Journal of Agrometeorology 6 (2) : 172 - 177 (Dec 2004)

Relative contribution of energy and aerodynamic components in Penman's equation at a semi arid tropical location

N.N.SRIVASTAVA, U.S.VICTOR and P. VIJAYA KUMAR
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad –500 059

ABSTRACT

Many weather stations include measurements of the evaporation from a U S Class – A pan evaporimeter as the basis for calculating the water loss from the crops. But most places are without such measurements, and, even where there is a pan, the measurements may be vitiated by poor maintenance.

This study has shown that the relative contribution between energy and aerodynamic terms in Penman's formula on potential evaporation exists in the ratio of Δ : γ which needs to be changed to Δ : 6.14 γ for the semi arid tropical location of Patancheru, Medak, Andhra Pradesh. With this modification the correlation coefficients between observed and estimated pan evaporation have changed from 0.46 – 0.66 to 0.94 – 0.99 during the test years of 1985 – 2002. Student's 't' test also confirmed validity of this approach.

Key Words: Pan evaporation, energy, aerodynamic, weightage

One of the most versatile equations for calculating natural evaporation was first derived by Penman (1948). In its original form, the equation was used to calculate monthly averages of evaporation from open water surfaces, given the relevant standard climatological records of sunshine, wind speed, temperature and humidity. The equation is essentially written as:

$$Eo = \frac{\Delta Rn + \gamma Ea}{\Delta + \gamma} \qquad (1)$$

Where Rn (mm day^{-1}) is the energy term and Ea (mm day^{-1}) is the aerodynamic term. Δ is the slope of saturation vapour pressure vs temperature curve at mean air temperature and γ is the aerodynamic psychrometric constant. Rn and Ea are written as:

$$Rn = Rs(1-r) - \sigma Ta^4 (0.55 - 0.092\sqrt{e_d})(0.10 + 0.90\frac{n}{N})$$

$$Ea = 0.35(e_s - e_d)(1 + 0.0098\,U_2)$$

Several research workers (Tanner and Pelton, 1960; Abdel Azeez *et al.*, 1964; Thompson and Boyce, 1967; Krishnan and Kushwaha, 1971 and Srivastava *et al.*, 1996) have reported that Penman's (1948) equation underestimated evaporation from open water surface. Underestimation was attributed mainly to less weightage given to aerodynamic term (Baier, 1967; Krishnan and Kushwaha, 1971; and Srivastava *et al.*, 1996).

Though the daily evaporation measurements are carried out using standard U S Class – A open pan evaporimeter at many locations, there is possibility of gaps/faulty recordings due to some practical administrative/technical problems. Thus, there is a necessity to estimate open pan evaporation from weather parameters with reasonable accuracy. We have attempted to assess the relative contribution of aerodynamic vis-à-vis energy balance term in the formula for local conditions of Patancheru region using the multiple regression methodology suggested by Krishnan and Kushwaha (1971).

MATERIALS AND METHODS

Weekly weather data were collected from the International Crops research Institute for the Semi-Arid Tropics (ICRISAT) located at Patancheru (17° 30' N, 78° 16' E and 549 m a.m.s.l.), Medak, Andhra Pradesh for the years 1975 – 2002. Weather data during 1975 – 84 were used to determine the relative contribution of aerodynamic vis-à-vis energy term in Penman's equation and calibration thereof. The data for 1985-2002 were utilized for testing the calibrated equation. Global radiation in equivalent evaporable water was interpolated from values given by Doorenbos and Pruitt (1975). Albedo (r) for the water surface was taken to be 0.06 (Michael *et al.*, 1977). To estimate solar radiation from sunshine hours the constants a and b were taken to be 0.14 and 0.55 (Gangopadhyay *et al.*, 1970). Possible sunshine hours (N) was interpolated from Smithsonian tables (List, 1949). Stefan-Boltzmann's constant σ in equivalent evaporable water was calculated as 1.998467×10^{-9} mm °K^{-4} day^{-1}. Saturation vapour pressure was calculated by Tetens (1930) equation. Actual vapour pressure was worked out using Regnault's formula as modified by August and used by IMD (Anonymous, 1988). Δ was worked out by differentiating the Tetens (1930) equation as given below:

$$\Delta = \frac{18772.02 * e^{\frac{17.269 * T}{T + 237.3}}}{(T + 237.3)^2} \qquad (2)$$

Wind speed at 2 m height was obtained by multiplying the wind speed recorded at 3 m height by a factor of 0.933 as used by Rao *et al.* (1971). γ was worked out to be 0.472 mm of Hg °C^{-1}.

