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Objekttyp: **Article**

Zeitschrift: **Ingénieurs et architectes suisses**

Band (Jahr): **116 (1990)**

Heft 18

PDF erstellt am: **25.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-77283

SYMPOSIUM 1 – METHODES DE MESURES HYDROLOGIQUES EN MONTAGNES

METHODES D'ESTIMATION DIRECTE DE L'EVAPORATION

EVALUATION OF EVAPOTRANSPIRATION ESTIMATION METHODS IN MOUNTAINOUS REGIONS

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ABSTRACT Estimates of evapotranspiration by three empirical formulae, namely radiation, Blaney-Criddle and Hargreaves, have been compared with that by the Penman formula for three stations in the western mountains of South India. There are wide variations between them. By a linear transformation of the empirical formulae, it is shown that closer agreement can be obtained. Transformation on a seasonal basis produces a much closer agreement than on an annual basis. Surprisingly, the Blaney-Criddle formula, considered as more empirical than the others, shows the best performance, as revealed by the difference as well as mean square error criteria.

INTRODUCTION

Evapotranspiration (ET) is the most difficult term to assess of all components of water cycle. It is also a key factor to be estimated for several problems in hydrology, agronomy, forestry and resource planning. Estimation of evapotranspiration is usually done through direct measurement using lysimeters or by using formulae based on climatic observations. Direct measurements of evapotranspiration would obviously be the best, but unfortunately such measurements would not be available in many places, especially in mountainous regions. Estimation is thus to be done from formulae, empirical or otherwise. Any review of literature reveals a large number of empirical equations for computing evapotranspiration. In a study for the Food and Agricultrual Organisation, Doorenbos & Pruitt (1977) recommended, after comparison with actual measurements worldwide, three methods namely, transformed versions of those originally suggested by Penman (1948), Makkink (1957) and Blaney & Criddle (1950). The method developed by Makkink is referred to as Radiation method in this study. Hargreaves & Samani (1982) proposed a simple method based on temperature and radiation data and tested in different climatic conditions for use in a wide range of climate. The main aim of this paper is to study the applicability of these methods to mountainous regions in estimating evapotranspiration.

Three stations ranging in climate from subhumid to perhumid from the western ghats (mountains) of India have been selected for the study. Among the four methods, Penman's formula was selected as the reference, because of its theoretical soundness and wide application, against which the other three formulae were calibrated.

STUDY AREA AND DATA

The details of the three selected stations in the Western Ghats in South India are summarised in Table 1. Daily data on maximum and minimum temperature (T_{max} & T_{min}), relative humidity in percentage measured at 8.30 h (RH1 and 17.30 h (RH2), actual duration of bright sunshine hours (n), wind speed in km h^{-1} (Uday) were collected from the India Meteorological Department.

The general recommended value for albedo has been taken as 0.25 and used in the Penman formula. Wind speed observations were reduced to the corresponding values at 2m height using the expression

$$U_1/U_2 = [Z_1/Z_2]^{1/7} \quad (1)$$

Table 1. – Stations studied in the Western Ghats.

Name	Latitude	Longitude	Altitude above mean sea level m	Radiation constants a	Radiation constants b
Kodaikanal	10°14'N	77°28'E	2343	0.31	0.52
Coimbatore	11°03'N	77°03'E	400	0.30	0.42
Chikmagalur	13°17'N	75°45'E	693	0.32	0.45

where U_1 and U_2 are wind speeds in km at heights Z_1 and Z_2 respectively. Since daily values of incident solar radiation (R_s) were not available, it was obtained from the equation

$$R_s = (a + b \frac{n}{N}) R_a \quad (2)$$

where R_a is the extraterrestrial radiation. The values of a and b for each station were calculated by regressing the published mean monthly values of R_s on n/N (India Meteorological Department) and are shown in Table 1. The value of the mean temperature T_{mean} on any day is taken to be the average of T_{max} and T_{min} of that day and the value of RH mean is taken to be the average of RH1 and RH2.

METHODOLOGY

Daily ET values were computed from the Penman (ET_p) Radiation (ET_R), Blaney-Criddle (ET_B) and Hargreaves (ET_H) methods. From the daily value weekly totals of ET values were computed over the length of record for all the three stations. The Blaney-Criddle formula is commonly believed to underestimate ET at elevated sites. An elevation correction factor (Ce) was therefore incorporated by Doorenbos Pruitt (1977) and is given by

$$Ce = 0.0001 \text{ (Elevation in m)} \quad (3)$$

This correction factor was found necessary only for Kodaikanal but not for Coimbatore and Chikmagalur, probably because of the much higher altitude of the former. The weekly ET_p values were regressed on the ET_R, ET_B and ET_H values individually. Since evapotranspiration is mainly dependent on weather parameters, which in turn change from season to season, regression equations for the three prevailing seasons namely summer, monsoon and winter have been obtained by taking the corresponding weekly estimates over all the years. These equations suggest the corrections to be applied to the Radiation, Blaney-Criddle and Hargreaves formulas (which need more readily available data) in order to make their estimates close to Penman's method estimates (which requires less readily available data).

