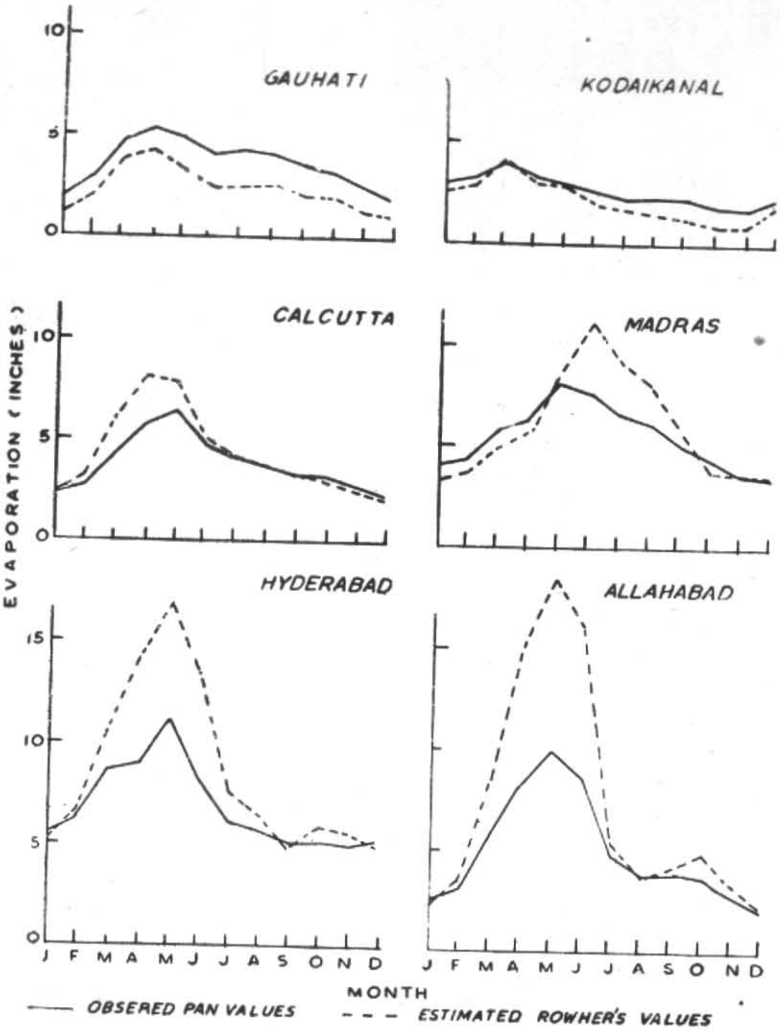


Fig. 9

Comparison of observed and estimated spot values

**8. Spot values comparison**

The charts are useful for finding the anomaly for any area under study. However since the grid values have been extrapolated from the isopleth charts without considering any contour effect a more precise comparison has been made by studying the variation of the spot values by the two methods.

Twelve stations distributed over the whole country were selected. The monthly variation of both the observed and estimated values at each stations is shown in Figs. 8 and 9.

As in the case of the monthly charts stations along the coastal belt, *viz.*, Bombay and Ahmadabad show very small anomalies. Even when the anomalies exist as in the case of Trivandrum and Visakhapatnam, the observed values are slightly higher than the estimated losses throughout the year. The interior stations like New Delhi, Nagpur, Hyderabad and Allahabad indicate lower observed values. The anomalies are high and more marked in the hot weather period when the temperatures are high. The anomalies are minimum during the monsoon season. At stations like Gauhati and Kodaikanal where the temperatures are moderate, and rainy or cloudy days are distributed throughout the year, the anomalies are not appreciable. It is interesting to observe the variation of the values at Madras. Like any coastal station during the major portion of the year positive anomalies exist and the observed values are high. The reversal takes place

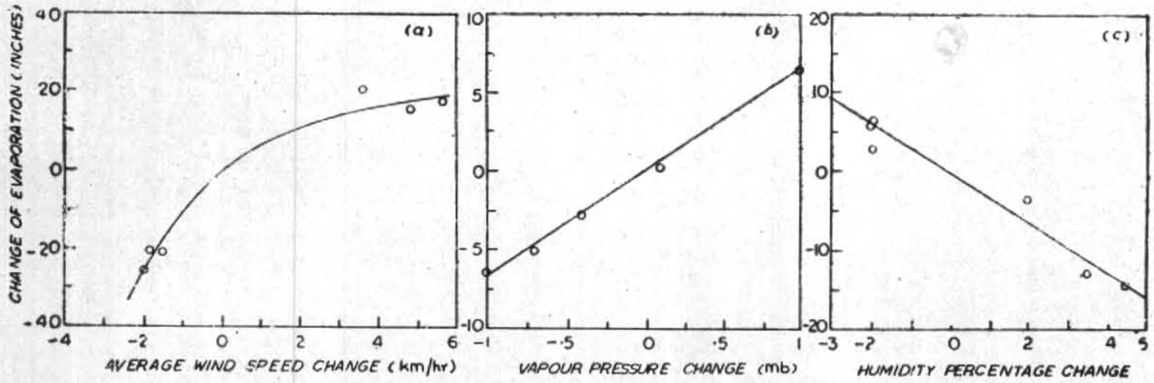


**Fig. 10**

during May, June, July and August when this area is not affected by southwest monsoon rains and high temperatures prevail.

