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# Assessment of Hargreaves and Blaney-Criddle Methods to Estimate Reference Evapotranspiration Under Coastal Conditions

**Muhammad Hafeez[1, *], Alamgir Akhtar Khan[2]**

[1]Department of Agricultural Engineering, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan

[2]Department of Agricultural Engineering, Muhammad Nawaz Sharif University of Agriculture, Multan, Pakistan

**Email address:**
mh9589041@gmail.com (M. Hafeez)

[*]Corresponding author

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**Abstract:** There are a lot of weather stations of the world like Pakistan where all the metrological parameters are not accessible to evaluate PM method for the approximation of ETo. So ablatives methods like Hargreaves and Blaney-Criddle methods are used which required small numbers of metrological parameters. A study has been directed to assess the accuracy of Hargreaves and Blaney-Criddle methods against standard PM method for approximation of reference evapotranspiration (ETo) in coastal arid locations of Sindh and Baluchistan. The statistical evaluation of the study indicated that the Hargreaves method underestimated ETo by 44.61%, 30.86%, 27.03% and 37.8% at Karachi, Gawadar, Jiwani and Pasni, respectively. The Blaney-Criddle method underestimated ETo in winter and overestimated ETo in summer by 14.91% at Karachi station, overestimated ETo by 23.98% at Gawadar station, underestimated ETo in January and December and overestimated ETo in remaining months by 22.38% at Jiwani station and overestimated ETo by 27.25% at Pasni station. The difference of variations of Hargreaves (HG) method with PM method with RMSE were 2.03 mm/day, 1.46 mm/day, 1.21 mm/day and 1.65 mm/day at Karachi, Gawadar, Jiwani and Pasni stations, respectively. The difference of variations of BC method with PM method with RMSE were 1.98 mm/day, 2.42 mm/day, 2.16 mm/day and 2.89 mm/day at Karachi, Gawadar, Jiwani and Pasni stations, respectively. The $R^2$ with Hargreaves method were 0.95, 0.92, 0.89 and 0.97 at Karachi, Gawadar, Jiwani and Pasni, respectively. The $R^2$ with BC method were 0.59, 0.78, 0.86 and 0.78 at Karachi, Gawadar, Jiwani and Pasni stations, respectively.

**Keywords:** Hargreaves, Blaney-Criddle, ETo, Coastal, Sindh, Baluchistan

## 1. Introduction

The pure water has been considered as precious as blue gold and it is designed to be the most serious concern of the present era [1]. Among the present fresh water availability in the world about 70% of fresh water is consuming by agriculture. So additional affective irrigation water application is necessary [2]. So improvements of maintainable irrigation methods require accurate thoughtful of biophysical developments of root-water application in soil and transpiration from vegetable covers [3]. Effective and maintainable organization of water reservoirs needs accurate knowledge of the source of generation and spreading of the resources. In water stability system, along with rainfall, ground and underground flow, evapotranspiration is a basic component [4]. This contains two practices (1) straight vaporization from surface water bodies, surface cover with plants and plain ground (2) transpiration that consists of the conveyance of water from earth surface/aquifer arrangement through vegetative origins and vapor from the vegetative greeneries into the atmosphere [5]. The evapotranspiration is the liquid that is essentially required for the plant metabolic movement [6]. Evapotranspiration is a significant variable for metrological and hydrological research and also for agrarian water reservoirs organization. The crop water necessity is usually estimated by multiplying reference evapotranspiration (ETo) with the already determined crop-specific factor, which is based on various parameters comprising irrigation patterns and managing [7].

$$\text{ET crop} = \text{ETo} \times \text{Kc (mm/day)}$$

Where, ETo= reference evapotranspiration, Kc= crop factor

The accurate and proper timing of irrigation has developed very significant in the last eras due to continually growing request of the water and declination of the water reservoirs [8]. Three significant procedures applied for the estimation of correct irrigation schedule are soil-data soil, plant-data based and metrological data based, but the weather-data based practice has got consideration in the methodical community because this practice needs no more high valued and exceptional indicators to define the wetness of the soil, atmospheric temperature and greenery part index [9]. The correct statistics about ($ET_O$) is vital for the metrological-dependent practices to be used [10]. Reference evapotranspiration (ETo) may be stated as; evapotranspiration from supposed crop with supposing crop altitude of (0.12) and a persistent covering defiance of (70 $sm^{-1}$) and reflective influence of (0.23) which could have evaporation from upper part of green pasture having permanent altitude, fast rising and earth is fully protected with pasture having no scarceness of water [2].

