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Estimation of potential evapotranspiration using a single weather element — The evaporation

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सार — फसल जल प्रबंध से संबंधित किसी भी अध्ययन के लिए विभव वाष्पोत्सर्जन की जानकारी एक मूलभूत आवश्यकता है। विभव वाष्पोत्सर्जन और वाष्पीकरण के बीच परिकल्पना की समानता को ध्यान मे रखते हुए इन दोनों के मध्य रैखीय संबंध स्थापित करने का प्रयास किया गया है।

विभव वाष्पोत्सर्जन और वाष्पीकरण के 10 वर्षों के आंकड़ों के उपयोग से रेखीय समाश्रयण विश्लेषण किया गया। इस अध्ययन के लिए भिन्न-भिन्न अक्षांशों में स्थित तीन केन्द्रों, अर्थात् बेंगलूर, पुणे और हिसार को चुना गया। यह ज्ञात हुआ कि वार्षिक अवधि को शुष्क और नम अवधियों में विभाजित करने से अच्छे परिणाम प्राप्त होते हैं। शुष्क और नम अवधियों के 10 वर्षों के आंकड़ों के विश्लेषण से ज्ञात हुआ कि प्रत्येक डाटा सैट के लिए सहसंबंध गुणांक 0.95 से अधिक है और अवशिष्ट परिवर्तन बहुत कम है।

रैखीय समाश्रयण समीकरण के उपयोग से, भिन्न-भिन्न डाटा सैटों के लिए विभव वाष्पोत्सर्जन का पूर्वानुमान ज्ञात किया गया। आकलित और प्रेक्षित विभव वाष्पोत्सर्जन के बीच सहसंबंध गुणांक 0.90 से अधिक पाया गया। इसका तात्पर्य यह है कि इस सरल पद्धति से विभव वाष्पोत्सर्जन में 80% से अधिक परिवर्तन का पता लगाया जा सकता है। त्रुटि विश्लेषण और काई-वर्ग परीक्षण (काई स्क्वेयर टैस्ट) से पता चलता है कि पूर्वानुमानित और प्रेक्षित मानों में अधिक अंतर नहीं है।

ABSTRACT. Knowledge of potential evapotranspiration is a basic requirement in any study related to crop water management. Observing the conceptual similarity between potential evapotranspiration and evaporation an attempt has been made to establish a linear relationship between the two.

Using 10 years' potential evapotranspiration and evaporation data, linear regression analysis was carried out. Three stations, namely, Bangalore, Pune and Hissar in different latitude belts, were selected for the present study. It was observed that partitioning of the annual period into dry and wet periods gives better results. Analysis of 10 years' data for dry as well as wet period shows that correlation coefficient is more than 0.95 and variance of residual is very small for each data set.

