Chapter 28
Comparison of Methods for Evapotranspiration Computation in the Tana Basin, Ethiopia

Hailu Birara, S. K. Mishra, and R. P. Pandey

28.1 Introduction

In many parts of the world, where rainfall amount necessary to meet the crop water requirement is limited, irrigation is a significant component of agricultural planning. In irrigation agriculture, it is very important to determine when and how much water applies to meet the water demand of the crops. The water demand is determined through proper estimation of evapotranspiration procedures. Evapotranspiration is described as the sum of evaporation and plant transpiration from the land and ocean surface to the atmosphere.

Evaporation accounts for the movement of water from the land surface (such as soil, canopy interception, and water bodies) to the air. It is an essential parameter in the hydrological cycle. Many researchers have projected that water resources will be influenced due to ET0 as the general effect of global climate change. High ET0 due to temperature increase will affect the watershed hydrological system and water resources of the globe (Shahid 2010). Thus, reliable and accurate estimation of ET0 is essential for the long-term water resources and irrigation management (Pour et al. 2016).

ET crop estimation for a given crop can be estimated as grass reference crop evapotranspiration (ET0) and crop coefficient, and several methods are available for the estimation of ET0 which depends on the availability of climate data. The method ranges from the most complex equation, which requires detailed climate data (Penman–Monteith [PM], Allen et al. 1989) to simple equations, which require

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H. Birara (✉) · S. K. Mishra
Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee 247667, Uttarakhand, India
e-mail: hailubirara@gmail.com

R. P. Pandey
National Institute of Hydrology, Roorkee 247667, Uttarakhand, India

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less meteorological data (Blaney–Criddle, Hargreaves). These methods can be also grouped into combination methods (PM, FAO-24 Penman, 1982 Kimberly-Penman, 1972 Kimberly-Penman, FAO-24 Corrected Penman), radiation-based methods (Turc, Jensen–Haise, Priestley–Taylor, and FAO-24 Radiation), temperature-based methods (Thornthwaite, Blaney–Criddle, and Hargreaves), mass transfer-based methods (WMO 1966), and pan coefficient-based methods.

The major factors in the estimation of ET0 are reliability and accuracy (Burnash 1995). A number of methods have been developed for given purposes and specific climate conditions. They may provide poor estimates of ET for other climatic conditions due to their different assumptions and input data requirements. However, various studies conducted in different parts of the world have used some specified models (such as PM, Priestley–Taylor, Turc, Thornthwaite, and Hargreaves) as the standard approach to estimate ET0 (Rácz et al. 2013; Wang et al. 2012). Nowadays, the PM method proposed by Allen et al. (1998) has become more reliable and provides accurate estimates of ET0 over a wide range of climatic regions (De Bruin et al. 2010; Rácz et al. 2013). The PM method requires many meteorological parameters such as temperature, humidity, wind speed, sunshine, and solar radiation, among others. However, measurement of all these parameters is not often available, particularly in developing countries like Ethiopia (Hubbard 1994; Pielke et al. 2007).

This study presents a performance comparison of seven widely used ET0 estimation methods, namely, Hargreaves, Thornthwaite, Blaney–Criddle, Priestley–Taylor, Turc, Abtew, and, the new method recently proposed by Temesgen and Melesse (2013), Enku, against the PM method in the study area as it is one of the most reliable methods to compute ET0 (Hubbard 1994; Irmak et al. 2002; Pielke et al. 2007; Rahimikhoob 2009). Table 28.1 shows the different methods with the required meteorological variables.

Table 28.1 Data requirement for the methods used

Methods	Temperature	Relative humidity	Solar radiation	Wind speed	Atmospheric pressure
Penman–Monteith	✓	✓	✓	✓	✓
Priestley–Taylor	✓	○	✓	○	○
Turc Method	✓	✓	✓	○	○
Hargreaves Method	✓	○	○	○	○
Makkink Method	✓	○	✓	○	○
Blaney–Criddle Method	✓	✓	✓	✓	✓
Abtew Method	✓	○	✓	○	○
EnkuTemperature Method	✓	○	○	○	○

28.2 Study Area

The Amhara National Regional State (ANRS) is located in Ethiopia's north-western and north-central parts (latitude 8°–13° 45′ N and 36° and 40° 30′ E). According to central Statistical Agency of Ethiopia (CSA 2008), the region has a total area of around 170,000 km^2 and categorized into 12 administrative zones and 105 woredas with different characteristics of the physical landscape, i.e., valleys, rugged mountains, and gorges with elevation ranging from 700 m a.s.l to 4,600 m a.s.l in the eastern and the northwest part, respectively. The lake Tana Basin is the largest sub-basin in the Amhara region, covering an area of 15,096 km^2, including the lake area (Fig. 28.1). The average annual precipitation and evapotranspiration of the basin are approximately 1,280 mm and 1,036 mm, respectively (Allam et al. 2016).