RESULTS AND DISCUSSION

The weekly total ET_p values over all the years together were regressed on ET_R, ET_B and ET_H separately for each station to obtain annual regression equations of the form

$$ET_p = m\, ET_{est} + 1 \quad (4)$$

where ET_{est} refers to the estimates from Radiation, Blaney-Criddle or Hargreaves methods. The resulting equations are shown in Table 2, with the corresponding coefficient of determination, standard error of regression coefficient (SE_r) and standard error of estimate (SEE). The SE_r values are low compared to the values of

Table 2. — Annual regression equations.

Station	Equation	R^2	SE_r	SEE
Kodaikanal	ET_p=1.038 ET_R-6.252	0.88	0.024	2.679
	ET_p=0.923 ET_B-12.461	0.89	0.020	2.518
	ET_p=1.658 ET_H-5.868	0.55	0.093	5.145
Coimbatore	ET_p=0.941 ET_R+2.802	0.63	0.045	4.431
	ET_p=0.724 ET_B+14.943	0.68	0.031	4.108
	ET_p=1.047 ET_H-0.463	0.82	0.031	3.115
Chikmagalur	ET_p=1.084 ET_R-3.249	0.83	0.034	2.901
	ET_p=0.745 ET_B+14.642	0.77	0.029	3.426
	ET_p=0.988 ET_H+4.888	0.83	0.031	2.905

slopes in all equations. Further, the SEE values are small, indicating that the regression equations are acceptable. The coefficient of determination is generally higher for Kodaikanal and Chikmagalur than Coimbatore, which is at a lower altitude.

The three plots of Fig. 1(a) show the comparison of weekly total ET values averaged over the total period of data availability from the four methods for Kodaikanal, Coimbatore and Chikmagalur respectively. From Fig. 1(a) it is clear that the B-C and Hargreaves formulae underestimate the ET values and Radiation formula overestimates them. For Coimbatore, the same figure shows that the BC formula underestimates ET values for the weeks from 14 to 42 and the other methods are estimating ET values fairly close to that of Penman's estimates. For Chikmagalur the same trend as that of Coimbatore has been observed.

