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Evaluation of pan coefficient methods for estimating FAO-56 reference crop evapotranspiration in a semi-arid environment

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ABSTRACT

Five empirical methods (*viz.* Cuenca, 1989; Snyder, 1992; Orang, 1998; Pereira, 1995 and Allen and Pruit, 1991) were evaluated to find out Kp using daily weather data (temperature, relative humidity and wind speed) of Indian Agricultural Research Institute station over the years 1997 to 2011. It was observed that the measured Kp values showed bi-modal variation during the year with values ranging between 0.72 to 0.93, being lower in the summer months and higher in rainy and winter months. Out of the five methods, Snyder method was found to be the best for estimating Kp with RMSE of 0.05, and MAD of 0.04. The ETo estimated with Kp of Snyder method also showed lowest RMSE of 0.19, and MAD about 0.16. It is recommended that temporal variation in Kp should be computed for each station for estimation of ETo and Snyder method is recommended for estimating Kp in semi-arid environments.

Key words: Pan coefficient, pan evaporation, reference crop evapotranspiration, FAO-56

Reference crop evapotranspiration (ETo) is essential for accurate estimation of the crop water requirements which is helpful in irrigation planning, field water balance studies, watershed hydrology, etc. Many methods have been proposed for the estimation of ETo, based on the energy budget approach, such as (a) FAO-24 Blaney-Criddle method, (b) Priestly-Taylor method, (c) the FAO-24 Penman Method, (d) Hargreaves method, (e) FAO-24 Radiation method, and (f) FAO-56 Penman-Monteith method. The FAO-56 Penman-Monteith method is the most popular and authentic methodology in agricultural studies. But these methods use climatic parameters like solar radiation, temperature, wind speed and relative humidity which are scarce in developing countries. Estimation of ETo from the pan evaporation (Ep) data using pan coefficient (Kp) is commonly practiced because of its applicability, ease and wide availability of pan evaporation data. Also, many works have reported a high degree of correlation between Ep and ETo when evaporation pan are properly maintained (Jensen *et al.,* 1961; Pruitt, 1966; Doorenbos and Pruit, 1977). But most users adopt generic Kp values or empirical methods without carrying out local calibration. It necessitates a reliable estimation of Kp as using a single Kp value for the majority of the stations throughout the year may entail significant error in the estimation of ETo. Therefore a study was conducted to find out the value of Kp for different months and evaluate different empirical methods for estimation of Kp in a semi arid region of India.

MATERIALS AND METHODS

There is a strong correlation between Ep and ET_O, and the relation between these two is given as follows:

$$ET_O = Ep \times Kp \qquad \text{(Eq. 1)}$$

The Kp accounts for relative humidity, wind speed and windward side distance of green crop or a dry fallow. The values of Kp cover a range between 0.3 to 1.1 (Aschonitis *et al.,* 2012) and is directly proportional to relative humidity and inversely proportional to wind speed (Allen *et al.,* 1998; Gundekar *et al.,* 2008 and Rahimikhoob, 2009). For a particular location the above values i.e., relative humidity and wind speed varies regularly and hence the Kp. So the Kp values were found out daily and then month-wise by averaging daily values. The following five approaches were considered.

Snyder (1992)

$$Kp = 0.482-(0.000376\times u_2) + (0.024\times \ln(F)) + (0.0045\times RH) \qquad \text{(Eq. 2)}$$

where, u_2 is mean daily wind speed at 2 m above the soil surface in km day^{-1}; RH is mean daily relative humidity in % and F is the windward side distance of green crop or a dry fallow in m.

Cuenca (1989)

$$Kp = 0.475- (2.4\times10^{-4}.u_2) + (5.16\times10^{-3}.RH) + (1.18\times10^{-3}.F)-(1.6\times10^{-5}.RH^2)-(1.01\times10^{-6}.F^2)-(8\times10^{-8}.RH^2.u^2)-(0.1\times10^{-7}.RH^2.F) \qquad \text{(Eq. 3)}$$

where, u_2 is mean daily wind speed at 2 m above the soil surface in km day^{-1}; RH is mean daily relative humidity in % and F is the windward side distance of green crop or a dry fallow in m.

Orang (1998)

$$Kp = 0.51206-(0.000321.u_2) + (0.031886.\ln(F)) + (0.002889.RH) \quad \text{(Eq. 4)}$$

where u_2 is mean daily wind speed at 2 m above the soil surface in m sec^{-1}; RH is mean daily relative humidity in % and F is the windward side distance of green crop or a dry fallow in m.

Pereira et al. (1995)

$$Kp = 0.85(\Delta+\gamma) / [\ \Delta+\gamma(1+0.33\times u_2)] \quad \text{(Eq. 5)}$$

where, Δ = slope of the saturation vapour pressure curve (kPa°C^{-1}); γ is psychrometric constant (i.e. 0.0642 k Pa°C^{-1}) and u_2 is mean daily wind speed at 2 m above the soil surface in m sec^{-1}.