The annual climate classified into two major seasons, viz. the rainy and the dry season. The rainy season is also divided into a minor and major rainy season, which lasts from March to May (Belg), and June to September (kiremt), respectively, and the dry season lasts from October to February (Bega). As a result of its diverse nature of the region with altitudes ranging from 1,327 to 4,009 m.a.sl, the basin contributes a national importance because of its high potentials for irrigation development, high-value crops, hydroelectric power development, livestock production, and ecotourism (CSA 2008).

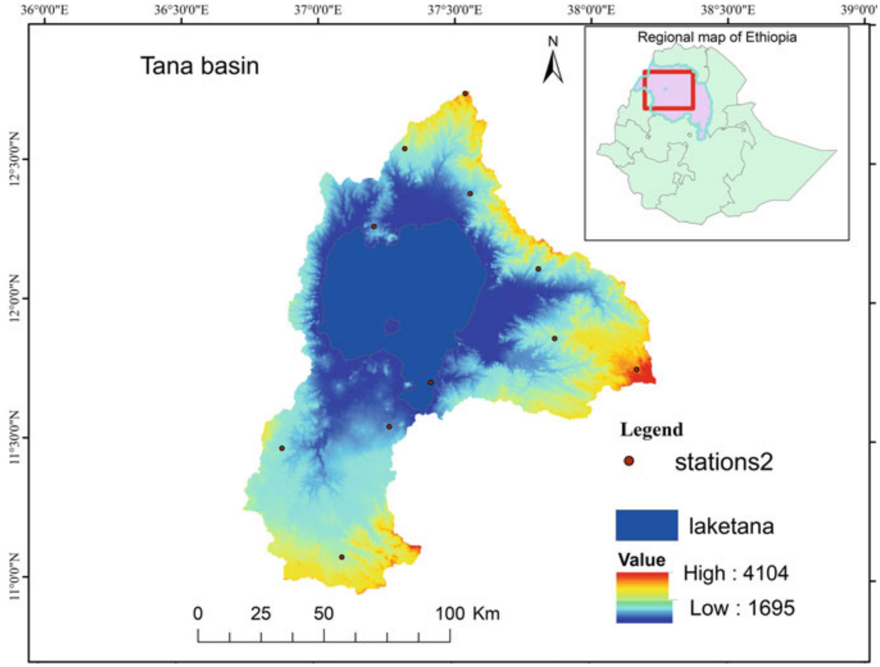

Fig. 28.1 Study area map

Lake Tana, among one of the Blue Nile River's main source, is Ethiopia's largest lake and the third-largest in the Nile Basin. It is about 84 km long and 66 km wide in the north-western highlands of the country. The lake is one of a natural freshwater, at an elevation of 1,800 m, covering an area of 3,000–3,600 km^2. Gumera, Ribb, Gilgel Abay, and Megech Rivers are among the main feeding of the lake Tana. These four rivers contribute to the annual water budget of the lake to more than 65% inflow (Setegn et al. 2008). The only surface outflow is the Blue Nile River, measured at the Bahirdar gauge station with an annual flow volume of 4BCM is sourced from lake Tana.

In the study area, land use is classified on the basis of Abay River master plan study conducted by BCEOM's (1998). Approximately 51.37% of the watershed area is covered by agriculture, 21.94% by agriculture, 0.15% by agrisilviculture, 0.03% by sylvopastoral, and 0.11% by urban use.

The main tributaries of the lake Tana are Gilge Abay, Gumera, Ribb, and Megech Rivers. The present study shows that these four rivers contribute to more than 45% inflow of the annual lake water budget. The only surface outflow is the Blue Nile (Abba) River with an annual flow volume of 4 billion cubic meters measured at the Bahir Dar gauge station.

Land use of the study area is classified based on Abay River master plan study conducted by BCEOM (1998), about 51.37% of the watershed area is covered by agriculture, 21.94% by agro-pastoral, 0.15% by silviculture, 0.03% by sylvopastoral, and 0.11% of urban.

28.3 Methodology

28.3.1 Data Source

For this particular study, daily weather data from 1980 to 2015 were obtained from the National Meteorological Service of Ethiopia. Meteorological variables including rainfall, maximum and minimum air temperature, relative humidity, wind speed, and bright sunshine hour has been collected. The climatic data used in this study consisted of daily maximum and minimum temperature (Tmax and Tmin), relative humidity (RH), wind speed (WS), and sunshine hours (N). Six stations average (referred in Table 28.2) climatic data for 35 years is used to calculate evapotranspiration. However, 10 (2004–2013) years pan evaporation data is used to estimate pan coefficient.

