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631.573 (540.53)

Evaluation of pan coefficient for estimating reference crop evapotranspiration in Solapur station, Maharashtra

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सार - पैन वाष्पीकरण (Epan) से संदर्भित फसल वाष्पोत्सर्जन (ET) के आकलन के लिए पैन गुणांक (Kpan) महत्वपूर्ण घटक होता है। इस शोध पत्र में 1983 से 2012 तक के वर्षों में सोलापुर स्टेशन के मौसम प्राचलों का उपयोग करते हुए क्यूएन्सा, एलेन और प्रुइट, स्नाइडर तथा ओरांग द्वारा प्रस्तावित पाँच पद्धतियों का मूल्यांकन किया गया। यह देखा गया कि वर्ष के दौरान मापे गए मान 0.46 से 0.87 तक की बाई-मॉडल विविधता दर्शाते हैं। पाँचों पद्धतियों में से, 0.38 के RSME के साथ Kpan तथा 0.34 के MAD का आकलन करने के लिए स्नाइडर पद्धति बेहतर पाई गई है। पेनमैन-मॉन्टीएथ पद्धति की तुलना में स्नाइडर पद्धति सही रही।

ABSTRACT. Pan coefficient (K_{pan}) is the important factor for computation of reference crop evapotranspiration (ET_r) from pan evaporation (E_{pan}). In this paper, the five approaches proposed by Cuenca, Allen and Pruitt, Snyder, Pereira and Orang were evaluated by using weather parameters for a Solapur station over the years 1983 to 2012. It was observed that, the measured value shows the bi-model variation during the year with values ranging from 0.46 to 0.87. Out of the five methods, Synder method was found to be the best for estimating K_{pan} with RMSE of 0.38 and MAD of 0.34. By comparing with the Penman-Monteith method, the Snyder approach was best suited.

Key words – Pan coefficient, Pan evaporation, Reference crop evapotranspiration, Penman-Monteith method, Climatological data.

1. Introduction

Reference crop evapotranspiration (ET_r) is an essential component for use in water requirement, design of irrigation, drainage system and real time irrigation scheduling (Snyder, 1992) since the crop evapotranspiration (ET_c) is estimated by ET_r multiplied by the crop coefficient (K_c). One common method to estimate ET_r is converting the class A pan evaporation (E_{pan}) into ET_r by using a pan coefficient (K_{pan}), which varies depending on the site and climatic conditions as showed by Doorenbos and Pruitt (1977) and Allen *et al.,* (1998). Hence, reliable estimation of K_{pan} is required.

To determine ET_r, other methods are available in the literature, which use climatic parameters such as solar radiation, temperature, wind speed and relative humidity (Pruitt, 1966; Doorenbos and Pruitt, 1977; Burman *et al*., 1980; Snyder, 1992) but these parameters are scarcely recorded over large number of stations, in developing countries. Also, these methods need good computational skill. On the other hand, estimation of ET_r directly from the pan evaporation data can easily be done. Many researchers reported a high correlation between E_{pan} and ET_r, when evaporation pans are properly maintained (Jensen *et al.*, 1961; Pruitt, 1966; Doorenbos and Pruitt, 1977). Therefore, a study was conducted to determine, which method is best for estimation of K_{pan} values for Solapur station, Maharashtra, India.

2. Data and methodology

There is a high correlation between E_{pan} and ET_r and expression can be given as follows (Snyder, 1992).

$$ET_r = K_{pan} \times E_{pan} \quad (1)$$

The locations of evaporation pans influence the proper interpretation of pan evaporation data (Howell *et al.*, 1983). The K_{pan} accounts for the upwind fetch of low growing vegetation mean daily wind speed and relative humidity effects on the difference between E_{pan} and ET_r (Jensen, 1974; Doorenbos and Pruitt, 1977). Since the location is important for converting E_{pan} to ET_r (Howell *et al.,* 1983), a study was conducted to identify the most suitable method to determine the K_{pan} values for Hot-agro climatic conditions of Solapur. The following five approaches were considered.

