Usefulness of class A Pan coefficient models for computation of reference evapotranspiration for a semi-arid region

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(*Received 8 April 2013, Modified 22 July 2013*)

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सार – पैन वाष्पीकरण (E_{pan}) का उपयोग करके वाष्पोत्सर्जन (ET_0) आकलन की विश्वसनीयता पैन गुणांक (K_{pan}) के सटीक निर्धारण पर निर्भर करती है। इस शोध पत्र में भारत के गुजरात राज्य के अर्द्धशुष्क क्षेत्र के 33 वर्षों के जलवायविक डेटा सेट का उपयोग करके छः वाष्पोत्सर्जन (ET_0) मॉडुलनों की उपयोगिताओं का आकलन किया गया है। जिन समीकरणों की तुलना की गई है वे हैं- क्वेन्का (1989), एलेन एण्ड प्रूत्त (1991), स्नीडर (1992), संशोधित स्नीडर (ग्रीस्मर एट. अल., 2002), ओरंग (1998) और पेरिस एट. अल. (1995)। इन समीकरणों से प्राप्त किए गए दैनिक K_{pan} मानों से वाष्पोत्सर्जन आँकड़ों की गणना की गई है और इसकी तुलना खाद्य एवं कृषि संगठन (FAO) – पेनमन - मोनटीथ (FAO56-PM) प्रणाली के साथ की गई है। दृष्टि तुलना और सांख्यिकीय मानदंडों पर आधारित संशोधित स्नीडर और ओरंग मॉडल का उपयोग करते हुए ET_0 मानों की गणना की गई है जो FAO56-PM प्रणाली से प्राप्त किए गए दैनिक, मासिक और वार्षिक आकलन के अन्य मॉडल की तुलना में काफी सही है। अभी तक तैयार किए गए मॉडलों का अनुक्रमिक प्रदर्शन इस प्रकार हैं: संशोधित स्नीडर (समीकरण 5) > ओरंग (समीकरण 6) > क्वेन्का (समीकरण 2) > एलेन एण्ड प्रूत्त (समीकरण 3) > (समीकरण 4) > पेरिरा एट. अल. (समीकरण 7)। इसलिए मौजूदा जलवायविक परिस्थितियों में अर्द्धशुष्क क्षेत्र की वाष्पोत्सर्जन (ET_0) की गणना करने के लिए संशोधित स्नीडर मॉडल (ग्रीस्मर एट. अल., 2002) को सर्वोत्तम मॉडल के रूप में अनुशंसित किया जा सकता है।

ABSTRACT. The reliability of estimates of reference evapotranspiration (ET_0) using pan evaporation (E_{pan}) depends on the accurate determination of pan coefficients (K_{pan}). Six ET_0 models were evaluated for their usefulness using 33-year climatological dataset of a semi-arid region of the Gujarat state of India. The equations compared include Cuenca (1989), Allen and Pruitt (1991), Snyder (1992), Modified Snyder (Grismer *et al.*, 2002), Orang (1998), and Pereira *et al.* (1995). The ET_0 data, calculated using daily K_{pan} values from these equations, were compared to the Food and Agricultural Organization (FAO)-Penman-Monteith (FAO56-PM) method as a reference. Based on the visual comparison as well as from the statistical criteria, ET_0 values computed using Modified Snyder and Orang model have very close agreement with the FAO56-PM method for daily, monthly, and annual estimates as compared to other approaches. The sequential performances of the explored models was found as: Modified Snyder (Eqn. 5) > Orang (Eqn. 6) > Cuenca Eqn. (2) > Allen & Pruitt (Eqn. 3) > Snyder (Eqn. 4) > Pereira *et al.* (Eqn. 7) model. Therefore, the Modified Snyder model (Grismer *et al.*, 2002) could be recommended as the best model for ET_0 computations under these prevailing climatic conditions for a semi arid region.

Key words – Reference evapotranspiration, Pan coefficient, Evaporation, FAO.