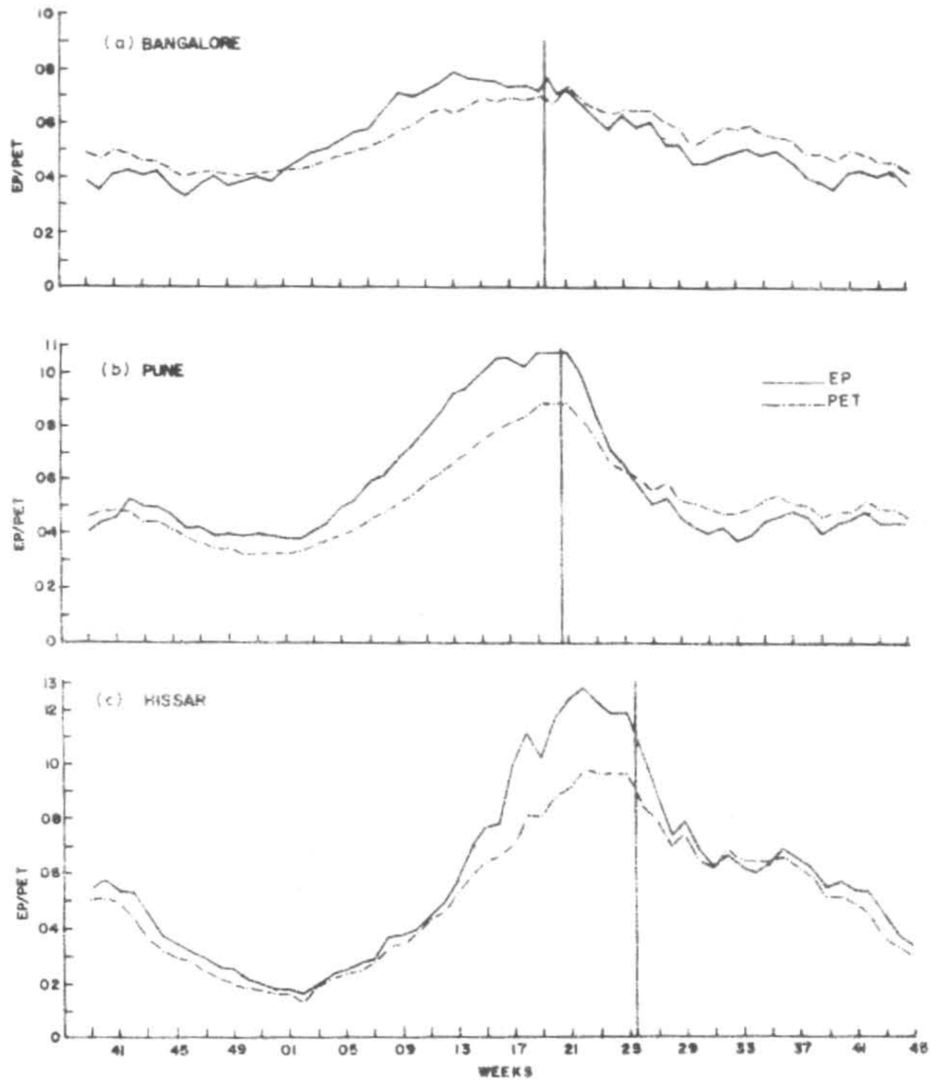
Using the linear regression equation, potential evapotranspiration values were predicted for independent data set. It was found that correlation coefficient between estimated and observed potential evapotranspiration exceeds 0.90, implying that more than 80% of the variation in potential evapotranspiration can be explained by this simple method. Error analysis and also Chi-square test show that predicted values are quite close to observed values.

Key words — Potential evapotranspiration (PET), Evaporation, Regression, Dry and wet periods, Correlation coefficient, Lysimeter.

1. Introduction

Potential evapotranspiration (PET) is a measure of water requirement of uniform short crop when there is no shortage of water and ground is fully covered by crop. While evapotranspiration (ET) is characterised by bio as well as micro meteorological aspects of crop growth, PET by virtue of its definition is derived from meteorological factors alone. A number of scientists have attempted to calculate evapotranspiration from lysimeter studies (Venkatraman *et al.* 1976, Battawar *et al.* 1983, Rathore 1989). However, there is no direct method or device for measurement of PET. Various empirical formulae/methods have been attempted to estimate PET from climatic variables. Among these the most acceptable method is the Penman's (1948) equation. Rao *et al.* (1971) have introduced some modifications in original Penman's equation and carried out extensive study on PET at more than 300 stations in India.

Observing the conceptual similarity it was anticipated that there should exist a direct relationship between PET and evaporation. Jensen (1974) studied the relationship between pan evaporation and potential evapotranspiration. In Puerto Rico scientists have identified pan evaporation as



Figs. 1 (a-c). Weekly averages of daily evaporation and potential evapotranspiration

a valuable tool for estimation of potential evapotranspiration. Studies have shown that PET is proportional to pan evaporation. Constant of proportionality may, however, depend on local climatic characteristics (Doorenbos & Pruitt 1977, Khambete and Biswas 1984, Goyal *et al.* 1989).