Table 28.2 Detail of selected stations

S. no.	Name of station	Lat. (N)	Long. (E)	Alt. (m a.s.l)	Duration
1	Bahir Dar	11° 71′	37° 50′	1800	1980–2015
2	Gondar	12° 63′	37° 45′	2133	1980–2015
3	Woreta	11° 55′	37° 42′	1828	1980–2015
4	DebreTabor	11° 86′	38° 02′	2506	1980–2015
5	Dangla	11° 25′	36° 74′	2122	1980–2015
6	Injibara	11° 70′	38° 43′	2372	1980–2015

28.3.2 Estimation of Evapotranspiration and (ET0) and Pan Coefficient ($\mathrm{K_P}$)

Evapotranspiration can be directly measured using lysimeters, but it can also be measured using empirical equations or simply be estimated by multiplying observed standard pan evaporation data by the pan coefficient (Grismer et al. 2002). The pan evapotranspiration (ET0) is obtained by the following formula:

$$ETo = E_p * K_p \tag{28.1}$$

where ET0 = Reference evapotranspiration (mm); E_p = Observed Pan evaporation data for class A pan (mm); K_p = Pan coefficient.

Equations have been developed by Cuenca (1989), Orange (1998), Allen and Pruitt (1991), and Snyder (1992) to estimate K_P for a class A pan with green vegetation on the surrounding condition. The calculated K_p value obtained from the above equation was compared and correlated with the observed value (ET0/Ep as ET0 calculated by the FAO-56 PM equation) since the FAO-56 PM is confirmed as a standard and suitable method to estimate ET0 for different climates (Allen et al. 1998, 2005; Irmak et al. 2003; Temesgen et al. 2005; Zhao et al. 2005; Garcia et al. 2007; Gundekar et al. 2008). Hence, one of the empirical formulas which are more correlated with the observed is considered as accurate method to estimate K_P in the study area.

The following four approaches have been considered to determine K_p as well as ET0 from class A pan evaporation:

Orange (1998)

$$K_p = 0.5126 - 0.00321u + 0.002889RH + 0.031886\ln(F) \tag{28.2}$$

where U = Wind speed (km/day), RH = relative humidity (%), and F = upwind fetch distance around the pan.

Snyder (1992)

$$K_P = 0.482 - (0.0003768u_2) + (0.0245 * 0.0045 * RH) \tag{28.3}$$

where RH is mean daily relative humidity in %

Cuenca (1989)

$$\begin{aligned} K_P = &(0.475 - 92.4 * 10^{-4} * u_2) + \left(5.16 * 10^{-3} * \mathrm{RH}\right) \\ &+ \left(1.18 * 10^{-3} * F\right) - \left(1.16 * 10^{-3}\mathrm{RH}^2\right) - \left(1.01 * 10^{-6} * F^2\right) \\ &- \left(8 * 10^{-8} * \mathrm{RH}^2 * U^2\right) - \left(0.1 * 10^{-7} * \mathrm{RH}^2 * F\right) \end{aligned} \tag{28.4}$$

Allen and Pruitt (1991)

$$\begin{aligned} K_P = 0.108 - 3.31 * 10^{-4} * U_2 + 4.22 * 10^{-2} * ln(F) + 10^{-1} \\ * ln(RH) - 6.31 * 10^{-4} * (F)^2 * ln(RH) \end{aligned} \tag{28.5}$$

The class A pan evaporimeter is sited on a short green grass cover and the value of F is 70 m.

28.3.3 Description of ET0 Estimation Equations

Penman–Monteith Equation The Penman–Monteith method is a combination method developed by Penman (1948). It combines the energy balance with mass transfer method and proposes an equation to estimate ET0 on daily basis using climatic variables viz., temperature, sunshine hours, relative humidity, and wind speed. It is expressed as below

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - G) + Y\frac{900}{T+278}U_2(p_s - p_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{28.6}$$

where ETo is reference evapotranspiration (mm day^{-1}); Δ is the slope vapor curve (Kpa $°\mathrm{C}^{-1}$); RN is the net radiation of the crop surface (MJm^{-2} day^{-1}); G is the soil heat flux density (MJm^{-2} day^{-1}); T is the air temperature (°C); U2 is the wind speed at 2 m height (m s^{-1}); ρ_s is the saturation vapor (Kpa); ρ_a is the actual vapor pressure (Kpa); and γ is the psychometric constant (Kpa $°\mathrm{C}^{-1}$).

Priestley–Taylor Method Priestley–Taylor method (Priestley and Taylor 1972) is a radiation-based method to estimate reference evapotranspiration (ET0). They establish that the potential evaporation is 1.26 times lesser than the actual evaporation and thus they replace the aerodynamic terms with constant (1.26). Therefore, the method needs only long-wave radiation and temperature for the assessment of ET0. The equation for calculating ET0 is given below

$$\mathrm{ETo} = 1.26 * \frac{\Delta}{\Delta + \gamma}(\mathrm{Rn} - G) * \frac{1}{\lambda} \tag{28.7}$$

where Δ is the slope vapor curve (Kpa °C^{-1}); γ is the psychometric constant (Kpa °C^{-1}); RN is the net radiation of the crop surface (MJm^{-2} day^{-1}); G is the soil heat flux density (MJm^{-2} day^{-1}); and λ is the latent heat of vapor (MJ kg^{-1}).

