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Performance Evaluation of Class A Pan Coefficient Models to Estimate Reference Evapotranspiration in Mymensingh Region of Bangladesh

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ABSTRACT

Reliable estimation of reference crop evapotranspiration (ET_0) is of great importance for irrigation planning and operation as well as for climatologic and hydrologic studies. This study evaluated the performances of pan evaporation-based ET_0 estimation methods. First, we detected the correlation between observed pan evaporation (E_p) and ET_0 estimated by Penman-Monteith FAO-56 (PMF-56). Second, we estimated ET_0 from E_p using six pan evaporation models (Cuenca, Allen and Pruitt, Snyder, modified Snyder, Pereira and Orang methods) and compared them with ET_0 by the PMF-56 method. The accuracy of the models was assessed based on three performance statistics such as R^2, mean absolute error, and root mean square error. We used daily meteorological data recorded at the Mymensingh weather station for the period of 2007–2016 to estimate class A pan coefficients (K_p) using the empirical equations proposed by the selected models. Daily ET_0 was then estimated by multiplying the K_p values with the corresponding daily E_p values. Daily E_P and ET_0 values showed moderate correlation whereas monthly values showed high correlation only for February, August, and September. The moderate correlation between daily values is mainly due to the dissimilar response of E_p and ET_0 to their influencing meteorological factors. In estimating daily and monthly ET_0, overall all methods showed poor performances with underestimated PMF-56 ET_0. However, in the case of August ET_0 estimation, we noticed better performances from pan evaporation models in terms of lower errors and high R^2 (> 0.70). Particularly, the Snyder model ranked first among the selected pan evaporation models as it closely predicted PMF-56 ET_0. So, after necessary calibration, this method can be considered for the estimation of ET_0 under the climatic condition of Bangladesh. To conclude, the findings of this study will be a useful reference for adopting a comparatively easier ET_0 estimation method in the country.

Introduction

Evapotranspiration (ET) is one of the fundamental components of hydrological processes, which represent the amount of water transferred to the atmosphere through evaporation and transpiration from the soil-plant system (Pandey *et al.*, 2016). Estimation of ET is of central importance for irrigation planning and operation as well as for climatologic and hydrologic studies (Snyder, 1992; Snyder *et al.*, 2005; Aydin, 2019). The ET can be computed as reference, potential, or actual evapotranspiration; of which actual ET is measured directly in the field and others are estimated from meteorological parameters. Lysimeters are commonly used to measure the actual ET, however, these are difficult and expensive to construct and their operation & maintenance require special care (Cai *et al.*, 2007). Owing to the difficulty of obtaining accurate field measurements, ET is generally computed from meteorological data by using the concept of potential evapotranspiration (PET) and reference evapotranspiration (ET_0) (Cai *et al.*, 2007). Both PET and ET_0 measure evaporative water demand in terms of evaporation and transpiration, however, crop conditions are assumed constant in PET estimation (Peng *et al.*, 2017). To avoid ambiguities involved in the definition and interpretation of PET, ET_0 has been introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The concept of ET_0 has been widely used as the basis for computing crop evapotranspiration and assessing crop irrigation requirements.

The methods for estimating ET_0 can be classified as empirical, temperature-based, radiation-based, pan

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evaporation based, and combination types (Peng *et al*., 2017; Poddar *et al*., 2018). These methods are being used to estimate ET_0 with varying degrees of reliability due to their data requirements and climatic variation (Aydin, 2019). The temperature-based equations include the Thornthwaite (Thornthwaite, 1948), the Blaney-Criddle (Blaney and Criddle, 1950), and the Hargreaves-Samani (Hargreaves and Samani, 1982), which are extensively adopted because of their solely dependence on easily-available temperature data. The physically-based combination methods explicitly incorporate physiological and aerodynamic parameters, and they can closely approximate ET_0 at the locations evaluated (Allen *et al*., 1998; Stockle *et al*., 2004). Among them, numerous studies have proved that the Penman-Monteith FAO-56 (PMF-56) method is considered standard and widely used for computing ET_0 across a wide range of climatic conditions (Allen *et al*., 1998; Irmak *et al*., 2003; Alexandris *et al*., 2006). However, daily or routine use of the method is constrained by the non-availability of weather data at some locations (Poddar *et al*., 2018). Specifically, the required data such as solar radiation, temperature, wind speed and relative humidity (Doorenbos and Pruitt 1977; Snyder, 1992) are sometimes scarce in developing countries and also necessitate good computational skill (Landeras *et al*., 2018). So, the relatively simpler pan evaporation based ET_0 method is thought to be a good alternative of PMF-56 method (Poddar *et al.*, 2018).