2.1. *Cuenca (1989)*

Frevert *et al.* (1983) proposed the following relationship for K_{pan} as a function of daily mean relative humidity, wind speed and upwind fetch distance. The relationship was then modified by Cuenca,(1989) and was given as follows:

$$K_{pan} = 0.475 - (0.245 \times 10^{-3} \times U_2) + (0.516 \times 10^{-2} \times RH) + (0.118 \times 10^{-2} \times F) - (0.16 \times 10^{-2} \times F) - (0.16 \times 10^{-4} \times RH^2) - (0.101 \times 10^{-5} \times F^2) - (0.8 \times 10^{-8} \times RH^2 \times U_2) - (0.10 \times 10^{-7}) \times RH^2 \times F \quad (2)$$

where,

U_2 – Daily mean wind speed measured at 2 m height above the soil surface in km day^{-1}, RH – Daily mean relative humidity in % and F – Upwind fetch distance of low growing vegetation (m).

2.2. *Allen and Pruitt (1991)*

$$K_{pan} = 0.108 - 0.0286 \times U_2 + 0.0422 \times \ln(F) + 0.1434 \times \ln(RH) - 0.000631 \times [\ln(F)]^2 \times \ln(RH) \quad (3)$$

where,

U_2 – Daily mean wind speed measured at 2 m height above the soil surface in km day^{-1}, RH – Daily mean relative humidity in % and F – Upwind fetch distance of low growing vegetation (m)

2.3. *Snyder (1992)*

Snyder (1992) reported that the K_{pan} relationship proposed by Cuenca (1989) was complex and gave unsatisfactory results for some climatic conditions when compared with original coefficients published by Doorenbos and Pruitt (1977). The following relationship was suggested.

$$K_{pan} = 0.482 + [(0.024 \times \ln(F)] - (0.000376 \times U_2) + (0.0045 \times RH) \quad (4)$$

where,

U_2 - Daily mean wind speed measured at 2 m height above the soil surface in km day^{-1}, RH - Daily mean relative humidity in % and F - Upwind fetch distance of low growing vegetation (m).

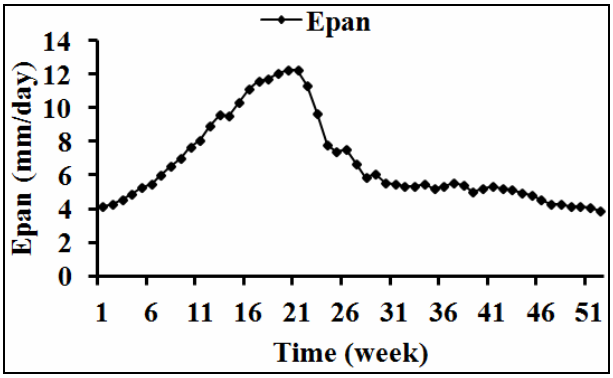


Fig. 1. Average weekly class A pan evaporation (mm) over 30 years

2.4. *Pereira et al. (1995)*

Pereira *et al.* (1995) developed the following relationship for K_{pan} based on temperature and psychometric constant.

$$K_{pan} = 0.85 \times \frac{(\Delta + \gamma)}{(\Delta + \gamma) \times (1 + 0.33 \times U_2)} \quad (5)$$

where,

Δ - Slope of the saturation vapour pressure curve (kPa^oC^{-1})

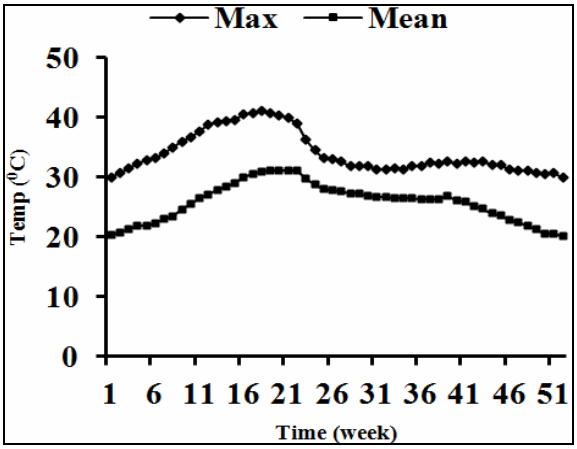
γ - Psychometric constant ($0.0634 kPa^oC^{-1}$)