1. Introduction

Evaporation and evapotranspiration processes are the major components of the hydrologic cycle which play a vital role in agricultural and hydro-meteorological studies as well as in the operation of reservoirs, design of irrigation and drainage systems, water resources management and irrigation scheduling (Ozturk and Apaydin, 1998; Lee *et al.*, 2004; Snyder *et al.*, 2005; Lopez-Urrea *et al.*, 2006; Gundekar *et al.*, 2008; Sabziparvar *et al.*, 2010; and Rahimikhoob *et al.*, 2012). Appropriate method of estimation has been at the forefront of the research community and has developed large and sound theoretical knowledge and practical applications, mainly validated through adequate field measurements. The evapotranspiration (ET) is a very

important and necessary parameter in many scientific fields in general and irrigation scheduling in particular. Many factors affect ET, including weather parameters such as solar radiation, air temperature, humidity, and wind speed; crop factors such as crop type, variety, density and the stage of growth and management and environmental conditions such as soil conditions, salinity, fertility, crop disease and pests (Allen *et al*., 1998). Because of the interdependence of most of these factors and their spatial and temporal variability, it is virtually impossible to formulate an equation that can be used to estimate actual ET from various crops under different conditions. About 50 methods are available for estimation of ET_0, often yielding inconsistent results as their assumptions and meteorological data requirements differ. It is expensive to equip meteorology stations with sophisticated instruments to measure these data essentially in developing countries. Therefore, it is recommended to apply simpler models because they need parameters that are readily available from station-observed meteorological data (Tabari, 2010). In many areas, the necessary meteorological data are lacking, and simpler techniques are required and therefore the idea of standardizing ET equations using what is termed as reference evapotranspiration (ET_0) was introduced (Jensen, 1968; Jensen *et al*., 1971; Doorenbos and Pruitt, 1975).

Reference evapotranspiration (ET_0) is defined as the "rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1}, and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and with adequate water" (Allen *et al*., 1994a). Many different methods for estimating ET_0 have been developed, most of which are complex and require a significant number of weather parameters such as solar radiation, temperature, wind speed and relative humidity (Pruitt, 1966; Doorenbos and Pruitt, 1977; Burman *et al*., 1980; Snyder, 1992; Smith *et al*., 1996). Notably, the availability of data on these parameters is scarce in developing countries and at the same time, these methods require good computational skills. One of the most common and fairly reliable techniques for estimating ET_0 is using evaporation pan data, with adjustments made for the pan environment (Singh, 1989). However, a reliable estimation of ET_0 using pan evaporation (E_{pan}) data depends on the accurate determination of pan coefficients (K_{pan}). Evaporation pans [Class A pan U.S. Weather Bureau (U.S.W.B.)] are used extensively throughout the world because of the simplicity of the method and ease of data interpretation.

Numerous studies (Jensen *et al*., 1961; Pruitt, 1966; Doorenbos and Pruitt, 1975) have shown that a high correlation exists between E_{pan} and ET_0, when evaporation pans are maintained properly. However, reliable estimation of reference evapo-transpiration (ET_0) using pan evaporation (E_{pan}) data depends on the accurate determination of pan coefficients (K_{pan}), which is defined as the ratio of ET_0 to E_{pan} and is found to vary from 0.35 to 0.80. K_p is basically a correction factor which depends upon the prevailing upwind fetch distance, average daily wind speed, and relative humidity associated with the installation conditions of the evaporation pan (Doorenbos and Pruitt, 1977). The relationship between ET_0 and E_{pan} can be expressed as (Snyder 1992):