Allen and Pruit, (1991)

$$Kp = 0.108 - 0.0286.u_2 + 0.0422.\ln(F) + 0.1434.\ln(RH) - 0.000631.[\ln(F)]^2.\ln[RH] \quad \text{(Eq. 6)}$$

where, u_2 is mean daily wind speed at 2 m above the soil surface in m sec^{-1}; RH is mean daily relative humidity in % and F is the windward side distance of green crop or a dry fallow in m.

The accuracy and reliability of the above mentioned empirical equations differ from one location to another and hence needs testing or calibration when they are to be used under different climatic conditions. So the Kp values obtained from the above empirical methods were compared with the most accepted methods of Kp which is obtained by dividing pan evaporation to reference evaporation as calculated by the FAO-56 Penman-Monteith Method (ETo/Ep) (Allen *et al.,* 1998; Gundekar *et al.,* 2008; Haldar *et al.,* 2005, so on). After that ETo obtained from pan coefficient values of different method were compared with the ETo of FAO-56 Penman and Monteith Method. The FAO-56 Penman and Monteith equation for calculating daily ET_0 (mm day^{-1}) using daily average data as expressed by Eq. (7) is shown below (Allen *et al.,* 1998):

$$ET_O = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)} \quad \text{(Eq. 7)}$$

where Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G the soil heat flux density (MJ m^{-2} day^{-1}); T the mean daily air temperature at 2 m height (°C); u_2 the wind speed at 2 m height (m sec^{-1}); e_s the saturation vapor pressure (kPa); e_a the actual vapor pressure (kPa); (e_s-e_a) the saturation vapor pressure deficit (kPa); Δ the slope of vapor pressure curve (kPa°C^{-1}); and γ the psychrometric constant (kPa°C^{-1}).

Study area and data

For the qualitative and quantitative evaluation of Kp for the semiarid region, the data of the Indian Agricultural Research Institute, Pusa were used. The region is located between 28°37' and 28°39' N latitude and 77°90' and 77°11' E longitude with an elevation of 228.7 m above mean sea level. The climate is semi arid and sub-tropical, and experiences average rainfall of 769 mm. About 80 % of total rainfalls are due to the South-West Monsoon (July to September). It is characterized by extreme temperatures, the annual maximum temperature goes as high as 45°C in summer, whereas the minimum temperature dip to as low as 1°C in winter. The area experiences extreme cold during the month of January and the maximum temperature is recorded in May. The yearly sunshine duration recorded over the region is between 5.2 and 8.2 h. The annual average evaporation is approximately 4.5mm day^{-1}. The annual wind speed ranges from 2.7 to 6.5 km hr^{-1}.

Daily weather data from 1997 to 2011 were obtained from the meteorological observatory of IARI, New Delhi. Meteorological variables included rainfall, maximum and minimum air temperature, relative humidity, wind speed at 2 m height, bright sunshine hour, and Class A Pan evaporation. The class-A pan evaporimeter (USWB) is sited on a short green grass cover. The value of F used for the computation of Kp is 10 m.

Evaluation of methods

The evaluation of different methods were done by using Root Mean Square Error (RMSE), Mean Absolute Deviation (MAD), correlation coefficient (r) and index of agreement (d) (Wilmott, 1981) and are given by:

$$r = \frac{\sum_1^N (Ci-Cm)(Oi-Om)}{\sqrt{\sum_1^N (Ci-Cm)^2}.\sqrt{\sum_1^N (Oi-Om)^2}} \quad \text{(Eq. 8)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_1^N (Ci-Oi)^2} \quad \text{(Eq. 9)}$$

$$MAD = \frac{1}{N}\sum_1^N |Ci-Oi| \quad \text{(Eq. 10)}$$

$$\text{Index of agreement} \quad d = 1-\frac{\sum_1^N (Ci-Oi)^2}{\sum_1^N (|Ci'|-|Oi'|)^2} \quad \text{(Eq. 11)}$$

where, *O* is the observed values, *C* is the computed values by the other methods and *Om and Cm* are the mean observed and computed values respectively, $C_i' = C_i - O_m$; $O_i' = O_i - O_m$.

RESULTS AND DISCUSSION

Meteorological parameters

May was the hottest month (T_{max} = 39.4°C) whereas January was the coldest (T_{min} = 6.2°C) month during the study period. Summer season was drier compared to *kharif* and winter season as indicated by lower relative humidity (51.83%). Summer season also showed more number of bright sunshine hours (7.6 to 8.2 hours) and higher average wind speed (3.7 to 5.9 km hr^{-1}). The higher pan evaporation in April (8.1 mm day^{-1}), May (9.1 mm day^{-1}) and June (8.4 mm day^{-1}) seems to be related to the higher temperature, lower humidity, more number of bright sunshine hours and higher average wind speed. The weather condition during the study period followed a similar trend to the long term average weather condition of the station. Relation between ETo (FAO-56 Penman and Monteith) and USWB Class A Pan evaporation (Average from 1997 to 2011) is presented in Fig. 1. It shows a good correlation between ETo and Pan evaporation (Jensen *et al.,* 1961; Pruitt, 1966; Doorenbos and Pruit, 1975), which indicates that with a suitable pan coefficient value, the pan evaporation can be used successfully for the estimation of reference evapotranspiration in this semi arid region.

