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ESTIMATION OF EVAPORATION FROM FREE WATER SURFACES

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ABSTRACT

Methods of estimating evaporation from free water surfaces are discussed. The status of Pan and lake evaporation studies carried out in India is reviewed and the procedure for the estimation of free water surface evaporation from Pan evaporation is described. Estimates of free water surface evaporation obtained from Pan evaporation data observed at 104 US Class A Pan evaporimeters in India is presented in the form of maps and discussed. The sources of data, analyses and limitations of the approach are described.

1.0 INTRODUCTION

The process by which water is lost in the form of vapour to the atmosphere from large open free water surfaces like lakes and reservoirs is known as evaporation. The efficient management of our water resources largely depends on the ability to estimate evaporation from lakes and reservoirs. The estimation of evaporation from reservoirs is of vital importance in the assessment of reservoir losses through evaporation for reservoir regulation. It is, therefore, essential to devise ways and means for the estimation of evaporation from lakes and reservoirs.

Although energy budget together with advection accounts for a major portion of evaporation from large free water surfaces, there is no single procedure which could be used to provide reliable estimates of evaporation from meteorological data. Morton(1979) highlighted the wide gap between the kind of information that is needed for reliable estimates of lake evaporation and the kind of information that is available for estimating the lake evaporation. The gap is bridged by using the results of detailed research to develop coefficients which can be applied to pan evaporation data from climatological observatories.

2.0 METHODS OF ESTIMATION OF EVAPORATION

The direct measurement of evaporation from large water bodies is not feasible under field conditions like one is able to measure temperature, humidity, wind speed etc. The techniques developed for estimating the loss of water from water surfaces are based on a rational understanding of the effects of all the factors affecting the evaporation process such as

(i) solar and sky radiation

(ii) temperature of both air and the evaporating surface

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(iii) wind speed
(iv) the difference between the maximum vapour pressure of the air at the evaporating surface temperature and the actual vapour pressure of the air
(v) atmospheric pressure
(vi) depth, size and state of the evaporating surface
(vii) state of the surroundingsand the configuration of the water body
(viii) impurities and vegetation in the water body

There are several well recognised methods for the estimation of evaporation from free water bodies. These include

(a) water budget or storage equation
(b) energy budget or insolation method
(c) mass transfer method or humidity and wind velocity gradients method
(d) combination of energy balance and mass transfer equations (The combination or Penman's equation)
(e) measurements in an auxiliary pan and reduction of the pan evaporation to natural free water surface evaporation.

These methods are described in great detail in the WMO Technical Note 83 (1966). The water budget method was used in the lake Hefner studies to compare the evaporation estimates with those obtained from the energy budget and the mass transfer methods (USGS,1954).

The mass transfer method was widely used in the evaporation studies of lake Hefner, lake Meade and the Great Lakes due to its proven ability and the availability of necessary data coupled with the ease of application. In the lake Hefner and lake Mead studies it was found that a simple form of Dalton equation has produced reliable results (USGS,1954).

$$E = 0.0024 (e_s - e_{ae}) V \quad . . . . \quad (1)$$

where E = evaporation in inches/day

e_s = saturated vapour pressure in inches of mercury at surface water temperature (obtained from surveys)

e_{ae} = vapour pressure in inches of mercury (obtained from climatological data)

v = wind speed in miles/day (obtained from climatological data)

The above equation, however, could not be used for big lakes with large area because of the non-representativeness of the land based climatological data to the weather over the large water bodies. One method of estimating the lake influence has been to obtain an empirical relationship between the parameters over water compared to the parameters over the land. This has the effect of combining into a single factor the various influences which causes the differences between conditions over land and water.

Kohler et al (1955) made further improvements over Lake Hefner studies by considering the effects of advected energy into the lake and heat transfer through the pan. Based on the classical Penman's equation the authors had developed what they called a 'universally applicable' relation for computing pan evaporation from meteorological data.

