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EMPIRICAL METHOD OF ESTIMATION OF WATER BALANCE

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Using new empirical formula, water balance has been studied over some Indian stations.

Estimation of water balance is made by a method suggested by Thornthwaite; but the potential evapotranspiration (*PE*) values used in this method are obtained using the formula, $PE = E + F$, where E is the pan evaporation which is obtained using Reddy and Rao (1973) formula and F is the function for the conversion of pan evaporation to potential evapotranspiration for different regions; F depends upon soil type and vegetation.

Water balances have been worked out for some stations widely distributed over India, using (i) normal data, (ii) one drought year's data (weak monsoon) and (iii) one successful monsoon year's data.

WATER BALANCE

Moisture Index

Since the moisture available to plants depends not only on the amount of rainfall but also on the evapotranspiration losses; a detailed analysis of various climatic types is necessary to investigate the hydrological balance of the region under consideration. One of the widely accepted methods for this type of study is obtaining an index of precipitation effectiveness. Thornthwaite (1948) introduced the potential evapotranspiration (*PE*) which is defined as the total amount of water that would evaporate and transpire if it were always available for full use. The numerical values of water surplus and water deficiency depend upon precipitation (*P*) and *PE*, where *P* is treated as income and *PE* as expenditure while the moisture stored in soil is a sort of reserve capable of being drawn as long as it lasts. Due to non-uniform distribution of *P* through the year, a region may experience water deficiency in one season and a surplus in another. Taking these moisture parameters into consideration Thornthwaite (1948) has defined effective precipitation as :

$$I_m = (100\ W_s - 60\ W_d)/M \qquad \ldots(1.1)$$

where I_m = the moisture index (non-dimensional parameter), W_s and W_d = annual water surplus and deficiency respectively, and M = annual water

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need (or PE), the positive values of I_m represent moist climates and negative values represent dry climates [for details see Subrahmanyam's (1953) paper].

The intensity of drought (DI) has been obtained as :

$$DI(i) = I_m(i) - I_m(N) \qquad \ldots(1.2)$$

where $I_m(i)$ and $I_m(N)$ respectively stand for the moisture indices of the year i under consideration, and the normal value (N).

The most important element to be estimated (as the observed data are not available) for the study of the above two indices is the potential evapotranspiration. This is dealt in (1.2).

Potential evapotranspiration (PE)

A number of formulae have been derived for the estimation of PE from meteorological data. It is generally accepted that the formula evolved by Penman (1948*b*, 1962) is more appropriate for the estimation of PE, for studies in India. However, it was observed by Gangopadhyaya *et al.* (1970) and later by Reddy and Rao (1973) that Penman's formula is not applicable for the estimation of evaporation under Indian conditions. Hence, a new equation for the estimation of evaporation (E) was suggested by Reddy and Rao (1973) and found good under Indian climatic regimes. Since the observed data for PE are not available, an indirect approach has been followed to get the formula for PE by applying a correction to E values. This is given as follows:

$$PE = E + F \qquad \ldots(1.3)$$

where PE = potential evapotranspiration, in mm/day; E = pan evaporation (Class A—covered with wire mesh), in mm/day; and F = correction factor, in mm/day.

In the above equation, values of E can be estimated using the formula of Reddy and Rao (1973). The correction factor F can be obtained as follows:

It is known that Penman's (1948*b*, 1962) formula given under pan evaporation (Ep) when used with the proper values for 'α' the reflection coefficient, appropriate to the vegetative cover and aerodynamic term gives the potential evapotranspiration, PE_p. Therefore, the correction factor is taken as:

$$F = PE_p - E_p \qquad \ldots(1.4)$$

in which

$$PE_p = \frac{1}{\left(1 + \frac{\Delta}{r}\right)}\left[\frac{\Delta}{59r}\left\{R_t(1 - \alpha_1) - X\right\} + 0.35(e_a - e_d)\left(1 + \frac{U}{100}\right)\right]$$

$$E_p = \frac{1}{\left(1 + \frac{\Delta}{r}\right)}\left[\frac{\Delta}{59r}\left\{R_t(1 - \alpha_2) - X\right\} + 0.35(e_a - e_d)\left(0.5 + \frac{U}{100}\right)\right]$$

[For details of E_p see Gangopadhyaya *et al.* (1970) and for PE_p see Rao *et al.* (1971)].

Therefore, finally F can be written as:

$$F = -\frac{\alpha' R_t}{59(1 + r/\Delta)} + \frac{0.175(e_a - e_d)}{(1 + \Delta/r)} \qquad \ldots(1.5)$$

where

R_t = total solar radiation, in cal/cm²/day; (The accuracy with which this can be estimated has been discussed by Reddy and Rao (1973)].

α' = [reflection coefficient of vegetative cover (α_1) − reflection coefficient of open water (α_2)];

e_a = saturation vapour pressure, in mm of mercury;

e_d = actual mean vapour pressure, in mm of mercury;
(The error involved in the estimation of α', e_a and e_d are insignificant);

Δ = rate of change of saturation vapour pressure with temperature, in mb/°C;

r = 0.66, (psychrometric constant, in mb/°C);

U = wind speed at 2 metres above ground, in miles/day;

T = mean temperature, in degrees Absolute; and

x = outgoing longwave radiation, in cal/cm²/day.

The error involved by assuming the correction factor in the above manner is negligible. Therefore, by substituting Eq. 1.5 in Eq. 1 3, potential evapotranspiration values can be obtained within the required accuracy.