### 9. Differences of evaporation estimates due to change in the meteorological normals

As already stated, the estimated values of evaporation were revised by making use of the latest normals of meteorological elements. In order to examine how the differences in the values of each normal affects the evaporation estimates, the change in the evaporation with corresponding changes in the value of wind speed, vapour pressure and humidity keeping constant the other factors of the Rowher's formula were computed. Results are shown in Fig. 10 (a, b and c). Slight changes in the wind speed affect significantly the estimate of evaporation values. Changes in vapour pressure and humidity normals also affect the estimates, but this is relatively higher in the case of change in humidity normals.

### 10. Some general remarks

One of the significant features of these monthly anomaly charts is the reversal of the sign of the anomalies or reduction in the magnitude of negative anomalies during the monsoon months. The observed values during this season are subject to inaccuracies on account of inherent difficulties in measuring evaporation on rainy days. The differences between the observed and estimated values are the least in this period. The empirically derived estimates are slightly lower than the observed pan evaporation losses.

During the non-monsoon months the estimated values are always higher over inland, the higher the temperatures, the larger are the anomalies. This is not so along the coastal belt, Jammu & Kashmir and Assam where positive anomalies prevail practically during the whole of the year. Apparently over the rainfall areas associated with moderate temperatures, the Rowher's values are fairly satisfactory. It will be an over-estimate over the interior of the country where generally high temperatures prevail. The reduced pan evaporimeter values are less than the Rowher's values.

On examining the charts, it can be seen that the highest negative anomaly is invariably associated with highest computed value of evaporation in all months. There is no such relationship in the case of the observed values of the positive anomalies.

In order to explain these features the following facts may be considered.

1. For the derivation of evaporation losses, the water temperature is assumed to be nearly the same as air temperature. This assumption may be valid in the rainy period and also over area with moderate temperatures. During the hot weather period, with higher air temperatures, the deviation of water temperature will be large and empirically computed evaporation losses will be an over estimate.

2. Owing to the differential expansion of water and metal, the drop in the level of water in the pan evaporimeter will be affected by variation of temperature (Krishnamurthy 1964). Suitable correction has to be applied to the readings for the errors due to—

(*a*) The cubical expansion of water and the container with higher temperature and

(*b*) Linear expansion of the still well and hook gauge is to reduce the pan evaporation losses at higher temperatures.

3. The pan evaporimeter observations have been reduced to lake evaporation by using a single value of coefficient for all the months. This

is subject to fluctuation especially when short monthly periods are considered. In the case of class A land pan, the coefficient ranges from 0·60 in winter to 0·82 in summer. Consequently during the hot weather period, the large negative anomalies are due to both an over-estimate of the Rowher's value and are under-estimate of the observed losses.

In addition to the seasonal variation of the pan coefficient values, the spatial variation is also likely to be pronounced over regions of high temperatures and large diurnal variation on account of the differential heating of the water in the pan and the lake and consequent water temperature differences over the two surfaces. It will be thus clear that investigations have to be made to determine the pan coefficients for reduction of pan evaporimeter observation to lake evaporation losses before making use of the observed data for accurate assessment of evaporation losses.

**11. Conclusion**

From these results it may be concluded that generally the estimated evaporation losses based on Rowher's formula can tentatively represent the evaporation from large surfaces even when observed pan evaporimeter data is not available. It will be an over-estimate in interior areas where high temperatures are recorded and rainfall is scanty in the hot weather period. The anomalies are not marked in the monsoon and winter seasons.

If the reservoir under consideration is located close to the sea coast or in the heavy rainfall belt of Assam or Sub-Himalayan regions, then the empirical values are nearly the same as the measured pan data and reduced to lake evaporation. In a few cases, they may be under-estimate. This might not lead to any large scale errors in the assessment of water yields since the losses due to evaporation are comparatively of a lower order.

As stated above the pan evaporimeter data is subject to a certain amount of error due to the difficulties in measurement with the pan and also due to subsequent reduction to losses for large surface using *ad hoc* pan coefficient. It is necessary to undertake extensive experiments to compare the evaporation losses with standard pan evaporimeter over land and water surface as well as with floating pans and determine the range of variation of pan reduction coefficients for various seasons and meteorological regions. During the preliminary stage of investigations of a project, a provisional estimate of the reservoir evaporation losses can be obtained with the charts based on Rowher's formula. In case observed data is also available, it may be necessary to obtain a mean value of the figures determined from both the empirical and measured data especially if the catchment area is situated in the interior of the country during the summer months when maximum day temperatures are experienced.

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