Morton (1979) presented a model for estimating lake evaporation from routine meteorological data. The model originally conceived in 1975 incorporated concepts of Penman (1948) and used some calibration constants derived by Morton himself. Morton verified his model by comparing the computed evapotranspiration estimates in 118 river basins in USA to water budget estimates for these basins. Anderson and Jobson (1982) used Morton's model for estimating monthly and annual lake evaporation values for 30 lakes in the United States by using monthly observations of temperature, humidity and sunshine. These estimates were compared with the reported values of evaporation determined from measurements on each lake.

3.0 APPLICATION OF PAN COEFFICIENT

The application of a lake to pan coefficient to observed pan evaporation is the most commonly used method for estimating lake evaporation.

3.1 Pan-evaporimeter

There are various types of evaporimeters. The evaporimeters generally used are the USA Class A pan, GGI 3000 and 20 m^2 Russian tank. Comparative studies of evaporation measured by these pans were carried out and the results were reported in the final report of Commission of Instruments and Methods of Observation (CIMO) of WMO

3.2 Pan - Lake Relationship

The relationship between evaporation from a given evaporimeter and from a given natural surface depends on the following three factors :

(i) physical characteristics of the bodies,
(ii) relevant meteorological conditions and
(iii) interaction between the evaporating surface and its micro-climate.

Theoretically it is possible to deduce the pan - lake evaporation relationship. For this purpose, the evaporation from open pan water surface of as large an area as possible was used as the standard for comparing. The WMO commission CIMO considered the combination equation of energy balance and mass transfer as given by Penman to be a simple method to estimate evaporation from large and shallow hypothetical open water bodiesexposed to the same set of climatic conditions as that for which the computations are made for climatological purposes.

While attempting the estimation of lake evaporation from pan evaporimeter data, of special interest would be the application of Pan data corrected for vapour pressure gradients over the pan and the lake:

Webb (1966) gave the formula:

$$E = 1.50 \frac{e_l - e_4}{e_p - e_4} E_p \quad \ldots \quad (2)$$

where, e_l and e_p are the maximum vapour pressures at the temperature of the lake and pan water (based on maximum temperature) respectively, e_4 is the vapour pressure at a height of four metres at 1500 hrs, E_p is the class A pan evaporation. The constant 1.50 was derived for lake Hefner and is dependant on lake size.

Another method for computing the lake evaporation based on pan data has been proposed by Konstantinov (1968). Evaporation from different lakes can be computed from:

$$E = k\ (s,\ h)\ .\ E_{20} \quad \ldots \quad (3)$$

where, K (s, h) is the coefficient taking into consideration the influence on evaporation of the area and depth of the lake. The value of the coefficient is computed using the water temperature, water vapour pressure in the air and wind speed above the lake and 20 m^2 tanks installed at different climatic zones in USSR.

3.3 Lake-Pan Coefficients

Reliable estimates of annual lake evaporation can be obtained by application of the appropriate lake-to-pan coefficient to observed annual pan evaporation. This is based on the assumption that on an annual basis the lake evaporation bears some relation to the pan evaporation.

The pan coefficient is given by the ratio E_L/E_p, where, E_p is the evaporation from the pan or tank evaporimeter and E_L is the lake evaporation. The W.M.O. Tech. Note No 126 has reviewed the studies on Pan-lake evaporation comparisons.

3.4 Variation of Lake-Pan Coefficients

The Lake-pan coefficients show considerable variation both in time and in space. They are different for various sizes and types of Pans and lakes. They vary from one location to another and for a specific location they also vary during the year (W.M.O. Tech. Note 126).

3.4.1 Spatial variation

The spatial variation in lake-to-pan coefficient is related to climate. In order to account for the variation of the lake-pan relationship under different climatic regimes, the observed pan evaporation is adjusted for heat gain or loss through the bottom of the pan. It is assumed that for the condition when the pan water temperature and ambient air temperature is on the average equal, the pan coefficient is 0.70. In warm, arid areas the class A pan water temperature is on the average less than the air temperature and, when compared with evaporation from lakes or large tanks, the coefficient would approach 0.60. In humid areas, the average pan water temperature exceeds air temperature and the coefficient would tend to be nearly 0.80.