Results and Discussion

Using the Eq. 1.3, monthly mean PE values have been computed for 14 stations in India, for two years (1964 — successful monsoon year and 1966 — weak monsoon year) and for normal data (1961 normal data). For these computations α' has been taken as 0.19. Table I shows the annual mean values of PE and precipitation (P) and departures of PE and P for the two years from normal values. Using the monthly mean values of P and PE, surplus is obtained as the sum of the differences between $P-PE$, in which months $P > PE$; deficiency is obtained as the sum of the differences between $PE-P$, in which months $PE > P$; and M is the sum of the PE values for the 12 months and thereby the moisture index is computed from Eq. 1.1 for 1964, 1966 and normal data separately. The results are presented in Table II. From these values, the drought indices are computed using the formula 1.2 and the results are also presented in Table II.

Generally, it is seen from Tables I and II, that the drought intensity values and precipitation and potential evapotranspiration departures from their respective normals for the years 1964 and 1966 are in line, suggesting that the amplitude departures of the moisture indices from its normal values can be taken to represent the severity of the drought on an annual basis. For example: (i) in the case of Hyderabad P and PE departures are respectively negative and positive in both years with the higher departures in the year 1966. (This is clearly seen in the drought index values, wherein both the years show negative departures,

TABLE I

Mean annual precipitation and potential evapotranspiration

	Normal		1964		1966					
	P	*PE*	*P*	*PE*	*P*	*PE*	$\Delta P(1)$	$\Delta P(2)$	$\Delta PE(1)$	$\Delta PE(2)$
1. Trivandrum	1839·3	1122·6	1776·6	1263·9	1739·0	1365·0	−62·9	−100·3	141·3	242·4
2. Coimbatore	612·3	2347 1	750·4	2232·8	645·8	2245·2	138·1	33·5	−114·3	−101·9
3. Bangalore	923·7	1063·4	1191·6	1582·7	1026·2	1539·6	267·9	102·5	519·3	476·2
4. Madras	1215·3	1862·6	1204·6	2328·1	1647·0	1616·3	−10·7	431·7	465·5	−246·3
5. Bellary	518·1	2248·8	669 0	2143·7	876·0	2314·3	150·9	357·9	−105·1	65·5
6. Sholapur	742·0	2032·7	948·9	2114·7	956·8	2189·8	206·9	214·8	82·0	157·1
7. Hyderabad	764·4	1696·7	700·8	1993·4	461·0	2049·6	−63·6	−303·4	296·7	352·9
8. Poona	714·6	1678·3	703·5	1671 1	490·5	1693·4	−11·1	−224·1	−7·2	15·1
9. Bombay	2099·0	1292·9	1958·8	1282·2	1252·9	1370·0	−140·2	−847·1	−10·7	77·1
10. Nagpur	1127·3	2380·3	1051·3	2538 2	1035·1	2554·6	−76·0	−92·2	157·9	174·3
11. Calcutta	1651·8	1211·4	1583·0	1177·5	1200·7	1235·2	−68·8	−451·1	−33·9	23·8
12. Jodhpur	380·1	2955·0	378 6	2916·1	389·1	2864·9	−1·5	9·0	−38·9	−90·1
13. New Delhi	714·2	2712·8	1229·9	2494·2	651·5	2638·0	515·7	−62·7	−118·6	−74·8
14. Amritsar	649·1	2419·1	800·9	2333·7	785·1	2396·4	151·8	136·0	−85·4	−22·7

(Units : mms)

P = Precipitation; PE = Potential Evapotranspiration

$$\left.\begin{array}{l}\Delta P(i) = P\,(\text{Normal}) - P(i)\\ \Delta PE(i) = PE\,(\text{Normal}) - PE(i)\end{array}\right. \quad i = \left.\begin{array}{l}1 \text{ for } 1964\\ 2 \text{ for } 1966\end{array}\right\}$$

TABLE II

Intensity of drought

		$I_m(N)$	$I_m(1)$	$I_m(2)$	$DI(1)$	$DI(2)$
1.	Trivandrum	62·9	58·2	45·3	−17·6	−14·0
2.	Coimbatore	−44·3	−38·0	−36·5	6·3	7·8
3.	Bangalore	3·8	− 1·2	−11·1	− 5·0	−14·9
4.	Madras	−12·1	−18·5	21·3	− 6·4	33·4
5.	Bellary	−46·1	−39·6	−33·7	6·5	12·4
6.	Sholapur	−36·2	−24·9	−26·6	11·3	9·6
7.	Hyderabad	−29·6	−36·3	−46·3	− 6·7	−16·7
8.	Poona	−31·5	−31·0	−46·0	0·5	−14·5
9.	Bombay	86·7	79·3	21·0	− 7·4	−65·7
10.	Nagpur	−25·3	−25·4	−30·1	− 0·1	− 4·8
11.	Calcutta	50·8	49·2	18·0	− 1·6	−32·8
12.	Jodhpur	−52·3	−52·1	−51·6	0·2	0·7
13.	New Delhi	−44·1	−20·7	−44·7	23·4	− 0·7
14.	Amritsar	−43·9	−36·4	−39·5	7·5	4·4

Note : I_m and DI=Dimensionless quantities.

$$DI(i) = I_m(i) - I_m(N), \qquad i = \left.\begin{matrix} 1 \text{ for } 1964 \\ 2 \text{ for } 1966 \end{matrix}\right\}$$

with higher departure in the year 1966); (ii) in the case of Madras the P and PE departures are respectively negative and positive in 1964 and vice-versa in 1966 [$\Delta P(1)$ is considerably smaller than $\Delta P(2)$], which is also seen clearly in $DI(1)$ and $DI(2)$ values.

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