To determine existing relative contribution of γ and Δ terms in Penman's formula, 520 (10 years namely 1975 - 1984 x 52 weeks) values of Δ were tabulated and the average worked out to be 1.509 mm of Hg °C^{-1}. Therefore, the existing mean weightage between radiation and aerodynamic term is as follows:

Rn : Ea = Δ : γ = 1.510 : 0.472 or 3.2 : 1

Pan evaporation is underestimated using the above weightage. Therefore,

Table 1: Correlation between weekly observed and estimated open pan evaporation (mm) at Patancheru, Medak during 1985 - 2002

Year	With original Penman's formula	With modified Penman's formula
1985	0.55	0.97
1986	0.58	0.98
1987	0.66	0.98
1988	0.65	0.99
1989	0.61	0.98
1990	0.61	0.98
1991	0.60	0.99
1992	0.62	0.98
1993	0.61	0.98
1994	0.57	0.99
1995	0.61	0.97
1996	0.63	0.96
1997	0.46	0.94
1998	0.62	0.97
1999	0.49	0.96
2000	0.65	0.97
2001	0.57	0.98
2002	0.64	0.97

multiple regression analysis was carried out between observed pan evaporation and the energy & aerodynamic (mm day^{-1}) terms of Penman's equation during the years of 1975 – 84. The following equation was obtained:

$$Y = 1.13 + 0.26\ X_1 + 0.50\ X_2\ (r^2 = 0.93)$$

Where Y, X_1 and X_2 are the pan evaporation, energy and the aerodynamic terms respectively. The weightage, as suggested by Krishnan *et al.*, (1971), should, therefore, be in the ratio of 0.26: 0.50 or 1: 1.92. Therefore, to get the above ratio we use the following relationship:

$$Rn : Ea = \Delta : 6.14\,\gamma \quad (6.14 = 3.20 \times 1.92)$$

Thus, the Penman's equation for estimating evaporation under ICRISAT (Patancheru) conditions could be written as:

$$Eo = \frac{\Delta\, Rn + 6.14\, \gamma\, Ea}{\Delta + 6.14\, \gamma} \qquad (3)$$

RESULTS AND DISCUSSION

The correlation coefficients (Table 1) between weekly observed and estimated open pan evaporation ranged between 0.46 – 0.66 during the test years of 1985 – 2002 by using Penman's original weightage (Eq. 1). These coefficients increased to very high values of 0.94 – 0.99 if the pan evaporation is estimated by Eq. 3 with revised relative weightage of aerodynamic vis-à-vis energy term.

Student's 't' statistics was also worked out (Table 2) along with the mean weekly observed and estimated (Eq. 3) pan evaporation during the test years of 1985 – 2002. It was worked out for all the 52 weeks using 18 years (1985-2002) of data on observed and estimated pan evaporation.

Observed 't' varies between 0.01 and 1.88 (Table 2) while theoretical value is 2.03 at 5 per cent level of significance and 34 degrees of freedom (n1+n2-2). This shows that the mean differences for the two series of observed and estimated pan evaporation are not significant for any of the 52 weeks. Thus, the approach is

Table 2: Mean observed and estimated weekly pan evaporation (mm) along with 't' statistics at Patancheru, Medak during 1985 – 2002

Weeks	Mean pan evaporation		't' Statistics	Weeks	Mean pan evaporation		't' Statistics
	Observed	Estimated			Observed	Estimated	
1	4.2	4.8	1.59	27	6.4	6.5	0.14
2	4.5	5.1	1.88	28	6.0	5.9	0.07
3	4.7	5.1	1.06	29	5.3	5.3	0.01
4	5.3	5.5	0.62	30	5.1	4.9	0.42
5	5.7	6.0	1.05	31	4.8	4.6	0.43
6	6.3	6.6	0.89	32	4.4	3.9	1.08
7	6.7	6.9	0.54	33	4.1	3.7	0.84
8	7.2	7.4	0.55	34	4.2	3.9	0.85
9	7.9	7.9	0.16	35	4.4	4.1	0.64
10	8.1	8.2	0.22	36	4.3	4.0	0.68
11	8.8	8.8	0.05	37	4.5	4.1	1.01
12	9.1	9.2	0.25	38	4.5	4.0	1.47
13	9.2	9.3	0.12	39	4.6	4.2	0.97
14	9.5	9.1	0.55	40	4.4	4.2	0.56
15	10.5	10.1	0.14	41	4.4	4.3	0.17
16	10.3	10.3	0.01	42	4.8	4.6	0.33
17	10.7	11.1	0.50	43	4.8	4.6	0.50
18	11.4	11.7	0.29	44	4.7	4.6	0.35
19	11.2	11.7	0.40	45	4.7	5.0	0.74
20	11.9	12.3	0.37	46	4.6	4.6	0.07
21	12.0	12.9	0.79	47	4.5	4.5	0.02
22	11.3	11.6	0.20	48	4.7	4.8	0.50
23	9.8	10.2	0.24	49	4.3	4.5	0.54
24	8.1	7.8	0.18	50	4.2	4.5	0.91
25	7.2	7.7	0.43	51	4.3	4.4	0.13
26	7.0	7.3	0.25	52	4.6	4.6	0.21

validated statistically too.