In many locations where weather data is not available, evaporation pans are extensively used for calculating ET_0, owing to simple operation and inexpensive instrumentation in comparison with other ET_0 measurement methods (Tabari *et al*., 2013). The way to calculate ET_0 from pan evaporation (E_p) is relatively straightforward where E_p is converted into ET_0 employing class A pan coefficient (Doorenbos and Pruitt, 1977; Allen *et al*., 1998). However, the most important challenge of this method is the accurate estimation of pan coefficients (K_p), which is indispensable for calculating ET_0 from pan evaporation (Irmak *et al*., 2002). There are several established models to find out K_p values, which usually depend on the prevailing upwind fetch distance, average daily wind speed, and relative humidity conditions associated with the location of the pan evaporimeter (Cuenca, 1989; Snyder, 1992; Pereira *et al.*, 1995). To estimate the value of K_p, Doorenbos and Pruitt (1977) first proposed a table for different ground cover and levels of mean relative humidity and wind speed. For more accurate prediction of ET_0, different models have been further developed to calculate K_p values (Cuenca, 1989; Allen and Pruitt, 1991; Snyder, 1992; Pereira *et al*., 1995; Orang, 1998). Nevertheless, K_p values need to be calculated at the local scale as the locations of evaporation pan and the surrounding climate are the important factors affecting these values. Several studies have been conducted for different climatic conditions to evaluate the pan coefficient models. Irmak *et al*. (2002) used Cuenca, Allen and Pruitt, Snyder, Modified-Snyder and Orang equations to convert pan evaporation into ET_0 in humid Florida zone and compared them with ET_0 by the PMF-56 method. They concluded that the Cuenca and the Snyder methods estimated ET_0 values closest to the standard method. Rahimikhoob (2009) showed that the Orang method elucidated the best results in Noshahr region in Iran for estimating daily, monthly and annual ET_0 data. Many studies have reported the best performances of Snyder (Gundekar *et al*., 2008; Sabziparvar *et al*., 2010; SreeMahewari and Jyothy, 2017; Aydin, 2019) and Pereira (Aydin 2019) methods in the semi-arid climate. The Pereira method was mainly found to give good results in warm climatic condition (Sentelhas and Folegatti, 2003). Although there are several performance evaluation studies for pan evaporation models available for many countries, there is no study yet conducted to determine ET_0 directly from E_p and assess the precision and accuracy of pan coefficient models in Bangladesh. In fact, using pan coefficient models to estimate ET_0 from E_p might be a practical approach, and the successful application of these models may ease the process of estimating ET_0. Hence, this study aimed to (i) assess the correlation between E_p and ET_0 to check the suitability of using pan coefficient models and (ii) compare the ET_0 estimated by six pan coefficient models (e.g., Snyder, modified Snyder, Allen and Pruitt, Cuenca, Pereira, and Orang) with that obtained by the PMF-56 standard model under the climatic condition of Mymensingh region in Bangladesh.

Materials and Methods

Study area and data collection

The study was carried out at Bangladesh Agricultural University (BAU) campus, Mymensingh, Bangladesh having a latitude and longitude of 24.75° N and 90.40° E, respectively, as portrayed in Fig. 1. Daily climatic data such as maximum and minimum temperature, wind speed, radiation, and humidity were collected from the Bangladesh Meteorological Department (BMD) operated weather station located at BAU campus. This region has an average annual highest and lowest temperature of 33.3°C and 12°C, respectively. The average annual rainfall in the area is 2174 mm. The time-series data of these climatic parameters, ranging from the year 2007 to 2016, were used for this study. The study also collected daily pan evaporation (E_p) data for the same period recorded by a class A pan having a diameter and height of 120.7 and 25 cm, respectively. Collected time series data were subjected to a continuity test. Some of the climatic data were found to have missing observations. These missing data were estimated by a simple arithmetic average technique. For one to three days missing values, we estimated the data for this particular day (days) by an average of the data before and after the particular day (days) (Rahman *et al.*, 2016; Mahmud *et al.*, 2018). We estimated more than 3 consecutive days missing data by the average of the data for the same days but from the previous and subsequent years (Mahmud *et al.*, 2018).