In the present study an attempt has been made to establish a linear regression equation between PET and evaporation. To examine the performance of the developed regression equation, the estimation of PET values is also made using observed values of evapotranspiration.

2. Material and methods

2.1. *Penman's method*

Penman's equation, in its modified form alongwith its computational procedure described by Doorenbos and Pruitt (1977), was adopted for calculation of PET from observed weather parameters. The equation is :

$$\text{PET} = c\,[w.\ R_n + (1-w)\,f(u)\,(e_a - e_d)] \qquad (1)$$

where,

w — The weighting factor. Represents the effect of the temperature and altitude on the relationship between solar radiation and potential evapotranspiration,

R_n — Net radiation in equivalent evaporation in mm/day.

$f(u)$ — Wind related function.

e_a — Saturation vapour pressure (hPa) at mean air temperature.

TABLE 1

Linear regression analysis (year-to-year)
Mean and extreme values of various statistical parameters of ten individual years

Period	Correlation coefficient			Variance of residual			Slope of regression line			Intercept of the line		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
						Bangalore						
Annual	0.82	0.87	0.78	0.41	0.48	0.33	0.57	0.66	0.48	2.41	2.83	1.82
Dry	0.90	0.94	0.88	0.24	0.37	0.14	0.59	0.75	0.53	1.87	2.27	0.71
Wet	0.91	0.96	0.87	0.17	0.27	0.07	0.68	0.79	0.55	2.19	2.97	0.94
						Pune						
Annual	0.90	0.94	0.88	0.55	0.71	0.43	0.61	0.66	0.56	1.67	2.06	1.40
Dry	0.96	0.98	0.91	0.26	0.54	0.15	0.67	0.74	0.61	0.84	1.14	0.40
Wet	0.96	0.99	0.93	0.15	0.28	0.06	0.61	0.65	0.51	2.37	2.88	2.12
						Hissar						
Annual	0.95	0.97	0.88	0.59	1.04	0.37	0.72	0.85	0.62	0.96	1.73	0.51
Dry	0.97	0.99	0.90	0.49	0.82	0.18	0.71	0.86	0.62	0.73	1.49	0.30
Wet	0.92	0.96	0.85	0.19	0.33	0.10	0.57	0.61	0.52	2.71	3.00	2.37

e_d — Actual vapour pressure (hPa).

c — Adjusting factor to compensate for the effect of day and weather condition.

2.2. *Regression analysis*

PET values, thus computed alongwith observed evaporation data, were utilised as input for regression analysis. A suitable computer programme was developed to carry out regression analysis of yearly data as well as of 10 years' data together.

Three stations at different latitude belt, namely, Bangalore (13.0° N), Pune (18.5° N) and Hissar (29.0° N) were selected for the present study. For each station weekly means (7 day's means of daily data) of meteorological data : Maximum and minimum temperature, wind speed, relative humidity at hr I (0700 hrs LMT) and hr II (1400 hrs LMT), bright sunshine hrs for the 10 years' period was collected and utilised for calculation of PET values using Penman's equation. Concurrent weekly means of evaporation data were also collected.

Preliminary investigation of a few years' data of Bangalore station revealed that there exists a very good correlation between PET and evaporation (EP). Having a closer look at weekly PET and EP values [Fig. 1 (a)], it was seen that in cloudy or rainy days, particularly in summer, drop in EP values is relatively more in comparison to that of PET values. Considering this, it was felt that the processing of data for dry and wet period would improve upon the results obtained for annual period (dry and wet period together).

Based on weekly rainfall normals, continuous period during May to October with 15 mms or more rainfall in a week for Pune and Hissar was taken as wet period. Comparatively rainy period and total rainfall being considerably higher at Bangalore, period having 20 mm or more rainfall has been taken as wet period. For continuity of data, dry period has been taken commencing after wet period of the year is over and continued up to starting of wet period of following year. According to this criterion annual, dry and wet periods of each station are defined as follows :

Bangalore

Annual : 44th week of year 1 through 43rd week of year 2.