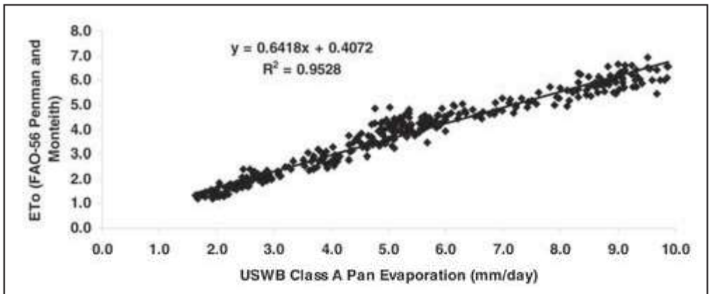

Fig. 1 : Relation between ETo (FAO-56 Penman and Monteith) and USWB Class A Pan evaporation (average from 1997 to 2011).

Evaluation of Pan coefficient methods

The mean monthly values of observed and estimated Kp are presented in Table 1. The Kp values varied between 0.72 to 0.93, 0.70 to 0.84, 0.67 to 0.76, 0.66 to 0.76, 0.77 to 0.81 and 0.69 to 0.78 for standard/observed, Snyder, Orang, Cuenca, Pereira and Allen and Pruit method. Except Pereira methods, rest of the methods Kp values showed bimodal variation across the years being lower in the summer months and higher in rainy and winter months. This is indicated by lowest SD and CV in Pereira methods. Goyal (2005) also reported higher Kp values for *kharif* and winter seasons compared to summer season in an arid environment of Jodhpur. The Snyder method showed highest correlation (0.68) with the standard/observed Kp followed by Cuenca (0.66), Orang (0.64) and Allen and Pruit (0.61). However, Pereira method showed negative correlation with the observed/standard method. Considering the statistical criteria r, RMSE, MAD and d index Snyder method was found to be the best for estimating Kp values followed by Cuenca, Orang, Allen and Pruit and Pereira *et al.,* method (Table 2). Guendakar *et al.,* (2008) also observed Snyder method is the best method for a semi arid environment in India.

Table 1 : Mean monthly values of the observed Kp (ETo/Ep) and mean monthly values using different equations

Month	ETo/Ep	Snyder	Cuenca	Orang	Pereira *et al.,*	Allen and Pruit
Jan	0.83	0.83	0.75	0.75	0.77	0.78
Feb	0.86	0.80	0.73	0.74	0.77	0.76
Mar	0.80	0.77	0.71	0.71	0.78	0.74
Apr	0.72	0.70	0.66	0.67	0.78	0.70
May	0.74	0.70	0.66	0.67	0.78	0.69
June	0.78	0.74	0.69	0.69	0.78	0.72
July	0.88	0.82	0.75	0.74	0.79	0.77
Aug	0.93	0.84	0.76	0.76	0.80	0.78
Sept	0.85	0.83	0.75	0.75	0.80	0.78
Oct	0.76	0.80	0.73	0.73	0.81	0.76
Nov	0.77	0.81	0.74	0.74	0.81	0.77
Dec	0.75	0.83	0.75	0.75	0.79	0.78
Mean	0.75	0.73	0.67	0.67	0.73	0.70
SD	0.06	0.05	0.04	0.03	0.02	0.03
CV (%)	9	7	5	5	2	4

Table 2 : Statistical test of Kp estimation methods with the observed method

Statistical test	Snyder	Cuenca	Orang	Pereira *et al.,*	Allen and Pruit
r	0.68	0.66	0.64	-0.05	0.61
RMSE	0.05	0.10	0.10	0.07	0.07
MAD	0.04	0.09	0.08	0.06	0.06
d-index	0.78	0.56	0.55	0.30	0.60

Evaluation of ET_O methods

The relation between monthly ET_O estimated by FAO-56 Penman and Monteith method and by Eq. 1 using different Kp equations (a) Snyder (b) Orang (c) Cuenca (d) Pereira *et al.,* and (e) Allen and Pruit method showed that all the methods estimated higher ETo values during the summer followed by rainy and winter months. Though Snyder method showed highest correlation (0.99) with the standard method and least by Pereira method (0.96), all the methods were significantly related to the standard method. Considering statistical tests such as r, RMSE and MAD, Snyder was the best method with r value of 0.99, RMSE of 0.186 and MAD of 0.160 and D index value of 1.00 followed by Orang, Cuenca, Allen and Pruit and Pereira *et al.,* Similar results were reported by Gundekar *et al.,* (2008) for a semi arid environment.

CONCLUSIONS

From this study it is recommended that temporal variation in Kp should be estimated for each station for computing representative ETo. The ETo computed using the Kp of Snyder method gave close agreement with the FAO-56 Penman-Monteith method. So, Snyder method is recommended for estimating Kp in semi-arid environments.

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