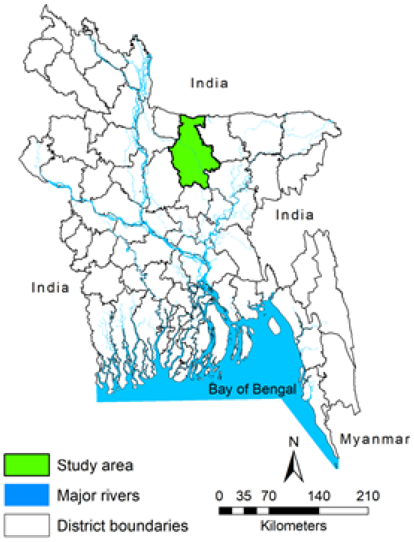

Figure 1. Location of the study area in the Bangladesh map

Estimation of ET₀ by PMF-56 method

For this study, the Penman-Monteith FAO-56 (PMF-56) method was chosen for the computation of ET_0 as it was recommended by FAO for different climatic conditions (Allen *et al.*, 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \tag{1}$$

where ET_0 represents reference evapotranspiration rate in mm/day, R_n indicates net radiation at the crop surface in MJ/m^2/day, G is the soil heat flux density in MJ/m^2/day, T is the air temperature at 2 m height in °C, u_2 is the wind speed at 2 m height in m/s, e_a is actual vapor pressure in kPa, e_s is saturation vapor pressure in kPa, Δ is slope vapor pressure curve in kPa/°C, and γ is psychometric constant in kPa/°C. In this equation, temperature (T) and wind speed (u_2) values were collected and directly used. For daily step ET_0 calculation, soil heat flux density (G) is considered zero, as it is reasonably small for 24-hour period below the grass reference surface (Allen et al., 1998). Psychometric constant (γ) was estimated to be 0.0672 for the study area throughout the study period as it is approximately constant at a given location or altitude. The remaining parameters (R_n, e_a, e_s and Δ) were computed from corresponding equations, detailed in Allen *et al.* (1998). All of the data processing and calculations were performed in Microsoft Excel 2010.

Estimation of ET₀ by pan coefficient models

Pan evaporation data were utilized to compute ET_0 by using the following equation (Allen *et al.*, 1998):

$$ET_0 = K_p \times E_p \tag{2}$$

where K_p and E_p represent pan coefficient and pan evaporation, respectively.

To estimate ET_0 from E_p, several empirical equations were developed by a number of researchers, known as pan evaporation models. Six pan evaporation models were employed in this study to estimate K_p, which are summarized below.

1. Cuenca (1989):

$$K_p = 0.475 - (0.245 \times 10^{-3} u_2) + (0.516 \times 10^{-2} RH) + (0.118 \times 10^{-2} F)(0.16 \times 10^{-4} RH^2) - (0.101 \times 10^{-4} F^2) - (0.8 \times 10^{-8} RH^2 u_2) - (0.1 \times 10^{-8} RH^2 F) \tag{3}$$

2. Allen and Pruitt (1991):

$$K_p = 0.108 - (3.31 \times 10^{-4} u_2) + [(0.0422 \ln(F)] + [0.1434 \ln(RH)] - [6.31 \times 10^{-4}((\ln(F)^2 \ln(RH))] \tag{4}$$