$$ET_0 = E_{pan} \times K_{pan} \tag{1}$$

The local environments (Pruitt, 1966; Doorenbos and Pruitt, 1977; Burman *et al*., 1980) in which the evaporation pans are located are critical to the proper interpretation of evaporation pan data (Howell *et al*., 1983). The K_{pan} values for upwind fetch of low-growing vegetation, mean daily wind speed, and mean daily relative humidity, have been used worldwide to convert E_{pan} data to ET_0 and were first published by Jensen (1974) and subsequently tabulated by Doorenbos and Pruitt (1977). Most of the K_{pan} estimation models have been developed based on the FAO-24 table using linear, nonlinear and indicator regression techniques or combinations thereof. Keeping the above in view, in this study, an attempt has been made to evaluate the relative performances of the six different K_{pan} models such as Cuenca (1989), Allen & Pruitt (1991), Snyder (1992), Modified Snyder (Grismer *et al*., 2002), Orang (1998), and Pereira *et al*. (1995) by comparing them against the Food and Agriculture Organization (FAO)-Penman-Monteith (FAO56-PM) (Allen 1986; Allen *et al*., 1994a, 1994b, 1998) ET_0 method. The FAO56-PM method was used in this study to test the accuracy of the K_{pan} equations because comparative studies (Jensen *et al*., 1990; Itenfisu *et al*., 2000) have confirmed the superior performance of the FAO56-PM method, and this method was accepted as a standard method for estimating ET_0 by the ASCE Task Committee on Standardization of Reference ET (Allen *et al*., 1994a,b; Smith *et al*., 1996; Allen *et al*., 1998, 2000; Walter *et al*., 2000) for a semi-arid region of the Gujarat state of India.

2. Data and methodology

In this section, a brief description of each of the six different K_{pan} estimation models along with Food and Agriculture Organization (FAO)-Penman-Monteith (FAO56-PM) has been discussed here. All the models are functions of daily mean relative humidity, RH (%), daily mean wind run, U_2 (km/day) and fetch distance, F(m).

2.1. *Models description*

2.1.1. *Cuenca (1989)*

A polynomial model was developed by Frevert *et al.* (1983) to calculate daily K_{pan} as a function of daily mean relative humidity, wind speed, and upwind-fetch, low-growing vegetation. However, the coefficients of this equation were later rounded off by Cuenca (1989). The final expression for K_{pan} can be expressed as:

$$K_{pan} = 0.475 - (0.245 \times 10^{-3} U_2) + (0.516 \times 10^{-2} RH) + (0.118 \times 10^{-2} F) - (0.16 \times 10^{-4} RH^2) - (0.101 \times 10^{-5} F^2) - (0.8 \times 10^{-8} RH^2 U_2) - (0.1 \times 10^{-7} RH^2 F) \quad (2)$$

where,

U_2 = daily mean wind speed measured at 2 m height (km/day), RH = daily mean relative humidity (%) and F = upwind fetch distance of low-growing vegetation (m).

2.1.2. *Allen and Pruitt model*

The general expression of Allen and Pruitt (1991) model can be expressed as:

$$K_{pan} = 0.108 - 0.000331 U_2 + 0.0422 \ln (F) + 0.1434 \ln (RH) - 0.000631[\ln (F)]^2 \ln (RH) \quad (3)$$

2.1.3. *Snyder model*

Snyder (1992) found that the Cuenca (1989) model (Eqn. 2) was complex, and under some climatic conditions the results were quite different from the original coefficients published by Doorenbos and Pruitt (1977). As a result, Snyder (1992) proposed a simpler equation to calculate daily K_{pan} values as a function of U_2, RH, and F. The final expression of the model can be expressed as:

$$K_{pan} = 0.482 + [0.24 \ln (F)] - (0.000376 U_2) + (0.0045 RH) \quad (4)$$

2.1.4. *Modified Snyder model*

Grismer *et al.* (2002) modified the Snyder (1992) model to compute K_{pan}. The modified model is based on the original data table rather than FAO 24 K_{pan} Table. The expression for modified Snyder model can be expressed as:

$$K_{pan} = 0.5321 - 0.00030 U_2 + 0.0249 \ln (F) + 0.0025 RH \quad (5)$$

2.1.5. *Orang model*

Orang (1998) developed a model to compute K_{pan} using interpolation between fetch distances (F) and based on the data used to develop FAO 24 K_{pan} values (Doorenbos and Pruitt, 1977). The general expression of the model can be expressed as:

