A SIMPLE APPROACH FOR AN OVERALL ASSESSMENT OF SURFACE WATER RESOURCES BY THE WATER BALANCE METHOD

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As early as in 1949 an attempt was made to assess surface water resources for irrigation in India by the use of observed rainfall and runoff data and estimating evaporation losses by means of empirical formula. Since then a large amount of observed evaporation data are available. By making use of these data and assuming suitable co-efficients for evapotranspiration losses, an attempt is made to obtain water balance and to make an overall assessment of total surface water resources for the whole country.

INTRODUCTION

The Indian Subcontinent is situated in a sub-tropical to tropical zone, where agriculture cannot be practised successfully without application of irrigation water according to the needs of the crops. Attempts have been made by various workers to estimate the total amount of water available for irrigation in India. Without such an estimate, it is not possible to plan, scientifically and with confidence, new projects for the conservation and maximum utilization of water resources.

One of the important contributions in this direction was made by Dr. A.N. Khosla as early as in 1949 (UNESCO 1949). He estimated surface water resources by modifying the Vermeule's formula to suit Indian conditions. For this purpose, he evolved the formula for obtaining L_m–monthly evaporation loss in inches:—

$$L_m = \frac{T_m - 32}{9.5}$$

where T_m is mean monthly temperature in Fahrenheit scale and is greater than 40°F This loss was accounted for in the equation of rainfall runoff relationship to obtain the runoff of the different river basins in India. His results showed, that out of 1355 MAF of total runoff in India, only 5.6 per cent were being utilized.

By now, a large amount of data of rainfall, evaporation and runoff have been collected. Spread over the country, there are about 4,000 rain gauge stations maintained by the India Meteorological Department, States and other agencies, but self-recording rain gauges are less than 300. The number of evaporimeter stations has increased in recent years from 70 to 100. Mesh covered U.S. standard pan evaporimeters are installed at these stations. Even so the number of evaporation stations operating in the country cannot be said to be fully adequate to determine the rainfall runoff relationship. However, it seems possible to make use of the available data to reassess the surface water resources by the water balance approach.

WATER BALANCE EQUATION

The water balance or water budget method provides measurement of continuity of flow of water. It is applicable to any drainage basin, and to the country as a whole, at any time interval. According to Horton (1917) the balance equation may be written as:—

$$E = I - O - S,$$

where E is evaporation, I is inflow or precipitation, 'O' is outflow or total runoff, and 'S' is the change in the reservoir contents.

The estimates of different components of the above equation cannot always be made easily and with precision, particularly so evaporation loss. However, for an overall assessment of water resources to an approximate degree of accuracy, some of the inadequacies may be neglected. For instance, the contribution of the term 'S' may be ignored on an annual basis, as recharge to the ground water storage during monsoon period depletes in the dry period. Any addition to the ground water storage in successive years of good rainfall may be depleted in a drought year.

RAINFALL

For the rainfall term 'I', mean rainfall over 22 meteorological sub-divsions were computed from the 1950 revised annual isohyetal maps. Table I shows the rainfall

TABLE I

Normal annual rainfall and evaporation in the various sub-divisions in India

Sl. No.	Sub-Division	Normal annual rainfall (inches)	Annual Pan Evaporation (inches)
1.	Gangetic West Bengal	56.51	61.2
2.	Orissa	58.35	83.1
3.	Bihar Plateau	54.02	80.7
4.	Bihar Plains	47.36	74.2
5.	U.P. East	39.67	86.4
6.	U.P. West	37.96	83.6
7.	Punjab (including Haryana & Delhi)	24.59	96.4
8.	Rajasthan, West	12.25	113.2
9.	Rajasthan, East	27.72	112.5
10.	M.P. West	41.14	108.1
11.	M.P. East	55.18	95.5
12.	Gujarat region	38.44	112.2
13.	Saurashtra & Kutch	19.00	115.9
14.	Madhya Maharashtra	36.25	122.8
15.	Marathwada	30.46	122.1
16.	Vidarbha	43.29	106.8
17.	Coastal A.P.	39.70	91.5
18.	Telengana	36.48	96.8
19.	Rayalseema	26.68	102.6
20.	Madras State	39.69	92.6
21.	Interior Mysore—North	26.57	119.4
22.	Interior Mysore—South	49.01	87.6
	Total area in sq. miles	974953	
	Weighted mean rainfall (Total area)	38.07"	97.96"
		1979 MAF	5093 MAF

of each of these sub-divisions. For reasons explained below, it is not considered necessary to include the following 6 sub-divisions in the calculation of total weighted mean rainfall for the country as a whole :—

1. Assam	The drainage in this area by the Brahmaputra river flows into Bangla Desh.
2. Sub-Himalayan West Bengal	Area available for irrigation is limited and the major inflow enters Brahmaputra river.
3. Jammu & Kashmir	The arable area in this state is limited and the major inflow of the rivers flows into Pakistan in terms of the Indus Water Treaty, 1960.
4. Konkan 5. Coastal Mysore 6. Kerala	The drainage in these coastal areas is provided by comparatively smaller steeply sloping streams. Areas available for irrigation are limited.

After excluding these 6 sub-divisions, the weighted mean rainfall for India works out to be 38.07 inches, equivalent to about 1979 MAF.