TABLE 2

Regression analysis of EP and PET (10 years' data together)

Period	Average EP	Average PET	C.C.	Variance of residual	Slope (B)	Intercept (A)
			Bangalore			
Annual	5.34	5.43	0.853	0.271	0.625	2.092
Dry	5.60	5.17	0.962	0.091	0.663	1.465
Wet	5.04	5.71	0.976	0.028	0.772	1.822
			Pune			
Annual	5.98	5.34	0.921	0.411	0.633	1.553
Dry	6.33	5.10	0.987	0.089	0.609	0.709
Wet	5.45	5.70	0.990	0.028	0.599	2.426
			Hissar			
Annual	5.98	5.23	0.978	0.279	0.762	0.674
Dry	5.60	4.71	0.992	0.112	0.742	0.555
Wet	7.09	6.80	0.952	0.053	0.595	2.578

Dry : 44th week of year 1 through 19th week of year 2 (28 weeks).

Wet : 20th week to 43rd week of year 2 (24 weeks).

Pune

Annual : 42nd week of year 1 through 41st week of year 2.

Dry : 42nd week of year 1 through 20th week of year 2 (31 weeks).

Wet : 21st week to 41st week of year 2 (21 weeks).

Hissar

Annual : 39th week of year 1 through 38th week of year 2.

Dry : 39th week of year 1 through 25th week of year 2 (38 weeks).

Wet : 26th week to 38th week of year 2 (13 weeks).

Regression analysis of weekly PET and EP values was carried out for annual as well as for dry and wet periods for each year separately. Summary of results is presented in Table 1.

Average weekly PET and EP values over 10 years' period under study were also worked out and analysed. Results of analysis for dry, wet and annual period for 10 years' data together are tabulated in Table 2.

2.3. *Validation*

Equations for regression lines obtained using 10 years' data for dry, wet and annual period respectively have been used as prediction equations for estimating PET from known values of evaporation of respective periods. Data set utilised for validation was of independent period of one year. Data of 1989-90 for Bangalore, 1987-88 for Pune and year 1989-90 for Hissar has been studied for validation of the prediction equation. To test the validation of the estimated PET, some statistical relations were evaluated. These are : (*i*) correlation coefficient between estimated and known PET values. (*ii*) root mean square error (RMSE) to study goodness of fit.

3. Results and discussion

3.1. *Annual variation of EP and PET*

In general, it is observed that by the end of summer when skies are cloudy evaporation drops more rapidly than PET with the result PET and EP are very close by or PET exceeds evaporation.

Bangalore is a high altitude (899.0m) and low latitude (13.0° N) station with moderate temperatures. Wet period extends from 20th to 43rd week and clouding persists a few weeks beyond wet period. Except for initial few weeks EP of dry period is more than PET while in wet period values of PET exceed EP [Fig. 1(a)].

Pune (Lat. 13.0° N, Alt. 560 m) climate is also moderate. However, days of bright sunshine may continue till May end. Consequently evaporation values are higher than PET during complete dry period and initial few weeks of wet period [Fig. 1(b)].

Hissar has relatively low altitude (215 m) and higher latitude (29.0°N). Winter temperatures at Hissar are lower while summer temperatures are higher to those at Pune and Bangalore. Wet period is very short (13 weeks) and receives more sunshine. As the temperatures in post-monsoon and winter period drop, PET and EP also gradually fall, till mid January. Except for the hot summer period, difference between PET and EP is very small, evaporation values being higher [Fig. 1(c)].

Peak values of PET and EP reach in 12/13th week, 19/20th week and 21st week, at Bangalore, Pune and Hissar stations respectively.