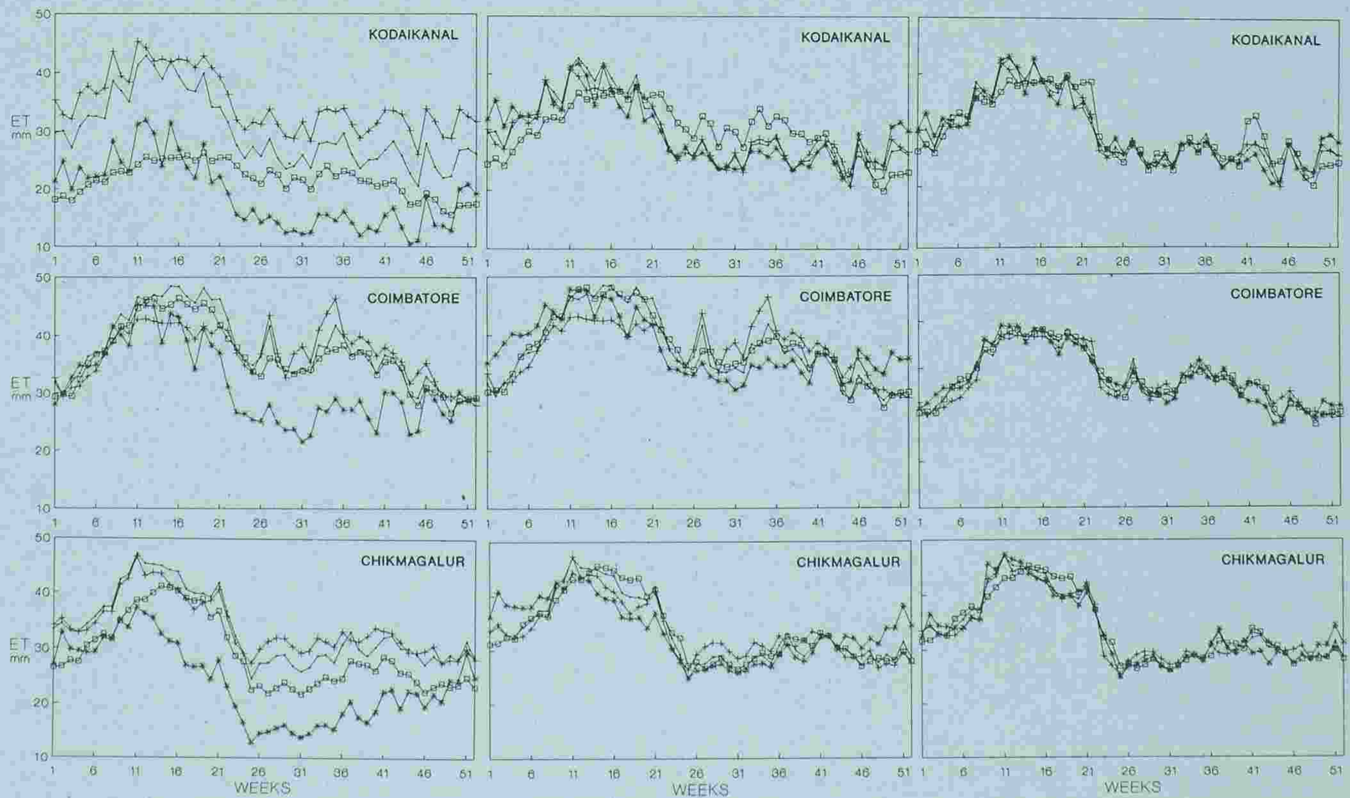
There are three distinct seasons in a year in the region studied. Counting from beginning of the calendar year, weeks 1 to 8 and 41 to 52 are classified as Winter, 9 to 22 as Summer and 23 to 40 as Monsoon. For all the stations, the magnitude of deviations of the ET estimates by Radiation, Blaney-Criddle and Hargreaves method from that of Penman's changes with season, with the deviation being larger in the case of Blaney-Criddle estimates. This suggests a seasonal influence on the coefficients of the Radiation, Blaney-Criddle and Hargreaves formulas. To explore this, weekly ET_p values for a given season over the entire period considered, were regressed on ET_R, ET_B or ET_H values and the resulting regression equations are of the form

$$ET_{p(s)} = m_s\, ET_{est(s)} + 1_s \qquad (5)$$

where $ET_{est(s)}$ is the ET estimated by Radiation, Blaney-Criddle or Hargreaves method over the season. These seasonal equations are listed in Table 3 alongwith the standard error of regression coefficient, coefficient of determination and standard error of estimates. It can be observed that the Blaney-Criddle estimate is in general very well correlated with the Penman estimates, where as the radiation and Hargreaves estimates do rather poorly, especially for Coimbatore. The equations listed in Table 3 follow the same trend as that of annual equations of Table 2, of course differing from season to season.

The ET values estimated by Radiation, Blaney-Criddle and Hargreaves formula show large deviations from the Penman estimates. To get estimates close to Penman's values, ET values computed from the Radiation, Blaney-Criddle and Hargreaves methods should be subjected to the linear transformation of eq.(4) (referred to as annual equation) or eq.(5) (referred to as seasonal equation). Figure 1(b), show the values thus transformed on an annual basis for Kodaikanal, Coimbatore and Chikmagalur respectively along with the Penman values. Comparing them with the corresponding Figure 1(a) it is apparent that the overall agreement with the Penman values has become much better, except for Chikmagalur during Winter when it has become worse.

The weekly total values from the formulae transformed on a seasonal basis are shown plotted against the week in Fig. 1(c) for the stations Kodaikanal, Coimbatore and Chikmagalur respectively. The agreement in this case is very close throughout the year for all the three stations.



(a) Untransformed (b) Transformed-annual (c) Transformed-seasonal

FIG. 1 Comparison of evapotranspiration estimates by different formulae
· Penman * Blaney-Criddle + Radiation ▫ Hargreaves

Table 3. – Seasonal regression equations.

