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A comparative study of the climatological estimation of potential evapotranspiration

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सार — कृषि जलवायु की दृष्टि से भिन्न-भिन्न क्षेत्रों में स्थिति 9 विकिरण स्टेशनों का विभिन्न विधियों, जैसे पेनमेन (1963), मोनतीथ (1964) एवं थोम और ओलिवर (1977), से प्राप्त संभावित वाष्पोसर्जन का, जाली से ढके ए श्रेणी वाले पेन वाष्पन के संदर्भ में, तुलनात्मक अध्ययन किया गया है। ऊंची फसल के लिए संभावित वाष्पोत्सर्जन के आकलन के लिए पेनमेन विधि (1963) के स्थान पर मोनतीथ विधि का उपयोग करने की सिफारिश की गई है।

ABSTRACT. A comparative study of potential evapotranspiration (P_{ET}) by various methods, *viz.*, Penman (1963), Monteith (1964) and Thom and Oliver (1977) in relation to mesh-covered class A Pan evaporation (EP) is presented for 9 radiation stations situated in different agroclimatic zones. Computation of P_{ET} by Monteith's method for a tall crop is recommended for adoption in place of Penman's method (1963).

1. Introduction

Faced with the problem of estimating evaporation from water bodies, without recourse to the use of generally unavailable water surface temperature, Penman (1948) suggested the following formula which combined the aerodynamic and energy-budget factors for estimating daily evaporation (E) :

$$E = \frac{Q_n \triangle/\gamma + (e_a - e_d) f(U)}{\frac{\triangle}{\gamma} + 1} \qquad (1)$$

where Q_n is net radiation (cal/cm²/day). $\triangle$ is the slope of the saturation vapour-pressure curve at mean air temperature, γ is psychrometric constant (0.66 mb/°C), e_a is the saturation vapour pressure (mm) at mean daily air temperature [*i.e.*, (max+min)/2], e_d is the actual mean daily vapour pressure (mm) of air, $f(U) = K(A+0.01U)$ where 'K' and 'A' are constants and 'U' is wind run at 2 m height (miles/day). Penman suggested 0.35 and 0.5 for 'K' and 'A' respectively.

(*i*) Penman (1956, 1963) suggested that the potential evapotranspiration (P_{ET}) which is the moisture lost back to the atmosphere from an extensive, short, actively growing grass surface, not short of water, can also be obtained from Eqn. (1) by using Q_n appropriate to a green grass cover and by taking $f(U)$ as equal to 0.35 [1+(U/100)]. However, this formula was found to underestimate P_{ET} in drier regions (Stanhill 1961).

(*ii*) Thom and Oliver (1977) suggested a modification of Eqn. (1) :

$$P_{ET} = \frac{Q_n \triangle + 2.5\gamma E_{ap}}{\triangle + 2.4\gamma} \qquad (2)$$

where $E_{ap} = 0.26 (e_a - e_d)(1 + U/100)$, in which e_a and e_d are expressed in mb, γ the psychrometric constant, equal to 0.66 mb/°C and other symbols have the same meaning as in Eqn. (1).

(*iii*) McIlroy (1960) suggested another formula using wet bulb depression instead of saturation deficit. He introduced the term "Equilibrium Evaporation" which constitutes the lower limit to the evaporation from a thoroughly moist surface (assuming wet bulb depression to be zero). The Equilibrium Evaporation (same as P_{ET} for a green crop cover) is given by

$$P_{ET} = S/(S + \gamma)\ (Q_n) \qquad (3)$$

where S is near enough to the slope of the saturation vapour pressure curve for water and γ is the psychrometric constant. The whole term $S/(S+\gamma)$ is a weighting factor relatively varying slowly. This Eqn. (3) is similar to energy term in Penman's equation neglecting the aerodynamic term under calm and humid conditions.