3. Snyder (1992):

$$K_p = 0.482 + [0.24 \ln(F) - 3.76 \times 10^{-4} u_2 + (0.0045RH) \tag{5}$$

4. Modified Snyder (Snyder, 1992):

$$K_p = 0.532 - (3 \times 10^{-4} u_2) + [0.0249 \ln(F)] + (0.0025RH) \tag{6}$$

5. Pereira *et al.* (1995):

$$K_p = 0.85 \times \frac{\Delta + \gamma}{[\Delta + \gamma(1 + 0.33u_2)]} \tag{7}$$

6. Orang (1998):

$$K_p = 0.51206 - (0.000321u_2) + (0.002889RH) + [0.03188 \ln(F)] - [0.000107RH \ln(F)] \tag{8}$$

In the above models, u_2 is the mean daily wind speed measured at 2 m height in km/day, RH is the mean daily relative humidity in %, and F is fetch length in m. According to Pereira *et al.* (1995), estimation of fetch length is difficult as it varies continuously throughout the year as crops grow or field dries down. After investigating the site of pan evaporimeter at Mymensingh weather station, the fetch length was taken as 10 m.

Comparison of the performance of different pan evaporation models

To evaluate the performance of the selected pan evaporation models, several statistical performance criteria were computed. Coefficient of determination (R^2) was employed to evaluate the degree to which the ET_0 best matches with the PMF-56 estimation. In addition, two statistical indices, namely root mean square error (RMSE) and mean absolute error (MAE) were computed to represent the deviation of estimated ET_0 by pan evaporation models from the PMF-56 estimation.

The governing equations for these statistical performance criteria are given below:

$$R^2 = \frac{[\sum_{i=1}^{n}[(Xi - \overline{X})(Yi - \overline{Y})]^2}{\sum_{i=1}^{n}(Xi - \overline{X})^2 \ \sum_{i=1}^{n}(Yi - \overline{Y})^2} \qquad (9)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}[Xi - Yi]^2}{n}} \qquad (10)$$

$$MAE = \frac{\sum_{i=1}^{n}[Xi - Yi]}{n} \qquad (11)$$

where Xi and Yi respectively represent the time series of ET_0 estimated by the PMF-56 and pan coefficient models, $\overline{X}$ and $\overline{Y}$ are the average values of Xi and Yi, respectively, and n is the total number of data.

Results and Discussion

Correlation between pan evaporation(E_p) and reference evapotranspiration (ET_0)

Daily values

The correlation between daily ET_0 and E_p was statistically significant ($p < 0.05$), but the magnitude of correlation was still moderate ($R = 0.65$) indicating the overall poor performances of pan evaporation-based models in estimating ET_0. A moderate correlation (Table 1) may be due to that these two parameters show asymmetric response to their influencing factors. We evaluated the influence of different meteorological parameters on E_p and ET_0; the sunshine hours and wind speed showed different degrees of influence on E_p and ET_0. For instance, the negative correlation of relative humidity with E_p was statistically significant; however, the correlation with ET_0 was insignificant (Table 1). Similarly, the wind speed showed higher influence on ET_0 compared to E_p. Other studies also reported the dissimilar response of the evapotranspiration and pan evaporation with the possible causes, which were attributed to the variation in surface temperature (Szilagyi, 2007), the conductivity of crop canopy, the atmospheric boundary depth and vegetation height (Pettijohn *et al*., 2009), and evaporation area (Szilagyi and Jozsa, 2008). Zhang *et al.* (2007) reported that ET_0 increased but E_p decreased with an increase in surface temperature, and this discrepancy is widely termed as pan evaporation paradox (Wang *et al.,* 2017).

The paradox prevails when the air-drying force is much smaller than the radiative energy. The drying force of the air denotes the evaporation capacity from water surface to air or the difference between vapor pressure in the air and saturation pressure at the same temperature. Actually, if the air-drying force is too weak to increase E_p, then the increase of E_p must be less than actual evapotranspiration that is mainly influenced by radiative energy (Zhang *et al.*, 2007). Similarly, Zou *et al*. (2016) showed that with the increase of humidity, the average daily pan evaporation tended to decrease whereas the daily actual evapotranspiration increased in the arid area of northwest China. Overall the result implies that the factors affecting pan evaporation may be different from that affecting crop evapotranspiration, and these factors may vary with climate condition.