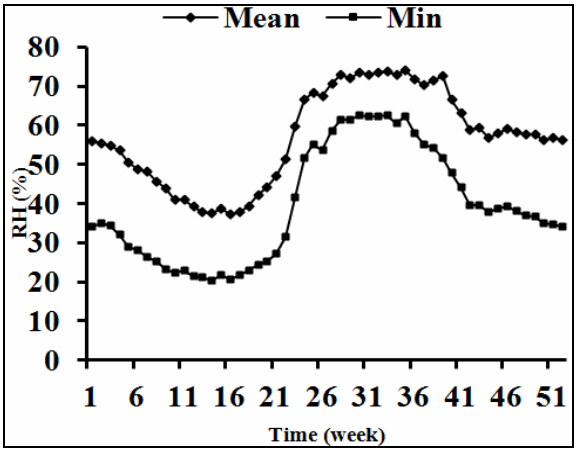
2.5. *Orang (1998)*

Orang (1998) developed an equation for K_{pan} using interpolation between fetch distances and based on the data used to developed FAO 24 K_{pan} values (Doorenbos and Pruitt 1977). Adopting linear regression techniques similar to Snyder (1992) he proposed the following equation.

$$K_{pan} = 0.51206 - (0.000321 \times U_2) + (0.002889 \times RH) + (0.031886 \times \ln(F) - 0.000107 \times RH \times \ln(F) \quad (6)$$

Equations (2) through (6) require testing or calibration when they are used under different climatic conditions. The accuracy and reliability of these equation may differ from one location to another because some assumptions might have been made that could limit the application in particular climate (Irmark *et al.*, 2002). To our knowledge, Eqns. (2) through (6) were not evaluated for Solapur stations. Also different researchers have reported dissimilar results for varying climatic conditions. Conceicao (2002) recommended Eqn. (3) for warm and





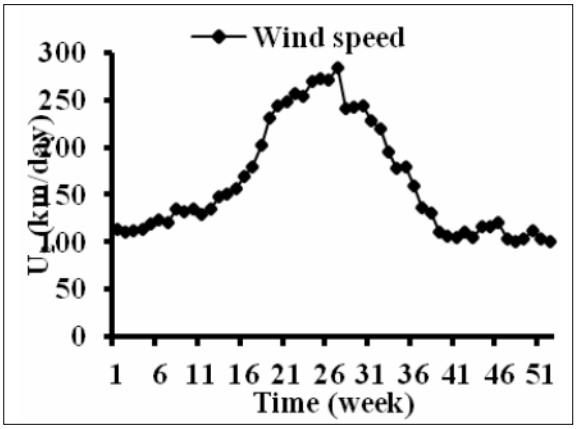


Fig. 2. Mean measured daily climatological parameters over 30 years at Solapur

mild climate of Nortwest Brazil. On the other hand Eqn. (2) gave better results in humid conditions (Irmark *et al.*, 2002). The reliability and accuracy of these relationships does need to be carefully tested and or calibrated for the local climate in order to obtain more reliable and accurate estimates of ET_r from K_{pan} data as in this case for Solapur regions.

2.6. *Penman-Monteith method*

The P-M method was used in this study to test the accuracy of the ET_r estimated from K_{pan} equations, because the comparative studies (Itenfisu *et al.*, 2000; Allen *et al.*, 1998 and so on) have confirmed the superior performance of P-M method. The Penman-Monteith method has strong likelihood of correctly predicting ET_r in a wide range of location and climates (Allen *et al.*, 1998). In the P-M method the daily values of reference ET_r were estimated in the by equation (1).

$$ET_r = 0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a) \quad (7)$$

where,

ET_r = Reference evapotranspiration (mm/day), G = Soil heat flux density (MJ / m^2 / day), R_n = Net radiation (MJ / m^2 / day), T = Mean daily air temperature (ºC), γ = Psychometric constant (kPa / ºC), Δ = Slope of saturation vapour pressure function (kPa / ºC), e_s = Saturation vapour pressure at temperature T (kPa), e_a = Actual vapour pressure at dew point temperature (kPa) and u_2 = Average daily wind speed at 2 m height (m/sec).

It is recommended to refer to Allen *et al.,* (1998) for the details of estimation of R_n, γ, Δ, e_s and e_a.

2.7. *Evaluation of methods*

An attempt was made to evaluate the performance of the K_{pan} estimation methods in daily ET_r estimates, using the pan evaporation data. Several performance criteria including root mean square error (RMSE), mean absolute deviation (MAD), percentage error (PE), correlation coefficient (r) and index of agreement (d) (Wilmott, 1981) were used to test the results through the following equations.