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

2.1.6. *Pereira et al. model*

Pereira *et al.* (1995) developed a K_{pan} estimation model based on temperature and the psychrometric constant. The general expression of the model can be expressed as:

$$K_{pan} = 0.85 \times (\Delta + \gamma) / [\Delta + \gamma (1 + 0.33 U_2)] \quad (7)$$

where, Δ = Slope of the saturation vapour pressure curve (kPa $^{\circ}C^{-1}$) and γ = Psychometric constant (*i.e.*, 0.067 kPa $^{\circ}C^{-1}$). In this study, we evaluate the relative performance of the above models, *i.e.*, Eqns. (2) to (7) in comparison to the Food and Agricultural Organization (FAO) – Penman - Monteith (FAO56 - PM) method for computation of ET_0 for a semi-arid region of the Gujarat state of India. A brief description of Penman-Monteith (FAO56-PM) is also being given here as follows.

2.1.7. *Penman-Monteith (FAO56-PM) model*

The Penman-Monteith (FAO56-PM) (Allen 1986; Allen *et al.*, 1994a, 1994b, 1998) ET_0 method has been used in this study to test the accuracy of the ET_0 estimated from K_{pan} models (Eqns. 2-7), because the comparative studies (Jensen *et al.*, 1990; Itenfisu *et al.*, 2000) have confirmed the superior performance of FAO56-PM method. Moreover, the method has also been accepted as a standard method for estimating ET_0 by the ASCE Task Committee on standardization of ET_0. The FAO56-PM method computes ET_0 using the following relationship along with other auxiliary equations presented in Allen *et al*. (1998), expressed as:

$$ET_0 = \frac{0.408 \, \Delta \, (R_n - G) + \gamma \, \dfrac{900}{T + 273} U_2 \, (e_s - e_a)}{\Delta + \gamma \, (1 + 0.34 U_2)} \quad (8)$$

where, ET_0 = reference crop evapotranspiration (mm/day); T = mean daily air temperature measured between 1.5 and 2 m height (°C) [$T = (T_{max} + T_{min})/2$]; R_n = mean daily net radiation (MJ m^{-2} day^{-1}); G = soil
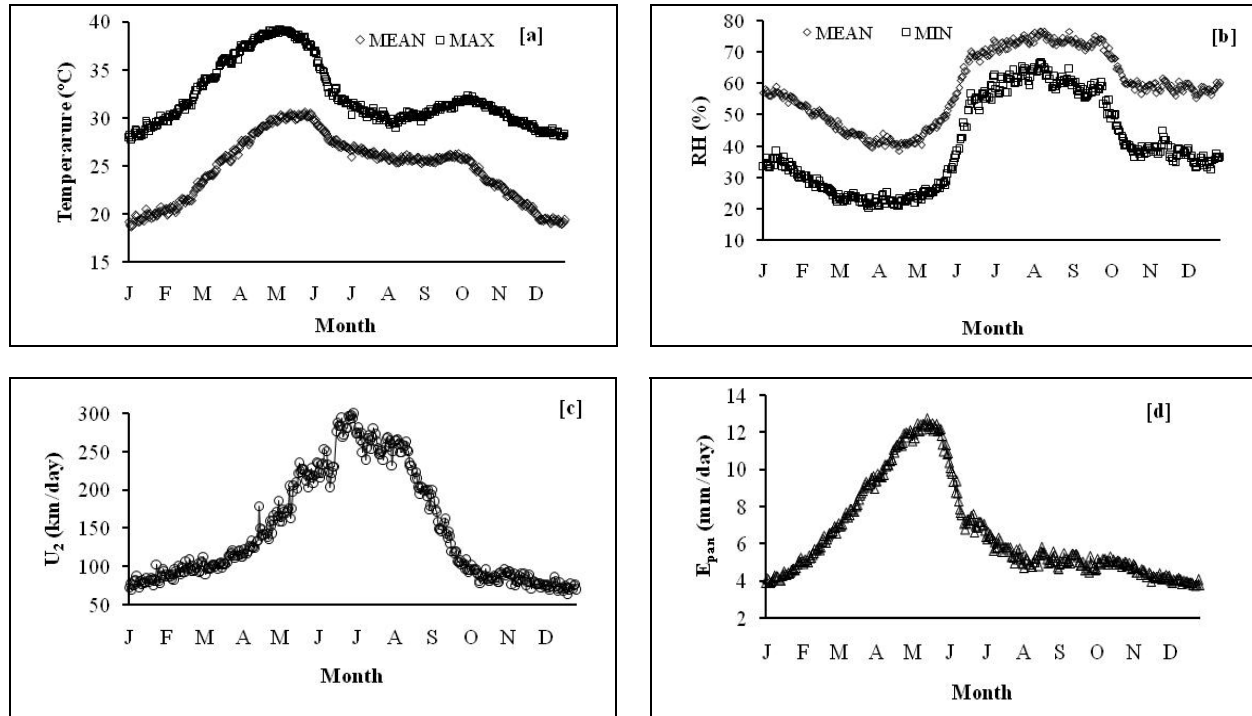
Figs. 1(a-d).   Mean measured daily meteorological parameters averaged over 33 years as: (a) mean daily mean and maximum temperature, (b) mean daily mean and minimum RH (%), (c) mean daily wind speed, and (d) mean daily evaporation