Monthly values

The correlation between monthly mean values of observed E_p and computed ET_0 over ten years period was also observed, presented in Table 2. The correlations between E_p and ET_0 were significant for the months of February ($R = 0.75$), August ($R = 0.90$), and September ($R = 0.73$).

Table 1. Correlation (R) matrix showing the relationship among mean daily values of evapotranspiration (ET_0), evaporation (E_p), temperature (T_{mean}), wind speed (WS), relative humidity (RH) and sunshine hours (SH)

	ET_0	E_p	T_{mean}	WS	RH	SH
ET_0	1					
E_p	0.65*	1				
T_{mean}	0.47*	0.48*	1			
WS	0.42*	0.24	0.43*	1		
RH	-0.18	-0.34*	0.075	0.18	1	
SH	0.26	0.37*	0.076	-0.22	-0.66*	1

* indicates statistically significant value at 95% confidence level

Table 2. Correlation (R) between monthly pan evaporation (E_p) and reference evapotranspiration (ET_0) by Penman–Monteith FAO-56 method (PMF-56)

Month	R
Jan	0.077
Feb	0.746
Mar	0.591
Apr	0.641
May	0.623
Jun	0.654
Jul	0.226
Aug	0.896
Sep	0.732
Oct	0.339
Nov	0.480
Dec	0.604

Generally, summer (winter) months showed a strong (weak) correlation between E_p and ET_0. Particularly, the correlation between E_p and ET_0 for January was unexpectedly low, and the causes need to be further investigated. The stronger correlation in the summer months may be due to these months have a higher temperature, which is considered as the most dominating factor affecting the amount of E_p and ET_0 and their interrelationship (Ahmed *et al.*, 2014). Moreover, higher humidity and soil moisture during the summer months are likely to have significant influences on the interrelationship of pan evaporation and reference ET. For instance, Lawrimore and Peterson (2000) and Du *et al.* (2016) recognized that the complementary relationship between pan evaporation and actual evapotranspiration even held for the wettest soils being dominantly affected by the atmospheric humidity and soil moisture. Precipitation was reported to have greater influences on the variations of ET as the seasonal variations of ET strongly correlated with the distribution of precipitation (Tiwari, 2016). However, Tiwari (2016) and Amatya *et al.* (2018) reported that the pan evaporation varied within a narrow range regardless of its sensitiveness to the variation in precipitation. Hence, it is difficult to infer about the influence of precipitation on the higher relationship between E_p and ET_0 during summer months.

Evaluation of Pan Coefficient models

Estimation of Pan Coefficients (K_p)

Daily and monthly K_p values were computed by using six pan evaporation models namely, Snyder (Sn), modified Snyder (MSn), Allen and Pruitt (AP), Cuenca (Cu), Pereira (Pe), and Orang (Or). Mean monthly pan coefficient (K_p) values over study period estimated by different pan coefficient models ranged from 0.7 to 0.9 with slightly higher values for the monsoon and winter months (June to February) and lower for the pre-monsoon months (March to May) (Fig. 2). Similar findings were found by Pradhan *et al.* (2013), who evaluated five empirical methods of pan coefficients for humid tropical monsoon climate region in India and showed that the calculated K_p values ranged between 0.72 and 0.93, being lower in the summer months and higher in the rainy and winter months. Our study showed that $K_p$values computed by Snyder model were clearly higher than that of other methods elucidating its best agreement to the PMF-56 in calculating ET from E_p. Similarly, Gundekar *et al.* (2008), Pradhan *et al.* (2013), Tabari *et al*. (2013), and Sree Maheswari and Jyothy (2017) showed that the Snyder method was found to be the best to estimate K_p. The poor performance of Pereira method might be due to the exclusion of the fetch distance (Conceiçã, 2002). To summarize, even though the Class A pan coefficients estimated by the selected methods may still produce substantial errors in converting ET_0 from E_p, however, the most advantage of these methods is that they are able to estimate pan coefficients using local climatic data at the station. Also, the methods can eliminate the uncertainties in derived pan coefficients due to pan type, ground cover, microclimatic conditions surrounding the pan, and the level of maintenance (Irmak *et al*., 2002).

