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# 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 Agricultural 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 sub-humid 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  $\text{km h}^{-1}$  (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

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

where  $U_1$  and  $U_2$  are wind speeds in  $\text{km h}^{-1}$  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  $T_{\text{mean}}$  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

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

where  $ET_{\text{est}}$  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 1. — Stations studied in the Western Ghats.

Name	Latitude	Longitude	Altitude above mean sea level m	Radiation constants	
				a	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



Table 2. — Annual regression equations.

Station	Equation	R <sup>2</sup>	SE <sub>r</sub>	SEE
Kodaikanal	ET <sub>p</sub> =1.038 ET <sub>R</sub> -6.252	0.88	0.024	2.679
	ET <sub>p</sub> =0.923 ET <sub>B</sub> -12.461	0.89	0.020	2.518
	ET <sub>p</sub> =1.658 ET <sub>H</sub> -5.868	0.55	0.093	5.145
Coimbatore	ET <sub>p</sub> =0.941 ET <sub>R</sub> +2.802	0.63	0.045	4.431
	ET <sub>p</sub> =0.724 ET <sub>B</sub> +14.943	0.68	0.031	4.108
	ET <sub>p</sub> =1.047 ET <sub>H</sub> -0.463	0.82	0.031	3.115
Chikmagalur	ET <sub>p</sub> =1.084 ET <sub>R</sub> -3.249	0.83	0.034	2.901
	ET <sub>p</sub> =0.745 ET <sub>B</sub> +14.642	0.77	0.029	3.426
	ET <sub>p</sub> =0.988 ET <sub>H</sub> +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<sub>p</sub> values for a given season over the entire period considered, were regressed on ET<sub>R</sub>, ET<sub>B</sub> or ET<sub>H</sub> values and the resulting regression equations are of the form

$$ET_{p(s)} = m_s ET_{est(s)} + l_s \quad (5)$$

where ET<sub>est(s)</sub> is the ET estimated by Radiation, Blaney-Criddle or Hargreaves method over the season. These seasonal equations are listed in Table 3 along with 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.

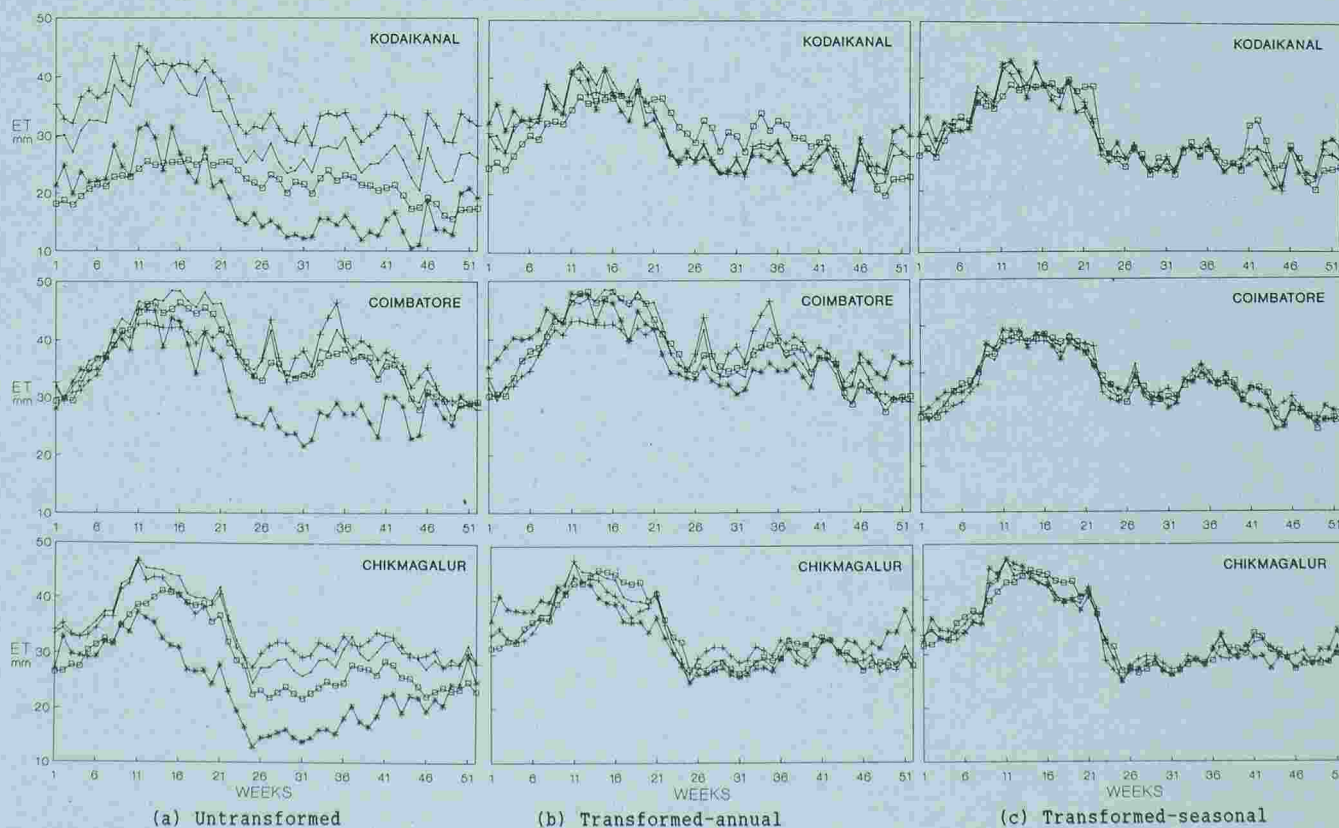


FIG. 1 Comparison of evapotranspiration estimates by different formulae  
 • Penman      \* Blaney-Criddle      + Radiation      □ Hargreaves



Table 3. — Seasonal regression equations.

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

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 formulae are to be preferred to the annual formula. For mountainous regions having an altitude 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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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