Turc Method Turc method (Turc 1961) provides an easy equation for calculating ET0 by using only a few climatic variables (relative humidity, solar radiation, and mean temperature). The Turc method gives reliable estimates of ET0 under humid conditions (Jensen et al. 1990). The equation is given as follows:

$$\mathrm{ETo} = 0.0133\frac{\mathrm{Tm}}{\mathrm{Tm}}(\mathrm{Rs} + 50) \tag{28.8}$$

when RH > 50%

$$\mathrm{ETo} = 0.0133\frac{\mathrm{Tm}}{\mathrm{Tm} + 15}(\mathrm{Rs} + 50)\left(1 + \frac{50 - \mathrm{RH}}{70}\right) \tag{28.9}$$

when RH < 50%

where Tm is mean temperature (°C); Rs is the solar radiation of the crop surface (MJm^{-2} day^{-1}); and RH is the relative humidity (%).

Hargreaves Method Hargreaves is the temperature-based method proposed by Hargreaves and Samani in 1982. The equation is given as

$$\mathrm{ETo} = 0.0023(T_{\mathrm{mean}} + 17.8)(T\mathrm{max} - T_{\mathrm{min}})^{0.5}\mathrm{Ra} \tag{28.10}$$

where $T_{\max}$, $T_{\min}$, and T_{mean} denote maximum, minimum, and mean temperatures (°C), respectively; and Ra is the extra-terrestrial radiation of the crop surface (MJm^{-2} day^{-1}).

Makkink Method

$$\mathrm{ETo} = 0.61\left(\frac{\Delta}{\Delta + \gamma}\right) * \frac{\mathrm{Rs}}{58.5} - 0.12 \tag{28.11}$$

Blaney–Criddle Method The Blaney–Criddle is the simple temperature-based method for the assessment of ET0. It is widely used method applied before Penman–Monteith method. This equation only considers changes in temperature for specific conditions for estimating ET0. The Blaney–Criddle equation is given below

$$\mathrm{ETo} = p(0.46\mathrm{Tm} + 8) \tag{28.12}$$

where p = percentage of average daily annual daytime hours due to the latitude of the region.

Abtew Method Abtew (1996) used a simple model to estimate ET from solar radiation. This method requires only solar radiation, and is less subject to local variations

$$\text{ETo} = K\frac{\text{Rs}}{\lambda} \tag{28.13}$$

where K is a coefficient (0.53).

Enku Temperature Method The method is developed by Temesgen and Melesse (2013) by replacing Abtewk and by a single constant $k*$. They used power form of maximum temperature (T_{mx}) to estimate ET0 and the method is hereafter denoted as ET_{Tm}

$$\text{ET}_{\text{Tm}} = \frac{(T_{\text{mx}})^n}{k*} \tag{28.14}$$

where $n = 2.5$ and they used maximum temperature dependent $k*$ of 48 T_{mx} -330 for dry and wet conditions or season.

28.3.4 Model Evaluation Methods

To evaluate the performance of the ET0 estimation model and K_P estimation equations, different statistical measures were used. Most of these methods are proposed to capture the degree of good agreement between observed and calculated (modeled) values. Some performance measures are described below (Jachner et al. 2007).

Root Mean Square Error (RMSE)

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (X_{\text{observed}} - X_{\text{model}})^2}{n}} \tag{28.15}$$

where
X_{observe} = observed ET0 value
X_{model} = calculated ET0 value

Mean Square Error (MSE)

$$\text{MSE} = \frac{\sum_{i=1}^{n} (E_{\text{observe}} - E_{\text{model}})^2}{n} \tag{28.16}$$

Coefficient of Determination (R^2)

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (E_{\text{observe}} - E_{\text{model}})^2}{\sum_{i=1}^{n} (E_{\text{observe}} - \overline{E_{\text{model}}})^2} \tag{28.17}$$

It is defined as the degree of collinearity between observed and calculated value data. The value of R^2 lies between 0 and 1

Efficiency Factor (EF)

$$\text{EF} = \frac{\sum_{i=1}^{n} (O_i - \bar{O})^2 - \sum_{i=1}^{n} (O_i - E_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \tag{28.18}$$

where EF = efficiency factor; O_i = observed value; E_i = estimated value; $\bar{O}$ = mean observed value.

28.4 Results and Discussion

28.4.1 Meteorological Parameters

A summary of average daily, monthly, and seasonal climatic data from 1980 to 2015 is described as follows: Maximum and minimum temperature occurred in April (T_{max} 33 °C) and July (T_{min} 9 °C) on the study area, respectively. The summer (kiremt) season is wet compared with winter (Bega) and spring (Belg), and the relative humidity is higher during July (81%). However, the bright sunshine hour of the summer season is less (from 0 to 4.6). The highest pan evaporation also occurred in April (8.1 mm/day), which seems to be related to the higher temperature, lower humidity, and longest bright sunshine hours. The reverse is true for July, which gives the lowest pan evaporation (2.4 mm/day). To develop the pan coefficient for different seasons of the study area, pan evaporation data should first relate to the PM equation. Since the pan coefficient is very dependent on local conditions, K_p should be determined by comparing the observed pan data with the PM ET0. Figure 28.2 shows a good relationship ($R^2 = 0.84$) between ET0 (FAO-56 PM) and standard class A pan evaporation (average from 2004 to 2013).

