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

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ABSTRACT. Pan coefficient (Kpan) is the important factor for computation of reference crop evapotranspiration (ETr) from pan evaporation (Epan). 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, Snyder method was found to be the best for estimating Kpan 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 (ETr) 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 (ETc) is estimated by ETr multiplied by the crop coefficient (Kc). One common method to estimate ETr is converting the class A pan evaporation (Epan) into ETr by using a pan coefficient (Kpan), 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 Kpan is required.

To determine ETc, 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 ETc directly from the pan evaporation data can easily be done. Many researchers reported a high correlation between Epan and ETc, 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 Kpan values for Solapur station, Maharashtra, India.

2. Data and methodology

There is a high correlation between Epan and ETc, and expression can be given as follows (Snyder, 1992).

\[ E_{Tr} = K_{pan} \times E_{pan} \] (1)

The locations of evaporation pans influence the proper interpretation of pan evaporation data (Howell et al., 1983). The Kpan accounts for the upwind fetch of low growing vegetation mean daily wind speed and relative humidity effects on the difference between Epan and ETc (Jensen, 1974; Doorenbos and Pruitt, 1977). Since the location is important for converting Epan to ETc (Howell et al., 1983), a study was conducted to identify the most suitable method to determine the Kpan 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:

$$K_{pan} = 0.475 - (0.245 \times 10^{-3} \times U_2) + (0.516 \times 10^{-2} \times RH) + (0.118 \times 10^{-2} \times F) - (0.16 \times 10^{-4} \times RH^2) - (0.101 \times 10^{-5} \times F^2) - (0.8 \times 10^{-8} \times RH^2 \times U_2) - (0.10 \times 10^{-7} \times RH^2 \times F)$$  \hspace{1cm} (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)

$$K_{pan} = 0.108 - 0.0286 \times U_2 + 0.0422 \times \ln(F) + 0.1434 \times \ln(RH) - 0.000631 \times [\ln(F)]^2 \times \ln(RH)$$  \hspace{1cm} (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.

$$K_{pan} = 0.482 + [0.024 \times \ln(F)] - (0.000376 \times U_2) + (0.0045 \times RH)$$  \hspace{1cm} (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).

2.4. Pereira et al. (1995)

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

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

where,

$\Delta$ - Slope of the saturation vapour pressure curve (kPa°C$^{-1}$)

$\gamma$ - Psychometric constant (0.0634 kPa°C$^{-1}$)

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.

$$K_{pan} = 0.51206 - (0.000321 \times U_2) + (0.002889 \times RH) + (0.031886 \times \ln(F) - 0.000107 \times RH \times \ln(F))$$  \hspace{1cm} (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
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).

\[
\text{ET}_r = 0.408 \Delta (R_n - G) + \gamma \left( \frac{900}{T + 273} \right) u_2 (e_s - e_a) 
\]

where,

ET$_r$ = Reference evapotranspiration (mm/day),
G = Soil heat flux density (MJ/m²/day),
R$_n$ = Net radiation (MJ/m²/day),
T = Mean daily air temperature (°C),
\( \gamma \) = Psychometric constant (kPa/°C),
\( \Delta \) = Slope of saturation vapour pressure function (kPa/°C),
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$_n$, \( \gamma \), \( \Delta \), 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)

\[
\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (C_i - O_i)^2} 
\]

2.7.2. Mean absolute deviation (MAD)

\[
\text{MAD} = \frac{1}{N} \sum_{i=1}^{N} |C_i - O_i| 
\]
TABLE 1

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

| Months   | $ET_r/EPan$ | 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, 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)

$$PE = \left( \frac{(C_i - O_i)}{C_i} \right) \times 100\%$$  \hspace{1cm} (10)

2.7.4. Corrélation coefficient ($r$)

$$r = \frac{\sum_{i=1}^{N} (C_i - C_m)(O_i - O_m)}{\sqrt{\sum_{i=1}^{N} (C_i - C_m)^2} \sqrt{\sum_{i=1}^{N} (O_i - O_m)^2}}$$  \hspace{1cm} (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 km², 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 $K_{\text{pan}}$ is 100 m.

3. Results and discussion

3.1. Climatological data

The average 30 years daily $E_{\text{pan}}$ was measured from class A pan evaporimeter is given in Fig. 1. The peak $E_{\text{pan}}$ 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 $E_{\text{pan}}$ 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 $K_{\text{pan}}$ are presented in Table 1. The $K_{\text{pan}}$ 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 $K_{\text{pan}}$ 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 $K_{\text{pan}}$ values in rainy and winter seasons compared to summer season in an arid environment of Jodhpur (Rajasthan). The Snyder method showed highest correlation (0.96) with $K_{\text{pan}}$ 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 $K_{\text{pan}}$ 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 $K_{\text{pan}}$ were computed using Eqns. (2 to 6) and were plotted in Fig. 3. The computed daily values of $K_{\text{pan}}$ were nearly similar for Eqns. (2) to (5), whereas Eqn. 6 gave lower value of $K_{\text{pan}}$. In particular, Eqns. (2) to (5) results are almost equal values of $K_{\text{pan}}$ infer during the monsoon (mid June to mid October). Estimated monthly mean $K_{\text{pan}}$ 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 $K_{\text{pan}}$ which might be due exclusion of the fetch distance (Conceiacao, 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 $K_{\text{pan}}$ 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 $E_{\text{pan}}$ using Eqns. (2 to 6).

3.3. Evaluation of $ET_r$ method

The relation between daily ET, estimated by Penman-Monteith method and by Eqn. 1 using different $K_{\text{pan}}$ 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 Gundeckar et al., and Pradhan et al., for semi-arid environment.

4. Conclusions

From this study, it is recommended that temporal variation in $K_{\text{pan}}$ should be estimated for computing representative $ET_r$. The $ET_r$ computed using the $K_{\text{pan}}$ of
Snyder (1992) method gave close agreement with the Penman-Monteith method. Hence, Snyder method is recommended for estimating $K_{\text{pan}}$ for Solapur station among the five approaches. Pereira et al., (1995) gave a poor performance in Solapur region.

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