heat flux density (MJ m^{-2} day^{-1}); U_2 = wind speed at 2 m height (ms^{-1}); e_s = saturation vapor pressure (kPa); e_a = actual vapour pressure (kPa); $(e_s - e_a)$ = vapor pressure deficit (kPa); Δ = slope of vapour pressure curve (kPa °C^{-1}) and γ = psychrometric constant (= 0.067 kPa °C^{-1}).

The daily wind speed measured at 3.0 m above ground was converted to 2 m height by using the relationship given by Allen *et al.* (1998). The equation can be expressed as:

$$U_2 = U_z \frac{4.87}{\ln(67.8\,z - 5.42)} \qquad (9)$$

where, U_2 = wind speed at 2 m above ground surface (m/s); U_z = measured wind speed at z m above ground surface (m/s); and z = height of measurement above ground surface (m).

However, the application of the FAO56 - PM approach is limited in many regions due to the lack of required weather data. In such circumstances, equations based on either radiation or on temperature are often used to estimate reference evapotranspiration. There is an urgent need to evaluate the simpler ET$_0$ equations relative to the FAO56 - PM equation. The practitioners

and researchers need to be provided guidance on the choice of the most appropriate ET$_0$ equation to be adopted when weather data are insufficient to apply the FAO56 - PM equation (Trajkovic & Kolakovic, 2009).

3.   Study area and climate dataset and procedures

Daily weather data for a period of 33-years (1975-2008) were obtained from the Agricultural Meteorological Department of Anand Agricultural University, Anand, Gujarat, India. The Anand district is situated between 22° 06' to 22° 43' N latitude and 72° 2' to 73° 12' E longitude at an elevation of 45.1 m above mean sea level. The climate in the study area is arid to semi-arid with an average annual rainfall of 858.8 mm, approximately 75% of which occurs during June through September. The mean maximum and minimum temperature ranges from 27.9 to 39.2 °C and 9.5 to 23.1 °C, respectively. Daily mean temperature ranges from 19 to 30.2 °C and relative humidity from 38 to 76%. In the present study, the value of upwind fetch distance of low-growing vegetation (F) was taken as 100 m for computing K$_{pan}$ values. Figs. 1 (a-d) show mean measured daily meteorological parameters averaged over 33 years as: (a) mean daily mean and maximum temperature, (b) mean daily mean and minimum RH, (c) mean daily wind speed and (d) mean daily evaporation.