3.2. *Regression analysis*

3.2.1. *Correlation coefficient* — At Bangalore (Table 1) for annual period, correlation coefficient for different years varies from 0.78 to 0.87. However, analysis of dry and wet period of each year shows better correlation (around 0.9 or more). At Pune (Table 1) even for annual period the correlation coefficient is around 0.90 which further improves to 0.96 when dry and wet periods are analysed separately. At Hissar mean correlation coefficient for annual period itself is 0.95 and its division into dry and wet does not make any significant improvement.

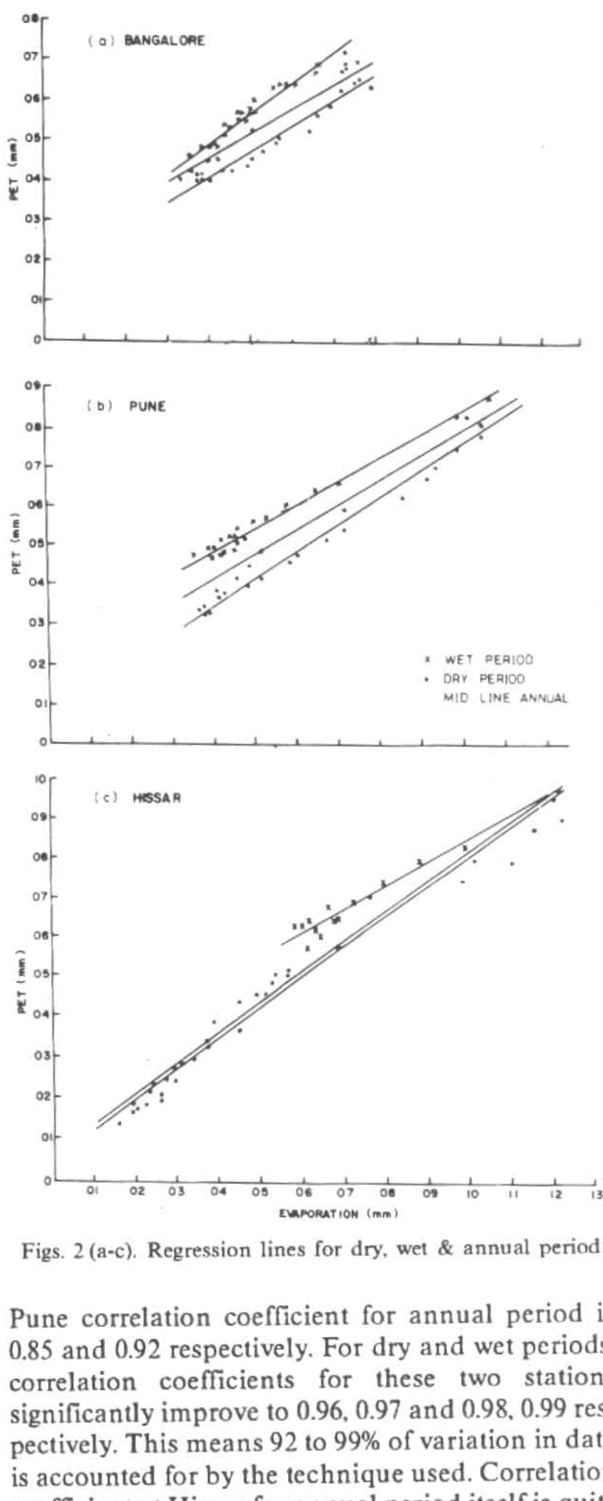
Thus, correlation coefficient between the two elements clearly shows that EP and PET are very closely related to each other and bear a linear relationship.