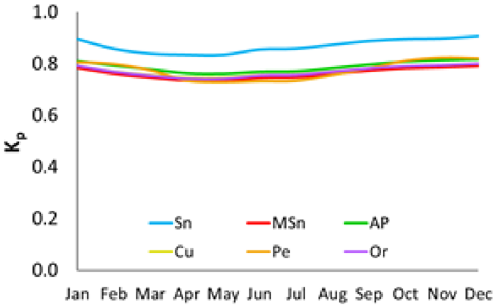

Figure 2. Variation of mean monthly pan coefficient (Kp) values estimated by different pan coefficient models: Snyder (Sn), modified Snyder (MSn), Allen and Pruitt (AP), Cuenca (Cu), Pereira (Pe), and Orang (Or).

Estimation of ET_0 by pan coefficient models

Daily ET_0

In general, none of the models predicted ET_0 at a satisfactory level ($R^2 < 0.5$) (Table 3). However, based on the error estimates (Table 3), the Snyder method gave the comparatively better agreement to the PMF-56 method as it had smallest errors (MAE = 0.87mm/day, RMSE = 1.13mm/day) compared to other models. The sequential performance for all the models was observed as follows: Snyder>Allen and Pruitt> Cuenca> Orang> Pereira> modified Snyder. The findings regarding the best performance of Snyder model were in line with other findings obtained in different climate conditions of the world. For instance, Gundekar *et al.* (2008), SreeMahewari and Jyothy (2017), and Aydin (2019) introduced Snyder as a suitable model to estimate ET_0 for

Table 3. Performance indices of selected pan coefficient models for daily reference evapotranspiration (ET_0) estimation

Model name	R^2	MAE (mm/day)	RMSE (mm/day)
Snyder	0.385	0.867	1.131
Modified Snyder	0.394	0.965	1.233
Allen and Pruitt	0.399	0.926	1.192
Cuenca	0.398	0.950	1.217
Pereira	0.381	0.954	1.225
Orang	0.394	0.954	1.222

R^2 = Coefficient of determination; MAE = Mean Absolute Error; RMSE = Root Mean Square Error

semi-arid regions. Sabziparvar *et al*. (2010) also reported the best performance of the Synder model for the warm arid climate of Iran. On the other hand, poor performances of Snyder were reported in warm humid Brazil (Sentelhas and Folegatti, 2003) and in the humid tropical region of Kerala, India (George, 2012). This study demonstrated the poor performance of Pereira method, which supports the finding of Gundekar *et al.* (2008) who reported poor performance of Pereira method under the semi-arid climatic conditions. Best performance of Pereira method in computing ET_0 was also seen in warm humid Brazil (Sentelhas and Folegatti, 2003) and arid climate of Pakistan (Shaikh *et al*., 2018). Our study also demonstrated that the modified Snyder showed the largest deviations in estimating ET_0 compared to PMF-56 method. This result contradicts with the result obtained by Ganji and Kajisa (2019), they found that the modified Snyder model was the best to estimate ET_0 using E_p data under semi-arid conditions. We also noticed moderate performances of Orang model, however, this method was found to provide good performances in warm arid climate (Sabziparvar *et al*., 2010). Overall, it can be concluded that the best performances of pan coefficient models in estimating ET_0 is highly dependent on local climatic condition.