Based on evaporation estimated with mateorological data observed at 225 basic weather stations in United States, Farnsworth et al (1982) presented a pan coefficient map for the season May-October. Average lake-to-pan coefficients in eastern United States varied from 0.72 to 0.78. In the west it varied from 0.68 to 0.86. Over Texas and neighbouring States it varies from 0.68 to 0.72.

In New Zealand open water evaporation was estimated by applying a reduction factor of 0.7 to class A pan evaporimeter. The evaporation from 20 m^2 Russian tank to the evaporation from class A pan is related by 0.70. It was observed that the readings obtained from sunken pans are more close to lake evaporation than those obtained by pans mounted above ground.

3.4.2 Seasonal variation

The seasonal variation in Pan coefficients is due to the phase differences between pans and lakes in the storage of heat due to solar radiation. The other factor is the difference in the behaviour of pan and lakes to advective heat transfer due to their different areal extent and exposure to wind.

W.M.O. Tech. Note No. 126 has presented a table of monthly values of lake-to-pan coefficients for a number of lakes in the United States and suggested against the usage of a constant lake-pan monthly coefficient in view of the large variation from month to month and year to year for the same month. The monthly variation was from 0.13 to 1.32 in case of lake Hefner and 0.48 to 2.53 in case of Lake Encmbene. The variation was less marked in case of other lakes.

4.0 EVAPORATION STUDIES IN INDIA

4.1 Evaporimeter Data

In India, the modified U.S. Weather Bureau class A pan covered with a galvanised iron wire mesh (22 s.w.g., hexagonal mesh 1.5 in between opposite sides) is used.

India Meteorological Department which is the authority for collecting, compiling and publishing meteorological data in India has installed a network of over 200 evaporimeters. Though it is known that evaporimeters are being maintained by some project agencies and research stations of State Irrigation Departments, adequate information on the number and location of such evaporimeters **is not** available.

4.2 Evaporation Maps

Rao et al (1971) have published maps of Pan evaporation in India based on the data of evaporation for 72 observatories and agrometeorological observatories in India.

Sarma (1973) has used the modified Rowher's formula to prepare the maps of evaporation based on the 1960 climatological normals and compared the estimated values with observed pan evaporation data.

4.3 Comparison of Evaporation from Pans and Lake Evaporation

The experiments at Poona have shown that the evaporation measured from the mesh covered Class A pan has to be adjusted by a factor of 1.144 to obtain the evaporation from a similar pan without any cover.

Comparisons at Poona have shown that the ratio of values from a 20 ft. diameter 10 in deep pan to a class A pan is 0.78.

I.S.I. standard (IS:6939-1973) recommended that the coefficient for conversion of class A pan (modified) being used in India was found to vary between 1.10 to 0.90 for lake evaporation of the order of 4 to 5 mm/day, between 0.75 and 0.65 for lake evaporation of the order of 10 mm and about 0.8 for transition months. The foot note mentioned that these coefficients were based on the paper by Gangopadhya et al.

River Research Institute, West Bengal found a ratio varying from 0.70 to 1.08 for the Class A pan while the Irrigation Research Institute, Poondi (Madras) noted a coefficient between 0.7 and 0.9 for the same pan.

No studies on the monthly variation of the lake to Pan coefficient are available for India.

5.0 PRESENT STUDY

In the present study an attempt has been made to estimate the free water surface evaporation on a monthly basis using monthly pan evaporation data observed at a number of evaporimeter stations in India.

5.1 Data

Pan evaporation data of 104 evaporimeters in India are collected for varying lengths of record ranging from 2 to 19 years during the period 1959 to 1977. Though it is meaningless to consider averages for less than 5 years of data, the data from evaporimeters of less than 5 years of record are used only to supplement the data for those which have longer record. This became necessary in view of the limited network of evaporimeters compared to the vast extent of the country.