TABLE 1

Computed monthly mean Kpan coefficients using Eqns. (2-7) and FAO56-PM (Eqn. 8)

Month	Pan Coefficients (K_{pan}) Models						
	Cuenca	Allen & Pruitt	Snyder	Modify Snyder	Orang	Pereira *et al.*	FAO 56-PM
January	0.82	0.82	0.84	0.79	0.79	0.80	0.80
February	0.79	0.80	0.80	0.77	0.77	0.79	0.80
March	0.77	0.77	0.77	0.74	0.75	0.79	0.80
April	0.75	0.76	0.75	0.73	0.73	0.78	0.80
May	0.76	0.76	0.75	0.73	0.73	0.76	0.75
June	0.80	0.78	0.82	0.76	0.76	0.72	0.75
July	0.82	0.80	0.85	0.77	0.77	0.71	0.75
August	0.83	0.81	0.87	0.79	0.79	0.72	0.75
September	0.85	0.84	0.89	0.81	0.81	0.77	0.80
October	0.84	0.83	0.87	0.80	0.80	0.81	0.80
November	0.83	0.83	0.85	0.79	0.80	0.80	0.80
December	0.83	0.83	0.85	0.79	0.80	0.81	0.80

TABLE 2

Monthly annual average of ET_0 (mm) and RMSE and PEE of ET_0 Estimates

Month	FAO 56-PM	Cuenca (1989)			Allen & Pruitt			Snyder (1992)			Modified Snyder			Orang			Pereira *et al.*		
	ET_0 (mm)	ET_K (mm)	RMSE (mm)	PE (%)	ET_K (mm)	RMSE (mm)	PE (%)	ET_K (mm)	RMSE (mm)	PE (%)	ET_K (mm)	RMSE (mm)	PE (%)	ET_K (mm)	RMSE (mm)	PE (%)	ET_K (mm)	RMSE (mm)	PE (%)
Jan	3.16	3.57	0.26	15.29	3.58	0.27	15.58	3.65	0.33	17.61	3.42	0.16	11.38	3.45	0.18	11.91	3.48	0.23	13.45
Feb	4.12	4.64	0.49	15.89	4.67	0.54	16.73	4.69	0.57	17.07	4.47	0.34	12.95	4.50	0.37	13.40	4.61	0.51	16.27
Mar	5.33	6.25	1.22	19.54	6.32	1.36	20.76	6.25	1.31	20.28	6.08	0.90	16.42	6.12	0.97	17.10	6.45	1.59	23.00
Apr	6.86	7.99	2.68	21.83	8.05	2.82	22.68	7.94	2.71	21.59	7.77	2.12	19.05	7.82	2.21	19.67	8.31	3.30	26.05
May	7.70	9.07	2.74	19.43	9.07	2.74	19.45	8.99	2.68	18.96	8.71	1.82	15.36	8.75	1.90	15.74	9.10	2.70	19.47
Jun	5.79	6.31	0.67	12.43	6.19	0.56	11.29	6.41	0.79	13.56	5.98	0.40	9.89	5.98	0.41	9.90	5.79	0.43	10.01
Jul	4.58	4.74	0.22	8.46	4.62	0.19	7.62	4.89	0.30	9.54	4.49	0.18	8.01	4.48	0.18	8.08	4.12	0.38	12.37
Aug	4.26	4.22	0.14	7.61	4.12	0.15	7.99	4.38	0.16	8.19	4.00	0.18	8.87	3.99	0.19	8.91	3.67	0.46	14.75
Sep	4.12	4.22	0.20	9.79	4.15	0.19	9.43	4.41	0.28	11.54	4.01	0.18	9.09	4.02	0.18	9.10	3.83	0.25	10.07
Oct	3.89	4.09	0.24	10.61	4.08	0.25	10.81	4.22	0.30	11.81	3.91	0.19	9.81	3.93	0.20	9.85	3.96	0.25	10.59
Nov	3.23	3.61	0.28	13.61	3.61	0.29	13.89	3.71	0.35	15.98	3.46	0.18	10.88	3.48	0.19	11.26	3.52	0.24	12.87
Dec	2.81	3.26	0.30	18.56	3.27	0.31	18.70	3.35	0.38	21.48	3.12	0.19	14.36	3.14	0.21	14.90	3.18	0.26	16.57
Avg.	4.65	5.16	**0.79**	**14.42**	5.14	**0.81**	14.58	5.24	**0.85**	15.63	4.95	**0.57**	**12.17**	4.97	**0.60**	12.49	5.00	**0.88**	15.46

