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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

(1)

$$U_1/U_2 = [Z_1/Z_2]^{1/7}$$

Table 1. - Stations studied in the Western Ghats.

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

$$R_s = (a + b \frac{n}{N}) R_a$$
 (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 (Elevation in m)

(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

$$ET_p = m ET_{est} + 1 \tag{4}$$

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_t) and standard error of estimate (SEE). The SE_t values are low compared to the values of

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Table 2. – Annual regression equations.

Station	Equation	R ²	SEr	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	
	$ET_p=0.745 ET_B=114.642$	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 ETR, ETB or ET_H values and the resulting regression equations are of the form

(5)

 $ET_{p(s)} = m_s ET_{est(s)} + 1_s$

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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.



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Table 3. - Seasonal regression equations.

Station 👘	Equation	R ²	SEr	SEE
Kodaikanal				
	ET _p =0.999 ET _R -3.302	0.75	0.071	3.021
Summer	ETp=0.843 ETB+16.31	0 0.91	0.031	1.756
	ET _p =1.535 ET _H -0.323	0.34	0.26	4.856
	ET_=0.834 ET0.026	0.84	0.039	1.629
Monsoon	ET_=1.146 ET_+9.976	0.89	0.043	1.369
	ETp=1.454 ETH-5.851	0.52	0.150	2.840
	ET_=0.968 ET6.252	0.86	0.039	2.681
Winter	ETp=0.829 ETB+12.33	8 0.90	0.029	2.310
	ETp=2.039 ETH-10.77	0 0.67	0.144	4.098
Coimbatore				
	$ET_p = 0.854 ET_R + 10.59$	5 0.46	0.113	3.362
Summer	$ET_{p}=0.557 ET_{B}+23.74$	5 0.67	0.048	2.619
	ETp=0.903 ETH+6.24/	0.59	0.092	4.940
	ET_=0.634 ET_+12.19	7 0.46	0.073	3.757
Monsoon	ETp=1.013 ETB+10.51	4 0.88	0.040	1.771
	ETp=1.140 ETH-4.020	0.44	0.138	3.838
	ET_=0.756 ET_+8.106	0.60	0.062	3.071
Winter	ET_=0.664 ET_+12.63	8 0.78	0.036	2.296
	ETp=0.974 ETH+1.856	0.76	0.056	2.418
Chikmagalur				
	$ET_p = 0.825 ET_R + 8.748$	0.73	0.069	2.454
Summer	$ET_{p} = 0.667 ET_{B} + 20.62$	4 0.86	0.036	1.737
	Ep=0.854 ETH+10.028	0.42	0.144	3.032
	ET_=0.925 ET_+0.030	0.56	0.098	2.580
Monsoon	ETp=1.095 ETB+9.739	0.95	0.029	0.841
	ETp=0.872 ETH+7.178	0.56	0.093	2,601
	ET _p =0.850 ET _R +4.654	0.73	0.058	2.332
Winter	ET_=0.649 ET_+13.81	6 0.79	0.038	2.068
	ET_=1.067 ET_+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}
	Summer	87.1	90.0	97.1	100	60.0	70.0
Kodaikanal	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
		1		1			
	Summer	62.9	91.4	84.2	95.7	92.9	92.9
Coimbatore	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
	Summer	85 7	96.4	83.9	100	85.7	83.9
Chikmagalur	Mongoon	90.2	03 1	100	100	91 A	03.5
Curvinggardi	Winter	94.9	98 7	72 5	100	03.8	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

$$MSE = (ET_{est} - ET_n)^2 / N$$
(6)

where N is the total number of weeks considered. $% \label{eq:stable}% \begin{tabular}{lll} \end{tabular} \end{ta$

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, 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 formula 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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