Such a relationship of comparing the observed pan data with PM indicates that with an appropriate pan coefficient value, the pan evaporation can be quite useful in estimating evaporation in the study area. The results also agreed with previous studies that showed a good relationship between pan evaporation and PM-based evapotranspiration values (Jensen et al. 1961; Pruitt 1966; Doorenbos and Pruit 1975).

28.4.2 Estimation of Pan Coefficient (K_P)

Pan evaporation data are important only if a suitable pan coefficient with local conditions is used to relate the pan data with different ET0 estimation methods. The mean monthly K_p values between the observed (FAO-56 PM/Ep) and the estimated value using different methods (Eqs. 28.1–28.4) are shown in Fig. 28.3. The monthly Kp values varied between 0.73–0.84, 0.75–0.84, 0.74–0.81, 0.7–0.83, and 0.71–0.84 for the observed, Snyder, Orange, Cuenca, and Allen and Pruitt methods, respectively.

The observed (FAO-56 PM/Ep) K_p value indicates the lowest value during January–February and June–August, which might be due to less sunshine hours that may decrease air temperature impacts.

The statistical test of the different equations to compute K_P is presented in Table 28.3. The statistical criteria of R^2 indicate that, except Allen and Pruitt, all tested equations' coefficient of determination (R^2) was above 0.8 (Table 28.3). It is also clear from Table 28.3 that the Snyder method showed a good correlation with the

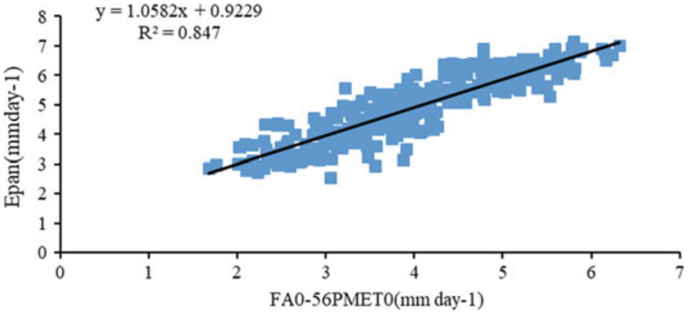

Fig. 28.2 Calculated ET0(FAO-56PM) versus measured Epan (average of 2004–2013)

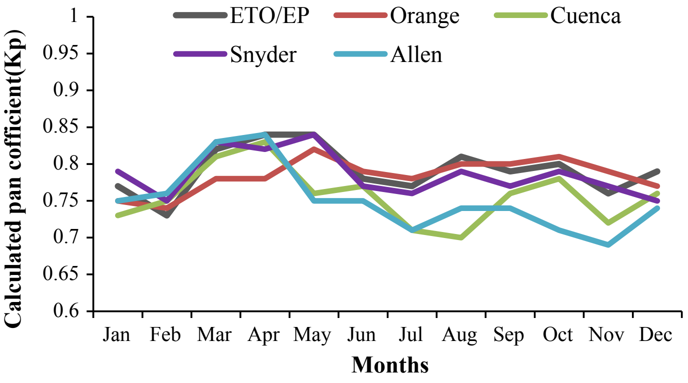

Fig. 28.3 Observed (ET0/EP) and calculated monthly pan coefficient(K_p) of the study area

Table 28.3 Ranking of K_p equations on the basis of statistical test with the observed value

Rank	Equations	R^2	RMSE	MAD
1	Snyder	0.93	0.46	0.97
2	Orange	0.89	0.51	1.07
3	Cuenca	0.86	0.68	1.18
4	Allen and Pruit	0.74	0.84	1.12

observed value followed by Orange. The Snyder value of the coefficient of determination (R^2) showed the highest (0.93) and lowest RMSE (0.46). Thus, this analysis suggests that Snyder can be used to compute reasonably accurate K_p values as far as monthly estimation is concerned, whereas the Allen and Pruitt method showed the weakest ability to estimate K_p in the study area.

Similar results were reported by Pradhan et al. (2013) on their studies of evaluation of K_p methods to compute FAO-56 crop evapotranspiration in the semi-arid region, which indicates that Snyder provides more accurate estimations of regional-based K_p values.

To estimate the accurate and consistent pan evaporation on the study area, ET0 between the observed (FAO-56 PM/E_p) with the pan value was compared. The comparison of monthly pan ET value between the observed and using different K_p estimation equations for 10-year data is plotted in Fig. 28.4. The closest relationship was observed between ET using the Snyder method and the observed, and Orange showed nearly the same performance (Fig. 28.4a–d). Accordingly, the annual ET value using Snyder, Orange, Cuenca, and Allen and Pruitt differed by 3.12%, 7.6%,