2.7.1. *Root mean square error (RMSE)*

$$RMSE = \sqrt{\frac{1}{N}\sum_{1}^{N}(C_i - O_i)^2} \quad (8)$$

2.7.2. *Mean absolute deviation (MAD)*

$$MAD = \frac{1}{N}\sum_{1}^{N}(C_i - O_i) \quad (9)$$

TABLE 1

Monthly mean values of the observed K_{pan} (ET_r/E_{pan}) and mean monthly values obtained from Eqns. 2 to 6

Months	ET_r/E_{Pan}	Cuenca	Allen and Pruitt	Snyder	Pereira	Orang
January	0.84	0.82	0.81	0.84	0.44	0.81
February	0.80	0.79	0.79	0.80	0.39	0.79
March	0.70	0.77	0.77	0.77	0.34	0.77
April	0.65	0.76	0.76	0.76	0.29	0.76
May	0.64	0.77	0.75	0.76	0.20	0.75
June	0.69	0.80	0.78	0.83	0.18	0.78
July	0.74	0.82	0.80	0.87	0.19	0.80
August	0.79	0.83	0.82	0.90	0.25	0.83
September	0.80	0.85	0.84	0.92	0.35	0.84
October	0.79	0.84	0.83	0.89	0.44	0.83
November	0.86	0.82	0.82	0.85	0.43	0.81
December	0.90	0.82	0.81	0.85	0.46	0.81
SD	0.08	0.03	0.03	0.05	0.11	0.03
CV (%)	11	3	4	6	32	3

TABLE 2

Statistical test for comparison of estimated mean and annual mean ET_r using Eqns. 2 to 6 and P-M method

Statistical test	Cuenca	Allen and Pruitt	Snyder	Pereira *et al.*,	Orang
r	0.93	0.87	0.96	-0.27	0.92
RMSE (mm/day)	0.71	0.70	0.38	1.22	0.75
MAD (mm/day)	0.71	0.70	0.34	1.61	0.75
PE (%)	14.60	14.34	8.20	50.56	15.90

2.7.3. *Percentage error of estimate (PE)*

$$PE = \left[\frac{(C_i - O_i)}{C_i}\right] \times 100\% \qquad (10)$$

2.7.4. *Corrélation coefficient (r)*

$$r = \frac{\sum_1^N (C_i - C_m)(O_i - O_m)}{\sqrt{\sum_1^N (C_i - C_m)^2}\sqrt{\sum_1^N (O_i - O_m)^2}} \qquad (11)$$

where,

O - Observed values based on P-M, C - Computed values based on K_{pan} of the various methods, O_m - Mean observed values, C_m - Mean Computed values, $C_i' = C_i - O_m$ and $O_i' = O_i - O_m$ and N - Number of observations.

2.8. *Study area and data*

The study is conducted for Solapur district and area is bounded by north latitude 17º10' to 18º32' and east longitude by 74º42' to 76º 15'. The study area is located in south east fringe of Maharashtra state and lies entirely in Bhima and Sina basins with total area of 14844.6 km^2, which is 4.82% of the total area of Maharashtra State. The district has altitude 483.5 m above mean sea level. This region is characterized by semi-arid climate with little or no water surplus. Agro-climatically the entire district comes under rain shadow area. Rainfall is uncertain and scanty. The monsoon period is from second fortnight of

June to end of September bringing rains from south-west monsoon.

Daily weather data from 1983 to 2012 were obtained from IMD, Pune, ADR and NRCP, Solapur. Climatological variables included maximum and minimum temperature, maximum and minimum humidity, sunshine hour, rainfall, wind speed as well as wind direction at 2 m height above ground surface and evaporation. The Class A pan evaporimeter is surrounded by fallow land. Value of F used for the computation of K_{pan} is 100 m.

3. Results and discussion

3.1. *Climatological data*

The average 30 years daily E_{pan} was measured from class A pan evaporimeter is given in Fig. 1. The peak E_{pan} was experienced during the period of 15 April to 15 May and the peak seems to be related to condition of high temperature, low humidity and increasing wind speeds (Fig. 2). A large drop in E_{pan} occurred when the air temperature decreased and relative humidity increased during the late May period.