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TABLE 1

Estimates of Penman P_{ET} (A), modified Penman P_{ET} (B), P_{ET} short crop (C), P_{ET} tall crop (D), Equilibrium evaporation (E) and mesh covered Class A Pan evaporation (F). (All values in mm/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Trivandrum							
A	4.09	4.59	5.00	4.86	4.10	4.04	3.46	4.00	4.33	3.66	3.47	3.76
B	4.14	4.59	4.92	4.80	4.08	3.96	3.32	3.93	4.27	3.53	3.38	3.85
C	4.14	4.61	4.90	4.65	3.89	3.81	3.17	3.74	4.01	3.45	3.39	3.80
D	5.68	6.20	6.30	5.69	4.90	4.79	3.78	4.45	4.76	4.01	4.24	5.51
E	2.93	3.38	3.79	3.71	3.11	3.08	2.67	3.14	3.36	2.93	2.72	2.79
F	4.90	5.50	5.60	5.00	4.60	3.80	3.50	3.90	4.10	3.80	3.50	3.90
					Jodhpur							
A	3.57	4.52	6.13	7.37	8.80	8.44	6.39	5.20	5.69	5.32	3.93	3.25
B	4.39	5.52	7.77	10.34	12.09	11.26	7.66	5.71	6.46	6.64	4.99	4.18
C	3.51	4.47	6.02	7.30	7.99	7.29	5.65	4.78	5.43	5.68	4.32	2.79
D	6.18	7.62	10.35	12.60	13.60	11.60	8.17	6.52	7.91	9.87	7.71	4.86
E	1.36	1.88	2.64	3.29	3.89	4.14	3.79	3.45	3.55	2.56	1.67	1.12
F	3.40	5.00	7.70	11.00	13.80	12.60	8.40	6.20	6.30	6.30	4.60	3.40
					Ahmedabad							
A	3.61	4.51	6.02	7.04	7.68	6.61	4.59	3.98	4.49	4.74	3.95	3.14
B	4.44	5.39	7.49	8.97	9.67	7.80	4.98	4.08	4.78	5.55	4.82	3.75
C	3.81	4.73	6.01	7.02	7.21	6.15	3.84	3.45	4.01	4.33	3.49	2.91
D	6.70	8.10	10.10	11.70	11.40	9.30	4.70	4.10	5.20	5.50	5.20	4.60
E	1.54	2.15	2.87	3.50	4.17	4.08	3.13	2.87	3.09	2.68	1.89	1.50
F	5.20	6.80	9.10	11.50	13.00	10.40	6.20	4.50	5.50	6.50	6.00	5.20
					Madras							
A	3.52	4.65	5.27	5.84	6.43	5.12	5.52	5.43	5.04	3.59	3.65	3.27
B	3.55	4.65	5.34	6.12	7.41	5.68	6.67	6.21	5.46	3.88	3.22	3.44
C	3.35	4.43	5.00	5.55	6.02	4.62	5.04	5.02	4.79	3.64	2.86	2.99
D	4.46	5.49	5.66	7.37	8.60	6.09	7.60	7.20	6.59	4.84	3.80	4.03
E	2.49	3.33	3.81	4.22	4.12	3.37	3.16	3.40	3.40	2.73	2.15	2.20
F	4.10	4.90	5.90	6.60	8.30	8.10	6.70	6.30	5.40	4.40	3.80	3.50
					Visakhapatnam							
A	3.16	3.99	4.76	5.52	5.80	4.25	3.90	4.14	3.90	3.78	3.57	3.04
B	2.77	3.53	4.55	5.35	5.75	4.30	3.93	3.49	3.67	3.64	3.65	2.96
C	2.96	3.75	4.42	4.95	5.18	3.84	3.43	4.13	3.63	3.58	3.41	2.88
D	3.41	4.27	5.26	5.70	5.91	4.58	4.02	5.03	4.18	4.37	4.58	3.73
E	2.59	3.31	3.72	4.36	4.60	3.28	2.94	3.43	3.18	2.94	2.49	2.22
					New Delhi							
A	2.41	3.61	5.35	6.98	8.24	7.82	5.04	4.61	4.87	4.32	3.39	2.45
B	2.73	4.09	6.43	8.98	11.07	10.30	5.73	4.91	5.49	5.13	4.19	2.97
C	2.38	3.42	5.13	6.83	7.87	7.26	4.91	4.48	4.79	4.62	3.66	2.54
D	3.97	5.47	8.37	11.55	13.50	11.83	7.22	6.23	6.99	7.83	6.51	4.44
E	1.09	1.93	2.51	3.14	3.74	3.93	3.30	3.25	3.02	2.31	1.42	0.96
F	3.20	4.40	6.10	10.10	12.00	12.80	6.70	5.00	5.50	6.00	4.70	3.40
					Pune							
A	3.18	4.12	5.24	6.04	6.92	6.49	3.61	3.49	3.87	3.87	3.19	2.84
B	3.71	4.78	6.29	7.24	8.52	7.95	3.78	3.44	3.79	4.06	3.55	3.29
C	3.65	4.57	5.69	6.39	6.97	6.21	3.24	3.20	3.77	4.09	3.56	3.28
D	6.51	7.65	9.65	10.42	11.51	9.95	4.22	4.22	4.81	6.01	5.89	5.67
E	1.57	2.08	2.61	3.26	3.67	3.49	2.46	2.55	2.83	2.58	1.81	1.43
F	4.70	7.00	8.90	10.90	11.00	8.60	5.80	4.40	4.90	5.30	4.40	4.00
					Dum Dum							
A	2.37	3.28	4.70	5.74	5.90	4.33	3.88	3.55	3.47	3.92	2.73	2.10
B	2.50	3.49	5.25	6.48	6.43	4.54	3.90	3.53	3.50	3.20	2.91	2.23
C	2.56	3.42	4.63	5.34	5.32	4.03	3.63	3.36	3.37	3.19	2.96	2.30
D	3.99	5.23	6.98	7.55	7.00	5.25	4.56	4.23	4.28	4.47	4.62	3.63
E	1.42	2.00	2.82	3.71	4.07	3.14	2.94	2.73	2.65	2.29	1.74	1.26
F	2.40	3.20	4.30	6.20	6.60	5.00	4.20	3.80	3.60	3.30	2.90	2.30
					Nagpur							
A	3.35	4.77	5.77	6.50	7.94	6.85	3.81	3.63	4.02	4.35	3.66	2.90
B	3.88	5.80	7.33	8.97	—	8.95	4.16	3.80	4.24	4.65	3.47	2.84
C	3.46	4.81	5.86	6.91	7.71	6.24	3.49	3.38	3.80	4.27	3.71	3.06
D	5.72	8.19	10.18	11.80	13.76	10.12	4.78	4.46	5.10	6.07	5.94	5.24
E	1.67	2.29	2.67	3.30	3.49	3.40	2.55	2.55	2.79	2.85	1.95	1.38
F	4.00	6.00	7.70	9.90	—	9.10	4.70	3.80	4.50	4.70	4.30	3.50