Daily ET_0 from Eqn. (8) was calculated using a 33-year weather dataset and then averaged over the 33 years to obtain a long-term daily average. Also, the values of ET_0, using the 33- year record of E_{pan} multiplied by the K_{pan} values [K_{pan} from Eqns. (2-7)] were calculated on a daily basis and then averaged over the 33 years to obtain a long-term daily average. Daily and monthly ET_0 values calculated using the data sets of K_{pan} values obtained from
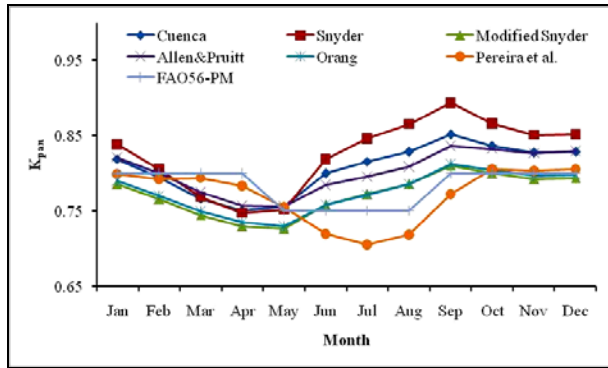
Fig. 2. Calculated daily Kpan values using Eqns. (2-7) and FAO56-PM model. Each data point represents an average of 33 measurements per day

Fig. 3. Comparison of calculated daily ET_0 using Eqns. (2-7) and FAO56-PM model

Eqns. (2-7) were compared to the ET_0 values calculated using Eqn. (8). The goodness-of-fit criterion (GOF) was evaluated in terms of root-mean-square error (RMSE) and percent error of estimates (PEE) as indicators of accuracy and reliability of all the six K_{pan} equations. The expressions for RMSE and PEE can be expressed as:

Root Mean Square Error (RMSE)

$$= \left[\frac{1}{N} \sum_{i=1}^{N} (ET_{k,i} - ET_{0,i})^2 \right]^{\frac{1}{2}} \qquad (10)$$

where, $ET_{K,i}$ and $ET_{0,i}$ are the ET_0 values based on K_{pan} and FAO56 - PM, respectively and N is the number of observations.

Percentage Error of Estimate (PEE)

$$= \left| \frac{ET_{K,i} - ET_{0,i}}{ET_{0,i}} \right| \times 100\% \qquad (11)$$

4. Results and discussion

The analysis was completed using daily, monthly and annual ET_0 as discussed here. This section briefly discusses the results obtained in this study as follows.