3.2.2. *Regression equation* — Regression analysis for 10 individual years shows that the slope of line of each year representing the relation between EP and PET is steady. Analysing the data of dry and wet period separately makes the slopes for each individual year virtually same (within ± 0.1 from mean value). The intercepts of these lines, however, are not same but do not differ much indicating that the lines are parallel and close to each other (Table 1). The intercepts significantly higher than zero indicate that when EP is low, EP and PET would come closer. When EP is sufficiently low PET may exceed EP. The situation is observed in wet period or in cloudy skies when incoming solar radiation is very little. In this context authors feel that reduction in radiation and increase in humidity in cloudy skies should cause proportional decrease in PET and EP, however, PET values which are calculated from Penman's equation show lesser drop in PET. This needs further investigation.

3.2.3. *Variance* — It was observed that the residual variance for each year data at all the three stations was very small. 10 years' mean values of variance are tabulated in Table 1. This shows that points (PET against EP) are very close to regression line and error involved in estimation of PET is small. As expected, variance of residual for dry and wet periods were less in comparison to annual period. Analysis of Bangalore shows that for dry and wet periods residual variance lies in between 0.14 & 0.37 and 0.07 & 0.27 respectively, corresponding values for Pune are respectively 0.15 & 0.54 and 0.06 & 0.28 while those for Hissar are 0.18 & 0.82 and 0.10 & 0.33 respectively.

3.3. *Prediction equation*

Results discussed above clearly indicate that a linear regression equation may be established for estimation of PET from known values of EP. To determine numerical constants of prediction equation two alternate methods are available. One way is to take mean of slopes and intercepts obtained in analysis of 10 independent years. Alternatively regression analysis may be carried out by taking 10 years' data together. However, in second method correlation was found to be higher than that for 10 individual years and hence has been used to formulate prediction equation. Results of analysis for annual, dry and wet period for each station are presented in Table 2. It may be seen that the results for all the cases are very good. For Bangalore and



Figs. 2 (a-c). Regression lines for dry, wet & annual period

Pune correlation coefficient for annual period is 0.85 and 0.92 respectively. For dry and wet periods, correlation coefficients for these two stations significantly improve to 0.96, 0.97 and 0.98, 0.99 respectively. This means 92 to 99% of variation in data is accounted for by the technique used. Correlation coefficient at Hissar for annual period itself is quite high (0.98) and partitioning into dry and wet makes no significant improvement. Corresponding regression lines for annual, dry and wet along with data distribution are presented in Figs. 2 (a-c) respectively for 3 stations. Plots show that data points are evenly distributed around corresponding regression line.