5.2 Method of Estimation

As all evaporimeter data in India are mesh covered class A pan data, the observed pan data are adjusted by the factor 1.144 to obtain the evaporation from open pan.

As no information on the monthly coefficients are available in India, the monthly coefficients are decided using the analogy of spatial variation from arid and humid regions to the conditions that prevail in India during winter and summer months. During the transition months, the ambient temperature and the pan temperature are considered to be same. Also, as it is generally observed that a factor of 0.7 is accepted the world over as the coefficient on annual basis, the monthly variation has to be plus or minus the value of the annual coefficient. These considerations have led to the selection of monthly coefficients as 0.6 in cold dry winter months, 0.8 in hot humid summer months and 0.7 in the transition months between the winter and the summer and summer and the winter. However, winter in southern India being less severe and brief, different months of winter season were considered for south and north. For this purpose the 22° lat. parallel has been taken as the demarcating line. The coefficients together with the months are given below:

	Coefficient		
	0.6	0.7	0.8
North of 22° lat.	Nov-Feb	Mar-Apr Sept-Oct.	May-Aug
South of 22° lat.	Dec-Jan	Feb-Mar Sept-Nov	May-Aug

Using the above criteria for the coefficient, the lake evaporation was estimated at the 104 evaporimeters using the period averages for the length of the data available. The estimated values are plotted on maps and isopleths were drawn. The maps of free water surface evaporation which could be considered as evaporation taking place from large lakes and reservoirs are presented in figures 1 to 3 for monsoon (Jun-Oct), non-monsoon (Nov-May) and the calendar year.