(*iv*) Monteith (1964) derived the following expression for arriving at P_{ET} (mm/day) :

$$\frac{\lambda P_{ET}}{Q_n} = \frac{\frac{\triangle}{\gamma} + \frac{r_i}{r_a}}{\frac{\triangle}{\gamma} + \frac{r_a + r_s}{r_a}} \tag{4}$$

where λ is the latent heat of evaporation (58.5 cal/mm), r_a is the aerodynamic resistance (sec/cm), r_s is the internal resistance of the crop (sec/cm) and r_i is the atmospheric diffusive resistance (sec/cm). Other symbols have the same meaning as explained previously. The atmospheric diffusive resistance (r_i) is given by :

$$r_i = \rho c_p (e_a - e_d)/\gamma Q_n \tag{5}$$

where ρ is the density of air above the vegetation (gm/cm^3), c_p is the specific heat of the air at constant pressure (cal/°C/gm), e_a and e_d are expressed in mb and Q_n is the net radiation (cal/cm^2/sec) and γ is equal to 0.66 mb/°C.

(*v*) As various formulae are available, it was decided to carryout estimates of P_{ET} by (1) classical formulation of Penman, (2) Modified Penman's formulation, (3) Equilibrium Evaporation of McIlroy and (4) Monteith's formulation as given by Eqns. (1) to (4) respectively and compare such estimates between themselves and with the standard Pan evaporation values with a view to suggest the best possible method that can be adopted for estimating crop water requirements.

2. Materials and methods

Potential evapotranspiration was computed for a network of stations in India by Rao *et al.* (1971). These estimates were found to be less than Pan evaporation on a monthly basis, specially at inland stations. This may be due to the use of sunshine/cloudiness data in computing short-wave radiation. Hence measured global solar radiation data (1957—75) 'A' published by IMD (1980) were used in the present study. The wind speed was reduced to 2 m height using the formula of Kohler *et al.* (1959) and tested by Venkataraman and Krishnamurthy (1965).

From a review of experimental data, Monteith (1964) showed that P_{ET} for tall crop can be significantly greater than P_{ET} for a short crop due to variations in 'r_a' relating to them. According to Monteith, 'r_a' varies between 0.5 and 2.0 sec/cm for short and between 0.2 and 0.5 sec/cm for tall crops. He suggested 1.1 and 0.36 sec/cm for r_a of short and tall crops respectively as mean values. These values are used in the present study. The value of r_s was taken as 0.5 sec/cm for both the crops. r_i was computed using Eqn. (5). The values of $S/(S+\gamma)$ at wet bulb temperature were obtained from tables prepared by McIlroy (1960).

The stations selected are Trivandrum, Madras and Visakhapatnam (coastal stations), Dum Dum (Calcutta moist sub-humid) Pune, Nagpur, Ahmedabad and New Delhi (semi-arid) and Jodhpur (arid). Thus, the selected stations covered a good range of the climatic spectrum.