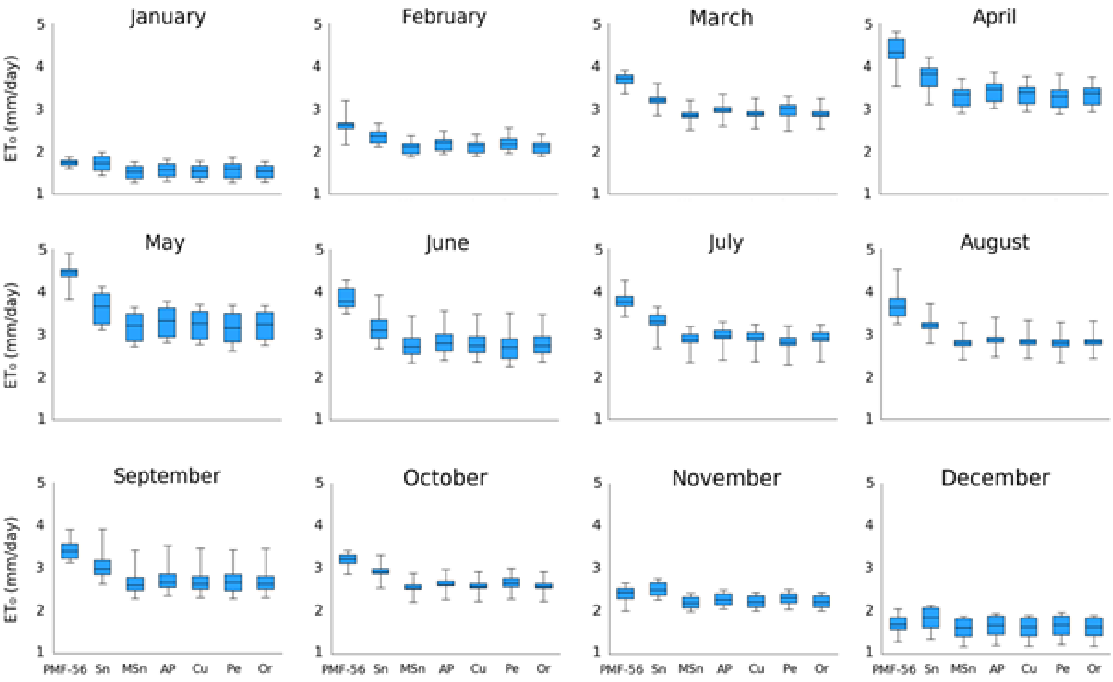

Figure 3. Comparison of monthly reference evapotranspiration (ET0) estimated by Penman-Monteith FAO-56 method (PMF-56)and selected pan evaporation models: Snyder (Sn), modified Snyder (MSn), Allen and Pruitt (AP), Cuenca (Cu), Pereira (Pe), and Orang (Or)

Monthly ET_0

The range of monthly mean ET_0 estimated by PMF-56 and 6 different pan coefficient models is depicted in Fig. 3. Generally, all the pan models underestimated mean ET_0 and the only exception was observed for dry months of November–January where only Snyder model overestimated PMF-56 ET_0 (Fig. 3). However, higher interquartile range (IQR) and higher total range reveal that monthly ET_0 estimated by different K_p models were inconsistent around the median for these winter (dry) months. In contrast, for the other months especially March, July, August, and October, lower IQR indicates the consistent results about estimating ET_0 by K_p models (Fig. 3). Performances of pan coefficient models in estimating monthly ET_0 values were also compared with respect to three performance statistics like R^2, MAE, and RMSE, which are presented in Table 4. Considering three performance criteria, all the models except Pereira performed better in estimating ET_0 for the month of

August with R^2 (> 0.70), MAE (0.480 mm/day to 0.903 mm/day), and RMSE (0.518 mm/day to 0.918 mm/day), however, error values were still beyond the acceptable limit. Pan coefficient models also showed comparatively better performances for the months of February, May, June, and September having larger R^2 (> 0.5) values. Considering all month values, the Snyder method performed best in ET_0 estimation, which is similar to that observed in daily ET_0 estimation. Considering monthly variation, the estimated errors by MAE and RMSE for all the pan coefficient models were higher for the months spanning from April to September (Table 4) than that observed in other months. The results are in line with Ganji and Kajisa (2019), who found that the differences between ET_0 by PMF-56 and ET_0 by Pan coefficient models were significantly large in the period from June to September, and they also demonstrated that the errors were strongly correlated with the wind speed. The result implies that the windy season is critical for accurate estimation of ET_0 using a theoretical model such as the PMF-56 model.

