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

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ABSTRACT. The reliability of estimates of reference evapotranspiration (ET0) using pan evaporation (Ep) depends on the accurate determination of pan coefficients (Kp). Six ET0 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), Modified Snyder (Grismer et al., 2002), Orang (1998), and Pereira et al. (1995). The ET0 data, calculated using daily Kp 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, ET0 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) > 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 ET0 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 ET₀, 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 (ET₀) was introduced (Jensen, 1968; Jensen et al., 1971; Doorenbos and Pruitt, 1975).

Reference evapotranspiration (ET₀) 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 ET₀ 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 ET₀ is using evaporation pan data, with adjustments made for the pan environment (Singh, 1989). However, a reliable estimation of ET₀ using pan evaporation (Epan) 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 Epan and ET₀, when evaporation pans are maintained properly. However, reliable estimation of reference evapotranspiration (ET₀) using pan evaporation (Epan) data depends on the accurate determination of pan coefficients (K_pan), which is defined as the ratio of ET₀ to Epan 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 ET₀ and Epan can be expressed as (Snyder 1992):

$$\text{ET₀} = \text{Epan} \times K_{\text{pan}}$$  \hspace{1cm} (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 Epan data to ET₀ 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 (Grissmer 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) ET₀ 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; Itenfsu et al., 2000) have confirmed the superior performance of the FAO56-PM method, and this method was accepted as a standard method for estimating ET₀ 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, U₂ (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 \( K_{\text{pan}} \) 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 \( K_{\text{pan}} \) can be expressed as:

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

(2)

where,

\[
U = \text{daily mean wind speed measured at 2 m height (km/day)}, \quad RH = \text{daily mean relative humidity (\%) and } F = \text{upwind fetch distance of low-growing vegetation (m)}.
\]

2.1.2. Allen and Pruitt model

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

\[
K_{\text{pan}} = 0.108 - 0.000331 U^2 + 0.0422 \ln (F) + 0.1434 \ln (RH) - 0.000631 \ln (F)^2 \ln (RH)
\]

(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 \( K_{\text{pan}} \) values as a function of \( U_2 \), \( RH \), and \( F \). The final expression of the model can be expressed as:

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

(4)

2.1.4. Modified Snyder model

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

\[
K_{\text{pan}} = 0.5321 - 0.00030 U_2 + 0.0249 \ln (F) + 0.0025RH
\]

(5)

2.1.5. Orang model

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

\[
K_{\text{pan}} = 0.51206 - 0.000321 U_2 + 0.002889RH + 0.031886 \ln (F) - 0.000107RH \ln (F)
\]

(6)

2.1.6. Pereira et al. model

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

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

(7)

where, \( \Delta = \text{Slope of the saturation vapour pressure curve (kPa °C}^{-1}) \) and \( \gamma = \text{Psychometric constant (i.e., 0.067 kPa °C}^{-1}) \). 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 \( K_{\text{pan}} \) 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:

\[
ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}
\]

(8)

where, \( ET_0 = \text{reference crop evapotranspiration (mm/day)} \); \( T = \text{mean daily air temperature measured between 1.5 and 2 m height (°C)} \); \( T = (T_{\text{max}} + T_{\text{min}})/2 \); \( R_n = \text{mean daily net radiation (MJ m}^{-2} \text{day}^{-1}) \); \( G = \text{soil...} \)
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); \( \Delta \) = slope of vapour pressure curve (kPa °C⁻¹) and \( \gamma \) = 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:

\[
U_2 = \frac{4.87}{\ln(67.8z - 5.42)} \quad (9)
\]

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 ET0 equations relative to the FAO56 - PM equation. The practitioners and researchers need to be provided guidance on the choice of the most appropriate ET0 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)

| Pan Coefficients (Kpan) Models | Cuenca | Allen & Pruitt | Snyder | Modify Snyder | Orang | Pereira et al. | FAO 56-PM |
|-------------------------------|--------|---------------|--------|----------------|-------|----------------|-----------|
| Month                         |        |               |        |                |       |                |           |
| 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 ET₀ (mm) and RMSE and PEE of ET₀ Estimates

| FAO 56-PM | Cuenca (1989) | Allen & Pruitt (1992) | Snyder (1992) | Modified Snyder | Orang | Pereira et al. |
|-----------|---------------|-----------------------|---------------|----------------|-------|----------------|
| Month     | ET₀ (mm)      | ETₖ (mm) | RMSE (mm) | PE (%) | ET₀ (mm) | ETₖ (mm) | RMSE (mm) | PE (%) | ET₀ (mm) | ETₖ (mm) | RMSE (mm) | PE (%) | ET₀ (mm) | ETₖ (mm) | RMSE (mm) | PE (%) | ET₀ (mm) | ETₖ (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 ET₀ 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 ET₀, using the 33-year record of Eₖ multiplying by the Kpan values [Kpan 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 ET₀ values were calculated using the data sets of Kpan values obtained from
Eqns. (2-7) were compared to the ET\textsubscript{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\textsubscript{pan} equations. The expressions for RMSE and PEE can be expressed as:

\[
\text{RMSE} = \left[ \frac{1}{N} \sum_{i=1}^{N} \left( ET_{K,i} - ET_{0,i} \right)^2 \right]^{\frac{1}{2}}
\]

(10)

where, ET\textsubscript{K,i} and ET\textsubscript{0,i} are the ET\textsubscript{0} values based on K\textsubscript{pan} and FAO56 - PM, respectively and \( N \) is the number of observations.

\[
\text{PEE} = \left( \frac{ET_{K,i} - ET_{0,i}}{ET_{0,i}} \right) \times 100\%
\]

(11)

4. Results and discussion

The analysis was completed using daily, monthly and annual ET\textsubscript{0} as discussed here. This section briefly discusses the results obtained in this study as follows.

4.1. Computation of daily ET\textsubscript{0}

The 33-year mean daily values of measured Class A E\textsubscript{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\textsubscript{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\textsubscript{pan} occurred when the air temperature decreased and relative humidity increased during late May. Daily computed K\textsubscript{pan} values using Eqns. (2-7) are found almost similar as compared to FAO56-PM K\textsubscript{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 K\textsubscript{p} values with the same precision as that given by the FAO – PM - 56 K\textsubscript{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\textsubscript{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\textsubscript{pan} values computed using Eqns. (2) to (7) were further used to estimate daily ET\textsubscript{0} using Eqn. (1) and were compared with ET\textsubscript{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\textsubscript{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\textsubscript{pan} during these months.

4.2. Computation of monthly and annual ET\textsubscript{0}

As stated earlier, analyses were also performed for the computation of monthly and annual ET\textsubscript{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\textsubscript{pan} equations.
with respect to FAO56-PM model. The monthly mean estimated values of RMSE and PE along with the computed values of ET₀ [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 ET₀ estimated from Eqns. (2-7) were found slightly higher than FAO56-PM ET₀.

5. Conclusions

The approaches for the estimation of Kᵦₑₑₑ 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 ET₀ 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, ET₀ 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 spreadsheet calculator, and therefore, simple, fast and reliable computations of ET₀.

(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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