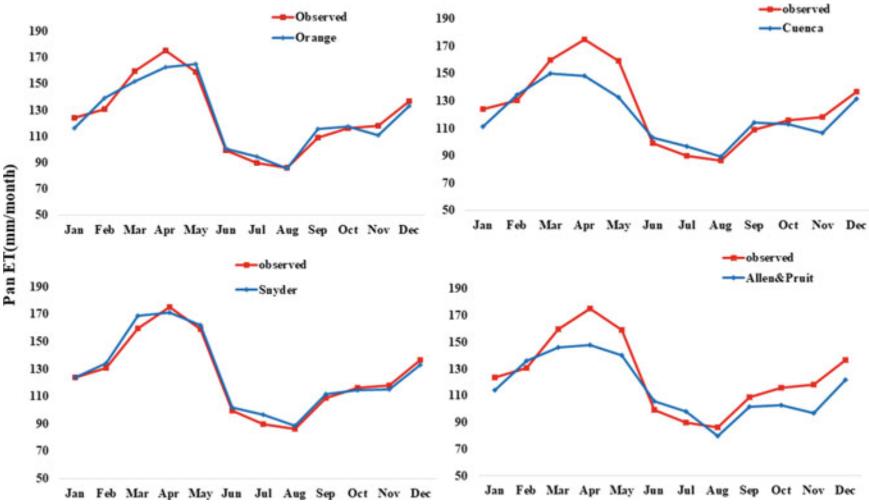

Fig. 28.4 Comparison of monthly calculated Pan ET with observed (FAO-56PM/Epan) using different K_p estimation methods

−9.2%, and −17.7% from the observed ET0, respectively (Fig. 28.4). Hence, Snyder provided by far a good correlation and is therefore recommended as a suitable method to compute K_p in the study area.

28.4.3 Cross Comparison of ET0 Estimation Methods

The comparison of the results of ET0 estimated from various methods against PM is presented in Table 28.4 and Figs. 28.5 and 28.6. ET0 was estimated by all the above-described methods (Eqs. 28.6–28.14) and used for comparison with the PM results. The calculated ET0 with various methods showed that the average yearly estimated ET0 for the study area ranges from 1240 to 1860 mm/year (Fig. 28.6). However, the total calculated annual ET0 value obtained by PM was 1501.6 mm on the study

Table 28.4 Daily Pearson's cross-correlation analysis between ET0 estimation methods

	PM	Turc	Enku	Mkn	Abt	B&C	Pt	Hg
PM	–	0.98	0.95	0.91	0.87	0.88	0.81	0.64
Turc	0.98	–	0.96	0.93	0.87	0.81	0.83	0.69
Enku	0.95	0.96	–	0.96	0.92	0.74	0.88	0.68
Mkn	0.91	0.93	0.96	–	0.84	0.79	0.84	0.71
Abt	0.87	0.87	0.92	0.84	–	0.92	0.83	0.74
B&C	0.88	0.81	0.74	0.79	0.92	–	0.78	0.76
Pt	0.81	0.83	0.88	0.84	0.83	0.78	–	0.74
Hg	0.64	0.69	0.68	0.71	0.74	0.76	0.74	–

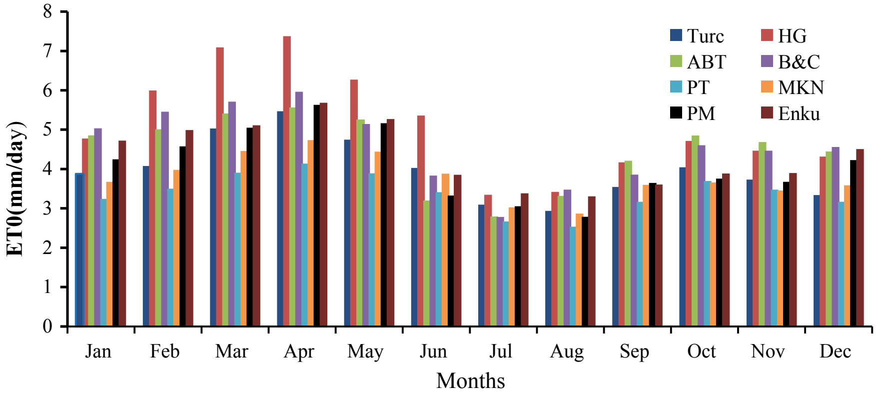

Fig. 28.5 Monthly average reference evapotranspiration(ET0) of the study area. Abbreviations: *PM* = Penman–Monteith method; *HG* = Hargreaves; *Abt* = Abtew simple method; *BC* = Blaney–Criddle method; *PT* = Priestley–Taylor method; *Mkn* = Makkink method; *Tur* = Turc Method

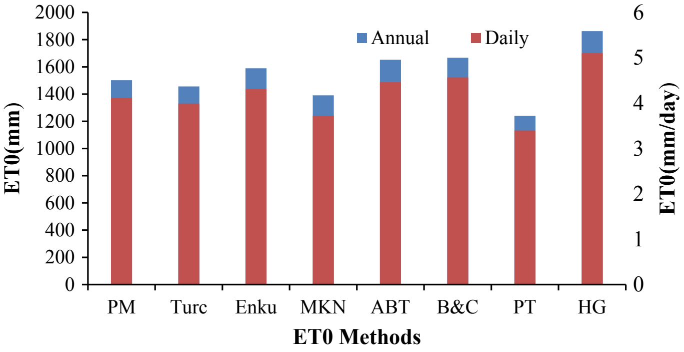

Fig. 28.6 Mean monthly and annual reference evapotranspiration

area. The result also showed that the peak annual value of ET0 was found to be higher during March–May as the period is associated with the highest temperature, low relative humidity, and highest wind speeds. The value of ET0 on these months accounts for 41.2% of the total annual ET0 and maximum mean monthly ET0 that has been observed during March (169 mm), while the minimum values occurred on August (51 mm), which is almost a decrease of one-third from the maximum value.