Table 4. Performance indices of selected pan coefficient models for reference evapotranspiration (ET_0) estimation at monthly scale

	Snyder			Modified Snyder			Allen & Pruitt		
Months	R^2	MAE (mm/day)	RMSE (mm/day)	R^2	MAE (mm/day)	RMSE (mm/day)	R^2	MAE (mm/day)	RMSE (mm/day)
Jan	0.017	0.149	0.194	0.011	0.258	0.288	0.008	0.22	0.255
Feb	0.471	0.268	0.313	0.489	0.518	0.548	0.496	0.432	0.466
Mar	0.159	0.478	0.512	0.176	0.83	0.848	0.182	0.709	0.731
Apr	0.331	0.611	0.687	0.229	1.057	1.107	0.228	0.933	0.99
May	0.377	0.846	0.898	0.383	1.28	1.309	0.386	1.164	1.198
Jun	0.362	0.696	0.756	0.363	1.098	1.13	0.362	1.013	1.05
Jul	0.04	0.513	0.598	0.052	0.934	0.974	0.061	0.848	0.898
Aug	0.726	0.48	0.518	0.747	0.892	0.914	0.757	0.809	0.831
Sep	0.466	0.351	0.432	0.472	0.747	0.78	0.475	0.666	0.705
Oct	0.043	0.317	0.372	0.059	0.657	0.689	0.069	0.574	0.611
Nov	0.175	0.184	0.218	0.169	0.224	0.271	0.164	0.179	0.222
Dec	0.318	0.184	0.258	0.324	0.208	0.243	0.327	0.193	0.229

	Cuenca			Pereira			Orang		
Months	R^2	MAE (mm/day)	RMSE (mm/day)	R^2	MAE (mm/day)	RMSE (mm/day)	R^2	MAE (mm/day)	RMSE (mm/day)
Jan	0.011	0.246	0.277	0.002	0.235	0.277	0.011	0.246	0.277
Feb	0.495	0.497	0.527	0.395	0.417	0.461	0.489	0.499	0.53
Mar	0.245	0.796	0.814	0.053	0.722	0.759	0.176	0.805	0.823
Apr	0.245	1.008	1.059	0.113	1.055	1.122	0.232	1.024	1.075
May	0.385	1.231	1.262	0.388	1.298	1.332	0.383	1.247	1.277
Jun	0.367	1.061	1.095	0.315	1.141	1.182	0.363	0.902	0.945
Jul	0.055	0.897	0.939	0.103	0.985	1.02	0.051	0.861	0.884
Aug	0.755	0.858	0.88	0.688	0.903	0.926	0.746	0.718	0.753
Sep	0.477	0.717	0.762	0.411	0.716	0.757	0.472	0.631	0.665
Oct	0.061	0.631	0.665	0.056	0.562	0.605	0.058	0.631	0.665
Nov	0.174	0.21	0.225	0.056	0.187	0.229	0.17	0.211	0.256
Dec	0.327	0.202	0.237	0.273	0.202	0.244	0.324	0.201	0.237

R^2 = Coefficient of determination; MAE = Mean Absolute Error; RMSE = Root Mean Square Error

Conclusion

Optimal estimation of reference evapotranspiration (ET_0) is extremely necessary for irrigation scheduling and planning. With a view to finding a suitable alternative to the most standard Penman–Monteith FAO-56 (PMF-56) method for ET_0 estimation, we evaluated the accuracy of six existing pan coefficient models in predicting ET_0 from pan evaporation (E_p) based on some statistical criteria. The monthly E_p and ET_0 by the PMF-56 method showed significant correlations for the months of February, August, and September, however, pan coefficient models estimated ET_0 with a good accuracy only for August. Even though, overall all the models showed poor performances in estimating ET_0 from pan evaporation, performance of Snyder model was better compared to the other models. However, the method still cannot be recommended as an alternative to the PMF-56 method. Further calibration of the Snyder model in the context of the climatic condition of Bangladesh is needed for closely estimating ET_0. Furthermore, we used the PMF-56 evapotranspiration model as the reference method for evaluation of pan evaporation models. Future studies should incorporate the actual evapotranspiration measured by field lysimeter as the reference to evaluate the pan evaporation models, which would make the results more reliable. In addition, further research can consider a longer period of meteorological data at larger number of weather stations for evaluating pan evaporation based ET_0 estimation methods.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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