3.2. *Evaluations of pan coefficient methods*

The mean monthly values of observed and estimated K_{pan} are presented in Table 1. The K_{pan} values varied between 0.69 to 0.83, 0.69 to 0.82, 0.67 to 0.87, 0.18 to 0.46 and 0.67 to 0.80 for Cuenca, Allen and Pruitt, Snyder, Pereira and Orang methods. Except Pereira method, rest of the methods K_{pan} values showed bi-modal variation across the years lower in the summer months and higher in the rainy and winter months. This is indicated by lowest in SD and CV (%) in Pereira method. Goyal (2005) also reported higher K_{pan} values in rainy and winter seasons compared to summer season in an arid environment of Jodhapur (Rajsthan). The Snyder method showed highest correlation (0.96) with K_{pan} followed by Cuenca (0.93), Orang (0.92) and Allen and Pruitt (0.87). Pereira *et al.* (-0.27) method showed negative correlation with the observed values. Considering the statistical criteria r, RMSE, MAD, PE and d-index, Snyder method was found to be the best for estimating K_{pan} values followed by Cuenca, Orang, Allen and Pruitt and Pereira *et al.,* methods (Table 2). Guendakar *et al.,* (2008) and Pradhan *et al.* (2013) also observed Snyder method is the best method for a semi-arid environment in India. Daily values of K_{pan} were computed using Eqns. (2) through (5) and were plotted in Fig. 3. The computed daily values of K_{pan} were nearly similar for Eqns. (2) to (5), whereas Eqn. 6 gave lower value of K_{pan}. In particular, Eqns. (2) to (5) results are almost equal values of K_{pan} infer during the monsoon (mid June to mid October). Estimated monthly mean K_{pan} values and are given in Table 1. In Table 1, it can be seen that the Snyder (1992) approach gave the best agreement. The Pereira *et al.* (1995) showed poor ability to predict K_{pan} which might be due exclusion of the fetch distance (Conceicao, 2002). The sequence of performance from the most to the least accurate methods is Snyder, (1992), Orang (1998) Cuenca (1989) and Allen and Pruitt (1991). Because of the poor performance of Pereira *et al.*, 1995, it is eliminated for further analysis. The K_{pan} values computed by Eqns. (2 to 6) were used to estimate daily ET_r (using Eqn. 1) and were compared with ET_r computed by P-M (Eqn. 7). A comparison in Fig. 3, revealed that the daily P-M ET_r tended to be higher than ET_r estimated from E_{pan} using Eqns. (2 to 6).

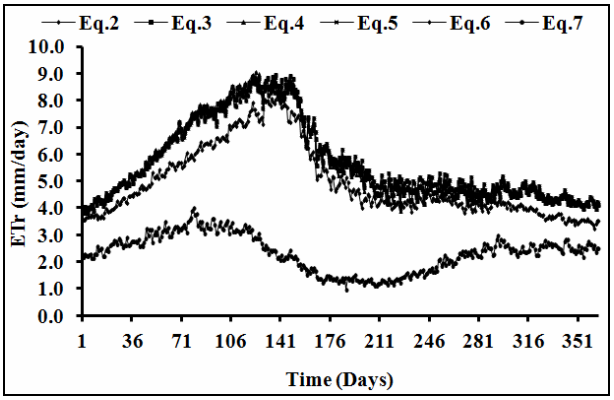


Fig. 3. Calculated daily ET_r by P-M method and using Eqn. (2) to Eqn. (6)

3.3. *Evaluation of ET_r method*

The relation between daily ET_r estimated by Penman-Monteith method and by Eqn. 1 using different K_{pan} equations shows that all the methods estimated higher ET_r values during the summer followed by rainy and winter months. Through Snyder method showed highest correlation (0.96) with standard method and least by Pereira *et al.*, method (-0.27), all the methods were significantly related to the standard method. Considering statistical tests such as r, RMSE, MAD and PE, Snyder was the best method with r value of 0.96, RMSE of 0.38 and MAD of 0.36 and d-index values of 1.00 followed by Allen and Pruitt; Orang; Cuenca and Pereira *et al.*, Similar result reported by Gundekar *et al.*, and Pradhan *et al.*, for semi-arid environment.

4. Conclusions

From this study, it is recommended that temporal variation in K_{pan} should be estimated for computing representative ET_r. The ET_r computed using the K_{pan} of

Snyder (1992) method gave close agreement with the Penman-Monteith method. Hence, Snyder method is recommended for estimating K_{pan} for Solapur station among the five approaches Pereira *et al.,* (1995) gave a poor performance in Solapur region.

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