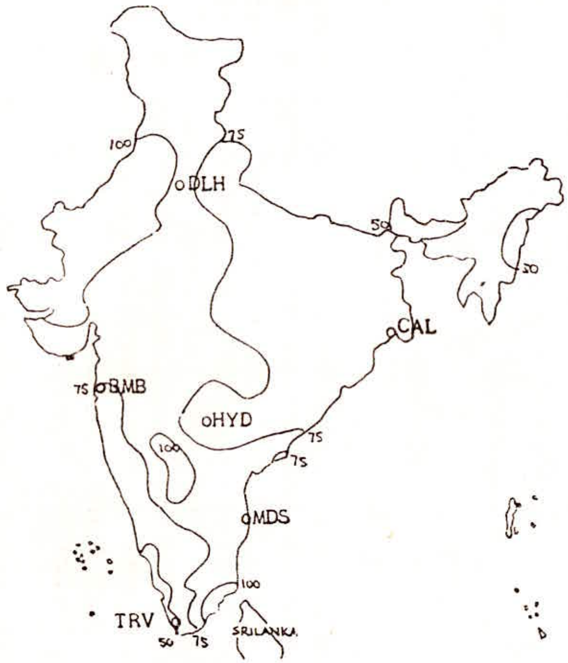

Fig.1: Free Water Surface Evaporation-
Monsoon (Jun-Oct)isopleths-cm

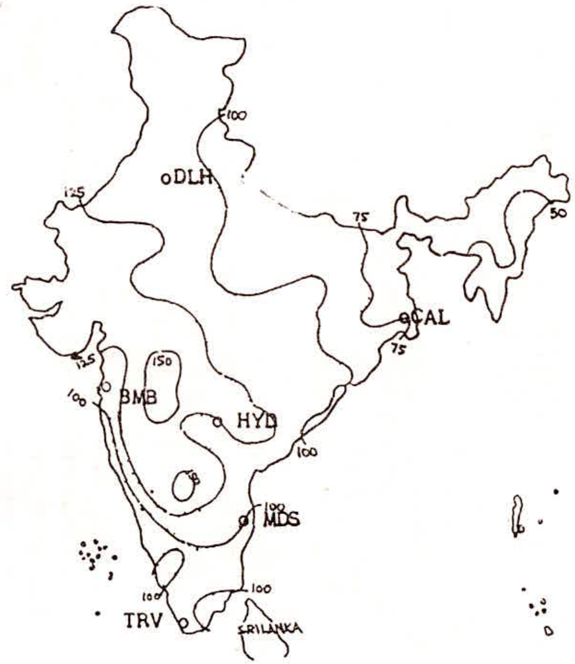

Fig.2: Free Water Surface Evaporation-
Nonmonsoon (Nov-May)isopleths-cm

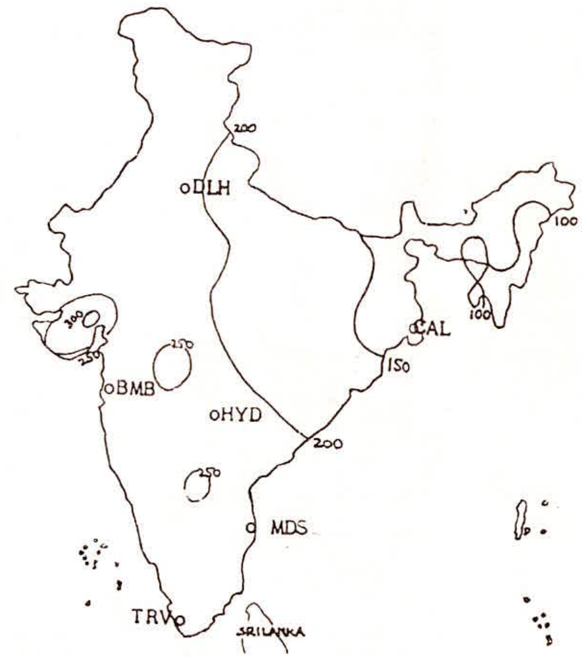

Fig.3: Free Water Surface Evaporation-
Annual (Jan-Dec)isopleths-cm

5.3 Discussion

January:

Evaporation is highest (16 cm) over Saurashtra-Kutch, 14 cm at Jalgaon in Maharashtra and Raichur-Bellary in north interior Karnataka. It is 8 to 10 cm over Rajasthan and Peninsular India, 6 cm over Uttar Pradesh and Bihar and less than 6 cm over Assam.

February:

There is an increase in evaporation by 2 cm over previous month. The increase is 4 cm in Saurashtra-Kutch and Jalgaon and 6 cm over Raichur-Bellary.

March:

The pattern is similar to January and February. The increase in evaporation is 9 to 12 cm, evaporation is same; 27 to 29 cm over Saurashtra-Kutch, Jalgaon and Raichur-Bellary. Over Rajasthan it varies from 15 cm to 20 cm and around 15 cm in Uttar Pradesh. Evaporation is less than 10 cm over Assam.

April:

There is an overall increase in evaporation by 8 to 10 cm over the previous month. In the Bellary-Raichur region and Assam, however, there was no increase.

May:

Evaporation is highest in this month. It varies from 12 cm over Assam to 50 cm over Jalgaon. Over Kota and Saurashtra-Kutch it is 40 cm. In north India it varies from 20 to 35 cm. Gaya with its characteristic semi-arid climate is isolated with 35 cm. In the peninsula it varies from 15 to 35 cm. Over Assam it is less than 15 cm.

June:

The distribution pattern is similar to May. However, values of evaporation are slightly less than those in May.

July:

There is appreciable fall in the evaporation as compared to the June values. Isolated pockets of 25 cm over Rajasthan and Bellary-Raichur region are noticed. Near Kovilpatti in Tirunalveli district in Tamil Nadu, the evaporation is more than 30 cm. It varies from 10 to 25 cm in the peninsula and 12 to 25 cm in north India including Assam.

August:

The evaporation varies from 10 cm in Assam and west coast to 20 cm in Rajasthan and central parts of the peninsula.

September:

Over Saurashtra-Kutch, Bellary-Raichur region and the Kovilpatti area the evaporation is 20 cm and rest of India it varies from 10 to 16 cm. Over Assam it is less than 10 cm.