Using the PM method as observed (standard), the performance evaluation and correlation of the tested methods that compute ET0 are presented in Tables 28.4 and 28.5 using statistical parameters. The correlation was calculated for each pair of models (Table 28.4).

The closest correlation was observed between PM and Turc followed by Enku and Makkink. Hargreaves showed the weakest correlation with PM and other tested methods, whereas Blaney–Criddle showed the weakest correlation (<0.8) with Enku, Priestley–Taylor, and Hargreaves methods.

Another statistical analysis was also performed. The mean deviation (%) coefficient of variation, efficiency factor, and root mean square error of the calculated mean daily ET0 of the various methods are presented in Table 28.5. All the methods

Table 28.5 Statistical evaluation of daily average ET0 estimation methods against PM

Rank	Methods	Mean deviation	*	R^2	*	RMSE	*	EF	*	MSE	*
1	Turc	−4.2	1	0.96	1	0.87	1	0.88	1	0.53	2
2	Enku	+5.7	2	0.89	2	0.90	3	0.86	3	0.51	1
3	Makkink	−7.2	3	0.87	3	0.89	2	0.88	2	0.61	3
4	Abtew	+9.9	4	0.86	4	1.20	4	0.83	4	0.64	4
5	Blaney–Criddle	+11	5	0.84	5	1.51	5	0.72	5	0.74	5
6	Priestly–Taylor	−17.6	6	0.84	6	1.62	6	0.67	6	1.16	7
7	Hargreaves	+22.5	7	0.67	7	2.91	7	0.53	7	1.11	6

*Daily estimate rank number for each statistical index that showed underestimated/overestimated of ET0 from the observed (PM) value present as negative and positive signs. Hence, the methods were ranked against the PM value using all the above-mentioned statistical indices (Table 28.5).

Based on the mean absolute deviation of the daily ET0 value against the observed value, the Turc method underestimates the mean daily ET0 by 4.2% with the coefficient of determination (0.96) and showed considerably lowest RMSE (0.87) among the rest of the methods. It underestimates ET0 particularly from January to May, as presented in Fig. 28.5. Though Turc slightly underestimates the daily ET0 value, it shows the closest value of mean daily and yearly ET0 value with the observed value (PM) followed by Enku and Makkink, whereas the Hargreaves and Priestley–Taylor methods provide relatively the highest positive and negative mean deviation value from the PM with 1.58 and 1.62 highest values of RMSE, respectively (Table 28.5). Therefore, the Turc method showed the best performance to estimate ET0 in the study area. Thus, estimating ET0 using the Turc method is considered more accurate and reliable than the other tested empirical methods in the study area. Studies by Trajkovic and Kolakovic (2009) state that the Turc performs well to compute reference evapotranspiration at humid regions. Similarly, Lu et al. (2005) state that radiation-based methods that were developed for warm and humid climate conditions (Priestley–Taylor and Turc methods) perform well for the southeastern United States.

Kashyap and Panda (2001) and Tukimat et al. (2012) also declare the same conclusion, that is, the Turc method provides the closest results to the PM model for sub-humid and humid climate conditions when weather data are insufficient to apply the PM equation. The Enku method also performs well because it yielded relatively least overestimated values by 5.7% with reasonable R^2 (0.894) and RMSE (0.90 mm/day) errors (Table 28.5 and Fig 28.7). It also slightly overestimated evapotranspiration almost seventh months of the year.

The Priestley–Taylor method gives the highest underestimated values by -17.6%. Conversely, the Hargreaves method overestimated by as much as 22.5%, giving the worst estimates among all the tested methods followed by Priestley–Taylor method. Similar performance of the Hargreaves method under humid and sub-humid conditions has been reported by different researchers (Droogers and Allen 2002; Temesgen et al. 2005; Alexandris et al. 2008) (Table 28.5).