3.4. *Validation of the technique*

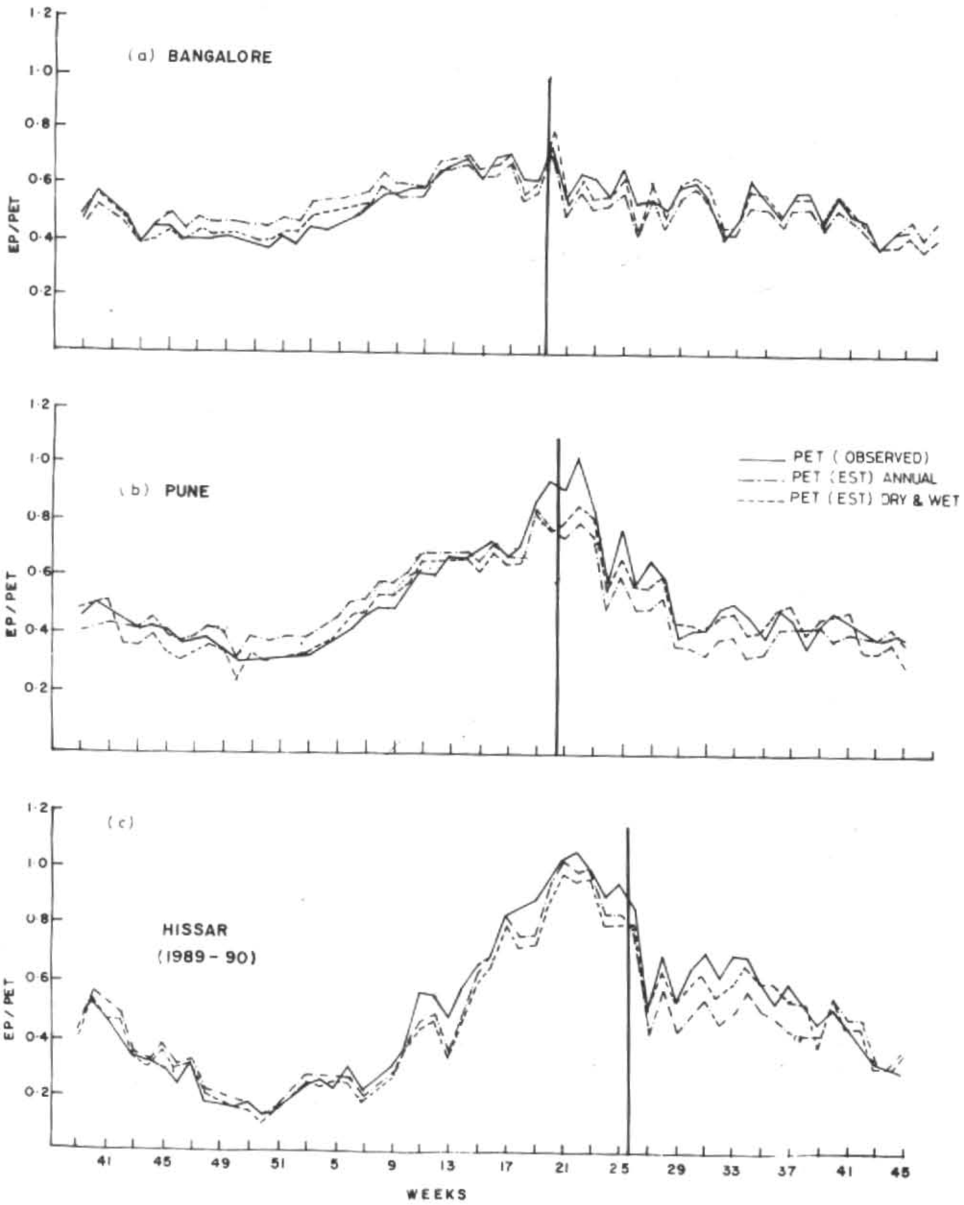
As stated in Section 3.3, regression equations derived using 10 years' data together have been utilised to predict PET from known values of EP picked up from independent data set. The Figs. 3 (a-c) show predicted PET for annual, dry and wet periods alongwith observed PET for Bangalore, Pune and Hissar respectively. It may be seen that predicted values are close to observed values. Results of Bangalore and Pune show further improvement if the annual period is partitioned into dry and wet, *i.e.,* departure from observed values is reduced. At Pune during 20, 21 and 22 weeks rather high PET may be attributed to prevailing high winds (Sec. 2.1), whereas this has little effect on pan evaporation. For Hissar, partitioning in dry and wet period has slightly improved the estimated values for wet period, however, there is no improvement for dry period. This is mostly in conformity to the results obtained in Section 3.3. Correlation coefficient between the two (observed and estimated) for dry and wet periods of each station is around 0.95, which indicates that the prediction equation used to compute PET is quite reliable (Table 3). The correlation coefficients of the order of 0.95 implies that 90% of the variation in PET can be accounted for. Similarly, root mean square errors (RMSE) are very small indicating the two sets of values are very close. To study the goodness of fit χ^2 values have also been worked out. It is seen that χ^2 values are insignificant. χ^2 in dry period, at Bangalore is only 0.74; for Pune it is 1.69 and for Hissar χ^2 is 3.35 while corresponding table values at 99% confidence level are 12.88, 14.95 and 19.97 respectively. Hence the method suggested can be used with reasonably good degree of accuracy to measure potential evapotranspiration.