Fig. 1 shows the scatter diagram of observed vs estimated pan evaporation for the entire test period of 1985 - 2002. Most of the points are seen to cluster around 1:1 line during the entire period of 1985-2002 validating the suggested modifications in relative contribution of aerodynamic vis-à-vis energy term quite satisfactorily.

Few data points (estimated evaporation of about 19 mm per day) out of a total of 936 in Fig. 1, represent inadequacy of Eq.3 under very dry and windy conditions (average temperature ~ 34°C, average RH ~ 37 % and wind speed ~ 19 km h^{-1}). Under such conditions the

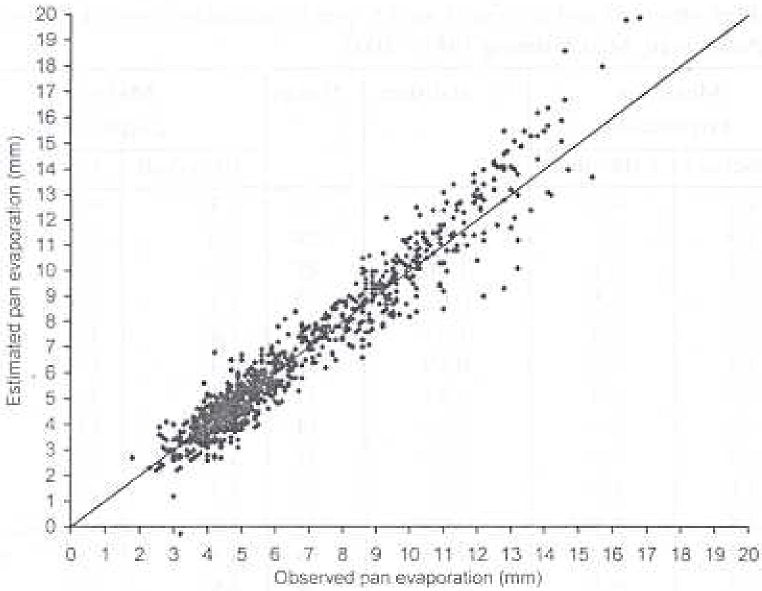

Fig. 1 : Plots of observed vs estimated pan evaporation (1985 - 2002)

estimated pan evaporation needs to be truncated at 16 mm – the highest recorded value.

ACKNOWLEDGEMENTS

The authors are grateful to Dr Y.S.Ramakrishna, Director, Central Research Institute for Dryland Agriculture, Hyderabad for his motivation and valuable encouragement in conducting the above study. We also earnestly express our thankfulness to ICRISAT for providing the weather data for conducting this study.

REFERENCES

Anonymous, 1988. Hygrometric tables (900 mb). India Meteorological Department. ADGM (R) Office, Pune – 411 005. pp 89.

Abdel Azeez, M.H., Taylor, S.A. and Ashcroft, G.L. 1964. Influence of advective energy on transpiration. *Agron. J.*, 56 : 139-142.

Baier, W. 1967. Relationship between soil moisture, actual and potential evapotranspiration. Proc. Hyd. Symp. No. 6. Nat. Res. Council. Canada. 155-204.

Gangopadhyay, M., Datar, S.V. and George, C.J. 1970. On the global solar radiation and evapotranspiration estimates in India. *Indian J. Met. Geophysics*, 210 : 23-30.

Krishnan, A. and Kushwaha, R.S. 1971. A critical study of evaporation by

Penman's method during growing season of vegetation in the arid zone of India. *Archiv. Met. Geophys. Biokl. Ser. B.*, 19 : 267-276.

List, R.J. 1949. Smithsonian Meteorological Tables. Smithsonian Institution. Washington, D.C.

Michael, A.M., Hukkeri, S.B. and Singh, N.P. 1977. Estimating water requirements of crops. IARI Monograph No. 4 (New Series). Water Requirements and Irrigation Management of Crops in india. Water Technology centre. IARI, New Delhi.

Penman, H.L. 1948. Natural Evaporation from open water, bare soil and grass. Proc. Roy. Soc. London(A). 193.

Rao, K.N., George, C.J. and Ramasastri, K.S. 1971. Potential Evapotranspiration (PE) over India. Pre-Publ. Sci. Rep. No. 136. India Meteorological Department.

Srivastava, N.N., Victor, U.S., Vijaya Kumar, P. and Ramana Rao, B.V. 1996. Balancing Penman's Formula on Potential Evaporation at a semi arid location. *Mausam*, 47(1) : 99-101

Tanner, C.B. and Pelton, W.L. 1960. Potential evapotranspiration estimates by approximate energy balance method of Penman. *J. Geophys. Res.*, 65 : 391-413.

Tetens, O. 1930. Uber Einige Meteorologische Begriffe Zeitschrift Geophysic, 6 : 297-309.

Thompson, G.D. and Boyce, J.P. 1967. Daily measurements of potential evapotranspiration from fully canopied sugarcane. *Agric. Met.*, 4 : 267-279.