28.5 Conclusions

With various methods and applications described in the study, the following conclusion was made. Estimation of ET0 using the class A pan evaporimeter is the simplest and most direct way, but if an appropriate pan coefficient is not used, the accuracy of ET0 estimation will not be satisfactory. Therefore, the monthly K_p values were estimated for the study area. To estimate accurate and reliable K_p, the different approaches were compared, and statistical indices resulted in the ranking from the

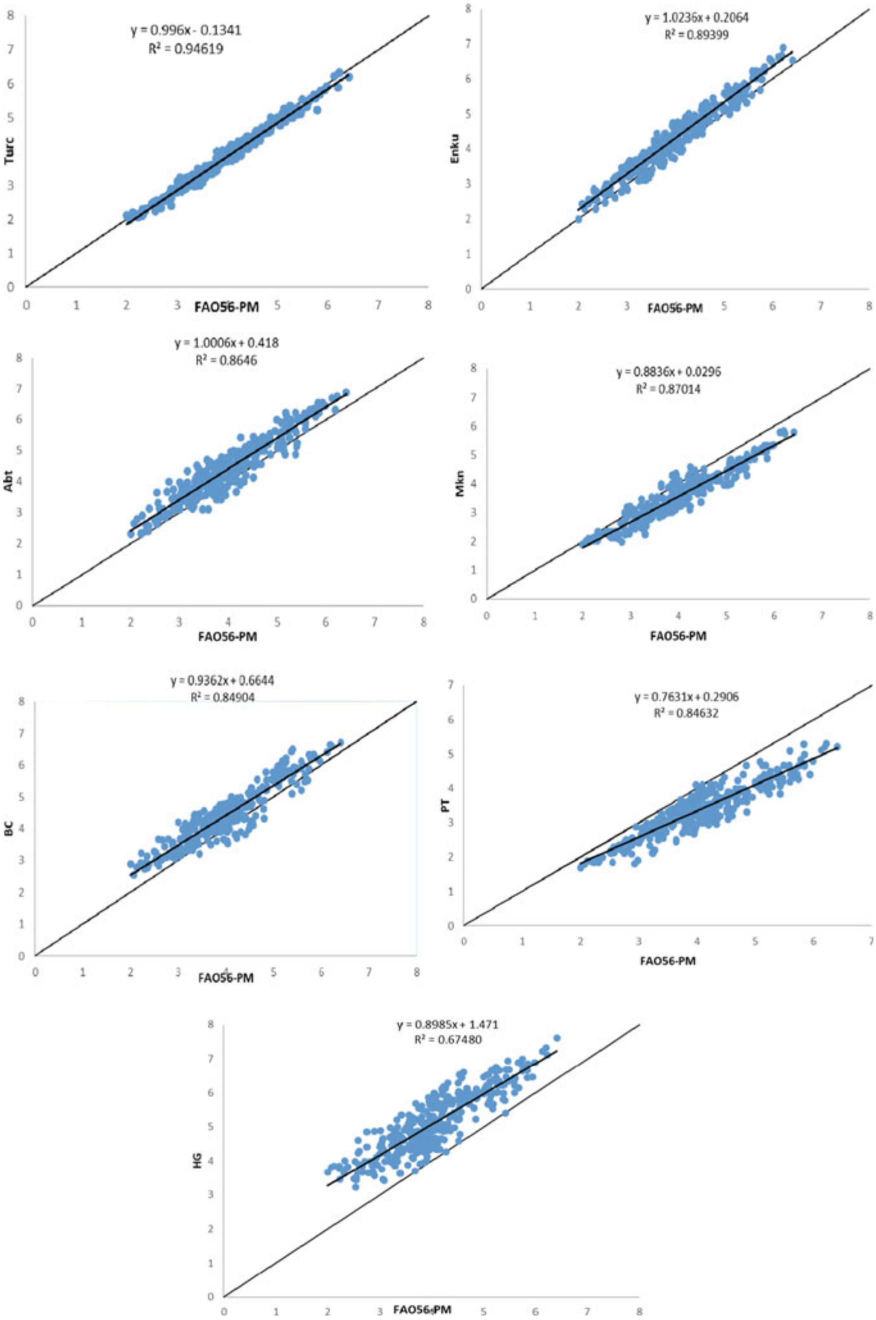

Fig. 28.7 Comparison of daily FAO-56PM versus the other tested methods

most to the least accurate. The comparison analysis between the different K_p estimation equations resulted in the following order according to prediction accuracy: Snyder > Orange > Cuenca > Allen and Pruitt. Therefore, the computed K_p of the Snyder method closely agreed with the observed K_p values (FAO-56 PM/E_p). As a result, the Snyder method is recommended as a good estimator of K_p followed by Orange. Allen and Pruitt showed the weakest ability to predict K_p.

The complexity and inaccuracies in ET0 estimation often appear as major constraints in developing effective water management strategies for maintaining crop water requirement. Therefore, in this present study, seven ET0 estimation methods have been compared with FAO-56 PM values to show the reliability of different ET0 estimation methods. The analysis revealed that the ET0 estimates using different methods significantly vary.

From the comparison between the above methods and PM ET0 values, a relative underestimated/overestimated of the calculated ET0 value has been found. The Turc method is found to be suitable to calculate ET0 as it provided the closest values with FAO-56 PM ET0 followed by Enku and Makkink. Due to large overestimated and poor statistical indices, the Hargreaves method is found to be the least to estimate ET0 in the study area. Therefore, the Hargreaves method should be used with caution if only less data availability conditions.

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