4. Conclusions

In crop water management and evapotranspiration studies, potential evapotranspiration is an essential input. The linear regression equations can be utilised to climatologically similar locations for the estimation of PET.

Following conclusions can be drawn from the present study :

(*i*) Correlation coefficient between evaporation and potential evapotranspiration is very high and EP and PET bear a linear relationship. However, in cloudy weather or in wet period, evaporation tends to



Figs. 3 (a-c). Observed and estimated potential evapotranspiration (Dry, wet and annual period) for independent data set

drop more rapidly than potential evapotranspiration. Consequently, when the data are processed for dry and wet period separately, departure from observed values is reduced.

(*ii*) Analysis for yearly data shows that slopes remain almost constant and intercepts differ very little, showing that, the regression lines are parallel and very close to each other.

(*iii*) Regression equation for 10 years' data together could be used for prediction of PET from known values of EP. Observed and estimated PET bear a high correlation. Also, χ^2 values are insignificant.

In other words, regression equation provides a useful practical method to estimate potential evapotranspiration from just a single weather element, evaporation.

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TABLE 3

Validity of estimated potential evapotranspiration for independent data set

Period	Mean PET (obs) (O)	Mean PET (est) (E)	CC (r)	RMSE	Chi-sq. (χ^2)	Table value of χ^2 at 95%	Table value of χ^2 at 99%
				Bangalore (1989-90)			
Annual	5.29	5.30	0.829	0.559	3.224	35.61	30.05
Dry	5.11	5.08	0.953	0.369	0.740	16.15	12.88
Wet	5.50	5.48	0.905	0.352	0.570	13.09	10.20
				Pune (1987-88)			
Annual	5.29	5.11	0.904	0.813	6.445	35.61	30.05
Dry	5.01	4.81	0.963	0.518	1.687	18.49	14.95
Wet	5.72	5.51	0.974	0.618	1.184	10.85	8.26
				Hissar (1989-90)			
Annual	5.20	4.84	0.967	0.787	6.622	35.61	30.05
Dry	4.18	4.49	0.984	0.653	3.348	24.09	19.97
Wet	6.38	6.13	0.911	0.485	0.499	5.23	3.57

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References

Battawar, H. B., Shukla, S. P. and Sachidanand, B., 1983, "Evaluation of evapotranspiration and crop coefficient values of Sonalika Wheat (HD-1553)", *Mausam*, **34**, 1, pp. 51-54.

Doorenbos, J. and Pruitt, W. O., 1977, Guide lines for predicting crop water requirements, FAO Irrigation, Drainage Paper No. 24, FAO, Rome.

Goyal, M. R., Ravalo, E. J. and Gonzales, E. A., 1989, "Normal monthly class A pan evaporation for agricultural experiment substations in Puerto Rico", *J. Agri. Univ.*, P.R., **73**, pp. 85-87.

Jensen, M. E. (Editor), 1974. Consumptive use of water and irrigation water requirements : Rep. Tech. Com. Irrigation water requirements, American Soc. Civil Eng. Irrigation and Drainage Div., 227 pp.

Khambete, N. N. and Biswas, B. C., 1984, "Estimation of weekly potential evapotranspiration", *Mausam*, **35**, 2, pp. 209-212.

Penman, H. L., 1948, "Natural evaporation from open water, bare soil and grass," Proc. Roy. Soc., London, series (A), 193, pp. 120-145.

Rao, K. N., George, C. J. and Ramshastri, K. S., 1971, Potential evapotranspiration over India, Scientific. Report No. 136, India Met. Dept.

Rathore, L.S., 1989, Water requirements, water use efficiency of some crops in India, Seminar on Bioclimatology, Mukteshwar.

Venkatraman, S., Sarker, R.P. and Subba Rao, K., 1976, A Comparative study of evapotranspiration of wheat at Akola, Pune and New Delhi, I.M.D., P.P.S.R. No. 76/16.