Station	Equation	R^2	SE_r	SEE
Kodaikanal				
Summer	ET_p=0.999 ET_R-3.302	0.75	0.071	3.021
	ET_p=0.843 ET_B+16.310	0.91	0.031	1.756
	ET_p=1.535 ET_H-0.323	0.34	0.26	4.856
Monsoon	ET_p=0.834 ET_R-0.026	0.84	0.039	1.629
	ET_p=1.146 ET_B+9.976	0.89	0.043	1.369
	ET_p=1.454 ET_H-5.851	0.52	0.150	2.840
Winter	ET_p=0.968 ET_R-6.252	0.86	0.039	2.681
	ET_p=0.829 ET_B+12.338	0.90	0.029	2.310
	ET_p=2.039 ET_H-10.770	0.67	0.144	4.098
Coimbatore				
Summer	ET_p=0.854 ET_R+10.595	0.46	0.113	3.362
	ET_p=0.557 ET_B+23.745	0.67	0.048	2.619
	ET_p=0.903 ET_H+6.247	0.59	0.092	2.926
Monsoon	ET_p=0.634 ET_R+12.197	0.46	0.073	3.757
	ET_p=1.013 ET_B+10.514	0.88	0.040	1.771
	ET_p=1.140 ET_H-4.020	0.44	0.138	3.838
Winter	ET_p=0.756 ET_R+8.106	0.60	0.062	3.071
	ET_p=0.664 ET_B+12.638	0.78	0.036	2.296
	ET_p=0.974 ET_H+1.856	0.76	0.056	2.418
Chikmagalur				
Summer	ET_p=0.825 ET_R+8.748	0.73	0.069	2.454
	ET_p=0.667 ET_B+20.624	0.86	0.036	1.737
	E_p=0.854 ET_H+10.028	0.42	0.144	3.652
Monsoon	ET_p=0.925 ET_R+0.030	0.56	0.098	2.580
	ET_p=1.095 ET_B+9.739	0.95	0.029	0.841
	ET_p=0.872 ET_H+7.178	0.56	0.093	2.601
Winter	ET_p=0.850 ET_R+4.654	0.73	0.058	2.332
	ET_p=0.649 ET_B+13.816	0.79	0.038	2.068
	ET_p=1.067 ET_H+3.288	0.70	0.078	2.459

Table 4. – Comparison of D_p values for transformed formulae.

Station	Season	Transformed Radiation		Transformed BC		Transformed Hargreaves	
		D_{py}	D_{ps}	D_{py}	D_{ps}	D_{py}	D_{ps}
Kodaikanal	Summer	87.1	90.0	97.1	100	60.0	70.0
	Monsoon	98.8	98.8	100	100	54.4	91.0
	Winter	92.0	96.0	90.0	100	70.0	74.0
	Annual	93.7	95.4	95.4	100	61.9	78.8
Coimbatore	Summer	62.9	91.4	84.2	95.7	92.9	92.9
	Monsoon	67.8	85.5	78.9	98.9	80.0	81.1
	Winter	89.0	90.0	64.0	98.0	96.0	97.0
	Annual	71.9	88.8	74.6	97.7	89.6	90.4
Chikmagalur	Summer	85.7	96.4	83.9	100	85.7	83.9
	Monsoon	90.2	93.1	100	100	94.4	93.1
	Winter	94.9	98.7	72.5	100	93.8	94.9
	Annual	90.9	96.2	85.1	100	91.8	91.3

The closeness of the ET estimates by the transformed formulae to those by Penman's formula was checked using two criteria namely difference criterion and error of estimate (MSE). In the difference criterion, the difference between the weekly total ET estimated by Penman's formula and that estimated by the annual or seasonal transformed formula is calculated. If the difference is less than 5 mm/week it is considered that the estimate is good. The number of weeks in which the difference is less than 5mm/week, expressed as a percentage (D_p) of the total number of weeks in the period considered, will give an idea of closeness of estimate and this criterion has been employed by Ward (1963). The mean square error of estimate is calculated from the expression

$$MSE = (ET_{est} - ET_p)^2/N \quad (6)$$

where N is the total number of weeks considered.

The D_p and MSE values were computed for all the three stations for the entire period and Table 4 shows D_p values for the annual formulae (D_{py}) and for seasonal formulae (D_{ps}). It can be seen that seasonal formulae perform better than the annual formulae, providing quantitative confirmation of conclusions from the graphical analysis. It is also observed that even though the Blaney-Criddle formula is considered to be more empirical than the other two formulae, it performs better than the other methods most often.

CONCLUSIONS

The study shows that the transformed Blaney-Criddle formula can be used for stations in the mountainous region in the states of Tamilnadu and Karnataka to estimate the evapotranspiration in any season of the year. The seasonal formuale are to be preferred to the annual formula. For mountainous regions having an altitutde of more than 1000 m, the elevation correction factor should be applied to the Blaney-Criddle formula for achieving better accuracy in the estimation of evapotranspiration.

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