RUNOFF

For the outflow component '*O*' in the equation given earlier, the discharges of major rivers flowing into the Arabian Sea and Bay of Bengal at the extreme site near the coast, have been considered. River Ganga has been considered at Farakka, whereafter it enters Bangla Desh. Rivers Sutlej, Beas and Ravi have been gauged at foothills in Punjab and discharge their waters into the Indus river. The annual average volume of flow in million acre feet, during the period 1951–52 to 1968–69, as far as data was available, were collected (Table II). From this average flow from each basin, the total annual outflow from India has been computed. It works out to be about 460 MAF.

TABLE II

Average annual volume of flow in million acre feet based on available data during the years 1951–1969

1.	Krishna at Vijayawada	42.98
2.	Godavari at Dholaishwaram	90.00
3.	Mahanadi at Kaimundi	50.00
4.	Sabarmati at Ahmedabad	1.20
5.	Narmada at Gardeshwar	30.00
6.	Tapi at Kathore	11.20
7.	Ganga at Farakka	220.00
8.	Ravi	4.43
9.	Beas	5.84
10.	Sutlej	—
11.	Mahi	1.64
	Total	457.29
	Say	460.00 M.A.F.

If we now substitute the volume of inflow and outflow in the water balance equation, we have:—

$E = 1979 - 460 = 1519$ MAF.

It is necessary to have a look at this huge loss, which apparently is on account of evaporation from free water surfaces and barren land areas, and evapotranspirational loss from vegetal cover on cultivated areas, both irrigated and unirrigated, and forests.

Evaporation Loss

Evaporation data from water surface is available for about 70 observatories and maps showing the isopleths of annual and seasonal evaporation are available. With these charts, and assuming that the entire surface is covered with water, weighted pan evaporation values for the 22 sub-divisions mentioned earlier have been calculated by planimetering areas. This value of 97.96 inches (5093 MAF) exceeds the inflow, even after applying a coefficient of 0.7 for converting the pan evaporimeter measurements to open water surface, by an amount 3565 MAF.

If we now consider the actual land and water surface distribution, and assume suitable ratios for evapotranspiration from land surface of varying characteristics, more realistic figures of the losses could be obtained. Area of land and water surface distribution have been computed from data of length of rivers and other published statistical data.

The problem that arises here is the inadequacy of the data available in the country on evapotranspiration. In fact, available information in this respect is very meagre. Work done so far in pot experiments is not of much value for its application in the field. The Central Agrimet Observatory at Poona is one of the few stations where systematic observations of evapotranspiration are being made under field conditions. Evapotranspiration from land surface is dependent on soil characteristics, nature of the crop and soil moisture conditions. It may be mentioned that the ratio of evapotranspiration to evaporation has been found to vary between 0.8 to 1.1; 0.3 to 1.1 and 0.5 to 2.0 in the case of wheat, cotton and sugarcane crops respectively as per the experiments conducted at the Central Agrimet Observatory at Poona

TABLE III

Sl. No.	Nature of surface	Percentage of total area under consideration	Ad hoc ratios of evapotranspiration to evaporation assumed for computation	Contribution to evaporation losses (M.A.F.)
1.	Free water surface	3	1.00	107
2.	Irrigated crop area	12	0.70	299
3.	Non-irrigated crop area	42	0.30	449
4.	Forest area	15	0.70	374
5.	Other uncultivated area	28	0.20	250
			Total	1479

Total area of 22 sub-divisions considered is 974953 sq. miles.

(Koteswaram 1970). Similar information about other crops is not available. No work seems to have been done for dry farming areas.

In view of these limitations, it is proposed to use ad hoc ratios of 0.7 in the case of irrigated area and forests, and 0.3 in the case of other cultivated areas. Over the remaining areas, the loss is assumed as only 20 per cent (ratio 0.2) of the evaporation from water surface. This low ratio seems reasonable from the fact that evaporation from the sandy soil of Rajasthan in non-monsoon months has been observed to be surprisingly low (Krishnan *et al.* 1968). Table III gives the details of percentage area of land and water surface distribution together with ad hoc ratios of evapo-transpiration losses assumed.

Conclusion

It will be seen that the evapotranspiration losses account for 1479 MAF, whereas difference between inflow and outflow is 1519 MAF. We can thus obtain a balance of the water budget, i.e.,

Inflow — Outflow — Evaporation Loss = 0 i.e., $1979 - 460 - 1479 \approx 0$.

This approach for obtaining a water balance may be adequate for large areas and for long intervals as in the present case on an All India basis where computations have been made for the whole year. When smaller areas are considered and the water balance attempted for shorter duration, other parameters like infiltration and temporal distribution of the components assume greater significance.

In a recent study for assessment of evaporation and evapotranspiration losses in Godavari catchment results have shown that such a technique can be adopted satisfactorily in the case of major river basins like the Godavari.

From the statistics available, the utilisation of water at the end of Third Five Year Plan is of the order of 160 MAF. This meets partly the evapotranspirational needs of the irrigated areas. The virtual overall outflow could, therefore, be considered at $460 + 160 = 620$ MAF., for purposes of utilization for irrigation. Thus only about 25 per cent of total inflow is available for irrigation. For the same areas, the estimate made by Dr. Khosla in 1949 seems to place the available water resources at 830 MAF.

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