4.1. Computation of daily ET_0

The 33-year mean daily values of measured Class A E_{pan} are given in Fig. 1(d), in which each data point represents an average of 33 measurements. The 33-year daily mean values of measured E_{pan} in Fig. 1(d) show that the peak evaporation was experienced during the period of 30 April to 15 May, and the peak seems to be related to high temperature, low relative humidity, and increasing wind speeds. A large drop in E_{pan} occurred when the air
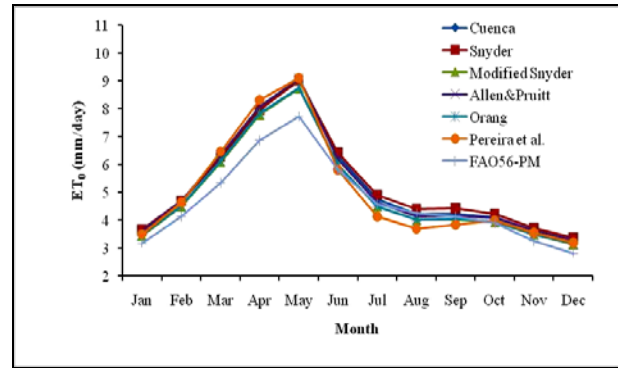
temperature decreased and relative humidity increased during late May. Daily computed K_{pan} values using Eqns. (2-7) are found almost similar as compared to FAO56-PM K_{pan} (Allen *et al.*, 1998) as given in Table 1 and graphically represented in Fig. 2. Overall it appears that the Cuenca (1989), Allen and Pruitt (1991), Snyder (1992), Modified Snyder (Grismer *et al.*, 2002) and Orang (1998) models accurately represent the Kp values with the same precision as that given by the FAO – PM - 56 K_{pan} values. It can be also observed from Table 1 that the Orang model has the best agreement with FAO - 56 PM model (percentage absolute deviation, PAD = 1.04), whereas Snyder has the poorest one (percentage absolute deviation, PAD = 5.47). Overall, the performance of the Orang (1998) model was found to be the best for K_{pan} computations followed by Modified Snyder (Grismer *et al.*, 2002), Pereira *et al.* (1995) model, Allen & Pruitt (1991), Cuenca (1998) and Snyder (1992) model.

The K_{pan} values computed using Eqns. (2) to (7) were further used to estimate daily ET_0 using Eqn. (1) and were compared with ET_0 computed by FAO56-PM (Eqn. 8) as shown in Table 2 and graphically represented in Fig. 3. It can be observed from Fig. 3 that the ET_0 values computed by all the six models (Eqns. 2-7) have good resemblance with FAO56-PM model; however, small deviations can be observed for the months of March to May. Possibly this could be attributed to biasness in the observed E_{pan} during these months.

4.2. Computation of monthly and annual ET_0

As stated earlier, analyses were also performed for the computation of monthly and annual ET_0 using Eqns. (2-7) and FAO56 - PM models. The root mean squared error (RMSE) and percentage error (PE) were used to test the accuracy and reliability of all the six K_{pan} equations

with respect to FAO56-PM model. The monthly mean estimated values of RMSE and PE along with the computed values of ET_0 [using FAO56 - PM and Eqns. (2-7)] are given in Table 2. The RMSE values (in mm) were found to vary from 0.57 (Modified Snyder) to 0.88 (Pereira *et al*. model). Similarly, the PEE values (%) were found to vary from 12.17 (Modified Snyder model) to 15.63 (Snyder model). It can be observed from Table 2 that Modified Snyder's (1992) method (Eqn. 5) gave best agreement to the FAO56 - PM method. The sequential performance of the tested models was observed as follows: Modified Snyder (Eqn. 5) > Orang (Eqn. 6) > Cuenca Eqn. (2) > Allen & Pruitt (Eqn. 3) > Snyder (Eqn. 4) > Pereira *et al.*,1995 (Eqn. 7) model. Annual mean daily ET_0 estimated from Eqns. (2-7) were found slightly higher than FAO56-PM ET_0.

5.   Conclusions

The approaches for the estimation of K_{pan} proposed by Cuenca (1989), Allen and Pruitt (1991), Snyder (1992), Modified Snyder (Grismer *et al*., 2002), Orang (1998), and Pereira *et al*. (1995) were evaluated for estimation of ET_0 of Anand (semi-arid region) of India using the 33 years of data. From this study following conclusions can be drawn.

(*i*)   Based on the visual comparison as well as from the goodness-of-fit criterion, ET_0 computed from Modified Snyder and Orang model gave closer agreement with the FAO56 - PM method for daily, monthly, and annual estimates as compared to other approaches. The calculations can be performed on a simple spread sheet calculator, and therefore, simple, fast and reliable computations of ET_0.

(*ii*)   The sequential performances of the approaches were: Modified Snyder > Orang (1998) > Cuenca (1989) > Allen & Pruitt (1991)>Snyder (1992)> Pereira *et al*. (1995) model for semi-arid climatic conditions.

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