3. Results and discussion

The mean daily values of P_{ET} as computed by Eqns. (1) to (4) alongwith Pan evaporation for each of the 12 months are presented stationwise in Table 1. Evaporation data of Visakhapatnam were found to be doubtful and hence no discussion could be made.

3.1. *Equivalance of P_{ET} short crop with P_{ET} Penman*

In general P_{ET} short crop estimated by the formulation of Monteith (1964) agrees within 10 per cent with P_{ET} estimates of Penman (1963). Penman's formulation required the use of wind run at 2 m level which is not generally available meteorological stations maintained by India Meteorological Department. Even at agrometeorological stations maintained by various Central and State organisations, the lowest point of measurement is 3 m. Again Penman's formula sets no limiting value of wind speed in realising P_{ET} as is to be normally expected. Monteith's formula does not require wind speed and hence this formula may be preferred for estimating P_{ET} of short crop.

3.2. *Relative magnitude of short and tall crop P_{ET}*

The soil evaporation will be negligible when the soil is completely shaded by the crop. Therefore, the only parameter that can lead to differences in the potential evapotranspiration of short and tall crops in the same macro-environment is the variation in the aerodynamic resistance r_a. The ratios of P_{ET} tall crop to P_{ET} short crop show that P_{ET} tall crop is always greater than P_{ET} short crop, *i.e.,* tall crops consume more water than short crops, sometimes 70 per cent or more. Monteith (1964) reported that in the humid Thames valley, UK and in the much drier Sacramento valley of southern California, the tall crops can consume 30 per cent more water than the short crops. However, in climates drier than Sacramento valley as above tall crops can consume even more than 70 per cent water than short crops.

3.3. *Modified Penman P_{ET} in relation to Pan evaporation*

Table 1 shows that P_{ET} by modified Penman is always less than P_{ET} tall crop but is closer to E_P. The ratios are slightly higher than those recommended by FAO (1977).

3.4. *P_{ET} tall crop in relation to E_P*

To judge the applicability of P_{ET} tall crop estimates as a measure of field crop water needs, ratios of P_{ET} tall crop to E_P were tabulated (Table 2). The ratios are generally higher in rabi season than in kharif season except at Ahmedabad. The results are in good agreement with lysimetric observations that peak E_T/E_P ratios are around 1.10 in summer and kharif seasons and around 1.50 in a rabi season (Venkataraman 1979).

3.5. *Equilibrium evaporation in relation to P_{ET} short crop*

It is already shown that P_{ET} short crop is closer to P_{ET} Penman. Priestly and Taylor (1972) had postulated that P_{ET} be taken as 1.26 times the energy compo-

TABLE 2

Ratio of P_{ET} tall crop to mesh covered Class A Pan evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trivandrum	1.16	1.13	1.13	1.14	1.07	1.26	1.08	1.14	1.16	1.05	1.21	1.32
Jodhpur	1.82	1.52	1.34	1.15	0.99	0.92	0.97	1.05	1.25	1.57	1.68	1.43
Ahmedabad	1.29	1.19	1.11	1.02	0.88	0.89	0.76	0.91	0.95	0.85	0.87	0.88
Madras	1.09	1.12	0.96	1.12	1.04	0.75	1.13	1.14	1.22	1.10	1.00	1.15
New Delhi	1.24	1.24	1.37	1.14	1.13	0.92	1.08	1.25	1.27	1.31	1.39	1.31
Pune	1.39	1.09	1.08	0.95	1.05	1.16	0.73	0.96	0.98	1.13	1.34	1.42
Dum Dum	1.66	1.63	1.62	1.22	1.06	1.05	1.09	1.11	1.19	1.35	1.59	1.58
Nagpur	1.43	1.37	1.32	1.19	—	1.11	1.02	1.17	1.13	1.29	1.38	1.50

nent term of the Penman estimate, the latter is Equilibrium Evaporation *vide* Eqn. (3.) This appears true during the months July to September. However, the ratio varies from 1.70 to 2.59 for north Indian stations during the months November to February when supplemental irrigation is accorded.

4. Conclusions

From the above discussion we may conclude as follows :

(*i*) P_{ET} short crop of Montein (1964) is close to P_{ET} of Penman (1963) and hence Monteith's formula may be preferred as it would also be more convenient for computation.

(*ii*) P_{ET} short crop would grossly underestimate the peak crop water demands while P_{ET} tall crop would give true peak water demand.

(*iii*) E_P data may be used where P_{ET} by modified Penman method is to be preferred.

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