October:

The pattern is similar to September, however, with reduced evaporation by 2 to 5 cm through out the country.

November:

The evaporation has decreased further and excepting for pockets over Saurashtra-Kutch, Jalgaon, Bellary-Raichur and Kovilpatti where it is 15 cm, the evaporation varies from 10 to 12 cm over peninsula and 5 to 10 cm in north India and less than 5 cm in Assam.

December:

The evaporation pattern is similar to January with high pockets (12-14 cm) over Saurashtra-Kutch, Jalgaon and Raichur-Bellary. In other parts it is around 6 to 10 cm.

Monsoon (June-October):

The pattern generally resembles those observed during the months of July, August and September. Evaporation over West-coast and Assam is less than 60 cm. It is more than 100 cm over Rajasthan and adjoining areas of Gujarat, Madhya Pradesh, and parts of Haryana and Uttar Pradesh. Isolated pockets of high evaporation could be seen around Kovilpatti in Tamil Nadu and Bellary-Raichur in Karnataka.

Non-monsoon (November-May):

The pattern very much resembles the monsoon. Evaporation is less than 100 cm over West-coast, East-coast and Assam and is around 125 cm over Rajasthan and adjoining areas. It is more than 100 cm around Kovilpatti in Tamil Nadu. Isolated pockets of high evaporation of 150 cm are seen around Jalgaon in Maharashtra and Bellary.

Annual:

As is to be expected, the pattern is broadly similar to the monthly distribution, with centres over Saurashtra-Kutch, Jalgaon and Kovilpatti in Tamil Nadu. It is lowest, 100 cm over Assam. The 200 cm isoline covers a narrow strip of north-south tract from Punjab to Karnataka through Rajasthan and Maharashtra. Parts of Uttar Pradesh and Bihar States have evaporation ranging from 150 to 200 cm.

5.4 Special Features

It is observed that lake evaporation values obtained by using the lake-to-pan coefficient were low in case of Erinpura, Chambal, Rawat Bhata and Allahabad. The low evaporation rates at Erinpura, Chambal and Rawat Bhata may be due to the location of the evaporimeter near the reservoir site and therefore, might not need any further correction or the correction factor can be higher than the one used. However, in case of Allahabad the reason for low evaporation is not known.

The isolated high evaporation pocket near Gaya is in confirmity with the potential evapotranspiration studies and the climatic type of Gaya which is semi-arid (Rao et al, 1972).

The annual rainfall map of India (Rainfall Atlas) shows the rainfall to increase from left to right in north and right to left in peninsula. It may be noticed from the monthly as well as the annual evaporation maps that the evaporation decreases from west to east in the north and east to west in the south. This is also true in the case of climatic types where the climates range from humid in Assam to arid in Rajasthan and from humid on the west coast to semi-arid in the east coast.

6.0 SUMMARY

Lake evaporation of 104 evaporimeter stations in India are estimated by using the lake-to-pan coefficients.

Evaporation is highest during the months of April and May and decreases during the rainy season and winter months.

Evaporation is highest around Jalgaon in Maharashtra, Bellary-Raichur in interior Karnataka, Coimbatore and Kovilpatti in Tamil Nadu and Saurashtra-Kutch region in Gujarat, besides the arid areas of Rajasthan.

The high values of Saurashtra-Kutch, Jalgaon, Bellary and Raichur and around Coimbatore and Kovilpatti in Tamil Nadu are due principally to the high wind speed in these regions.

The low evaporation values at the hill stations are essentially due to the low temperatures experienced at high altitudes.

7.0 LIMITATIONS

The important limitation in the present study besides the inadequate evaporimeter network is the lake-to-pan coefficient which is decided upon based on limited field studies conducted in India and other countries. The coefficient needs improvement when more data is made available through field experiments preferably at reservoir sites. This is essential to arrive at reliable and realistic estimates of reservoir evaporation losses.

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