There are several methods for the estimation of (ET0) like Penman-Monteith (FAO-56 PM) [2] Blaney-Criddle [11] and Hargreaves-Samani [12] but international scientific society has considered the Penman-Monteith (FAO56PM) [2] method as best procedure because it gives accurate results when examined with other methods in several locations of the globe [13]. There are many revisions that have given the accuracy of Penman-Monteith (PM) method [2], when examining with lysimteric values particularly when routinely calculations are done [14]. The exploration for explanations for estimating ETo in the deficiency of completely metrological parameters has directed to establish various methods [15, 16] comprising application of computer models: multiple regression analysis, synthetic neural system and genomic algorithms [17, 18];. Regardless of presentation of gradually increasing refined models of calculation and innovative remote sensing calculation procedures, ETo atmospheric temperature-dependent methods are very valuable in limited data locations of the globe. The atmospheric temperature is the maximum measured metrological variable required for ETo estimation [19].

The empirical reference evapotranspiration methods that use small number of input parameters are present. Three various natures of ETo estimation methods i-e temperature-dependent method, radiation dependent-method and mass-transfer-dependent methods are generally applied to estimate reference evapotranspiration reliant on the accessibility of metrological parameters [20]. Temperature-dependent methods consist of the Blaney–Criddle (BC), Hargreaves (HG) and the Thornthwaite methods, radiation-dependent methods include Priestley–Taylor (PT), Makkink and Ritchie-type methods and the Dalton and Rohwer methods are mass-transfer-dependent methods [21].

The temperature-dependent methods are particularly exciting due to involvement of small number of metrological data i-e atmospheric temperature which can be determined simply and worldwide [22]. The atmospheric temperature and sun-radiations clarify at minimum about 80% of ETo variation [23]. A study has been conducted to examine the twelve various ETo methods against standard Penman-Monteith (PM) method for windy locations of South Nebraska. The consequences of the study revealed that Blaney-Criddle (BC) procedure was most accurate temperature-dependent procedure and had (RMSE) of 0.64 mm/day that was alike to some of the grouping methods. The found calculation were well and were close to 3% of the ASCE-PM [24] ETo with coefficient of determination ($R^2$) 0.94. The estimations were reliable with no greater undervalue or overvalue for most of the metrological data [25]. A research has been conducted to examine the various ETo methods against standard Penman-Monteith method at moist Goiânia locations of Brazil. Findings of the research indicated that the Blaney-Criddle (BC) method showed the most accurate consequences after the standard Penman-Monteith (PM) method [26]. The objective to conduct this study is to check the performance of Hargreaves and Blaney-Criddle methods in Coastal locations of Sindh and Baluchistan, Pakistan.

# 2. Methodology

### *2.1. Location of the Study Area and Data Collection*

The metrological parameters of four coastal weather stations i-e Karachi, Gawadar, Jiwani and Pasni stations were utilized to approximate reference evapotranspiration (ETo) by Hargreaves (HG) and Blaney-Criddle methods. The climate of these stations, GPS (Global positioning system) and mean monthly metrological data utilized are given below in table.

***Table 1.*** *Geographical coordinates and climate of metrological stations used in the study.*

| Station | Latitude | Longitude | Elevation (m) | Data used | Climate |
|---|---|---|---|---|---|
| Karachi | 24.86 N | 67.00 E | 8 | 2007-2016 | Coastal moderate arid |
| Gawadar | 25.19 N | 62.32 E | 7 | 2007-2015 | Coastal hot arid |
| Jiwani | 25.04 N | 61.74 E | 57 | 2002-2011 | Coastal hot arid |
| Pasni | 25.28 N | 63.40 E | 10 | 2005-2014 | Coastal hot arid |

### 2.2. Overview of Methods for the Estimation of ETo

#### 2.2.1. PM Method (FAO-56 PM)

For the approximation of Penman-Monteith ETo, Computer model CROPWAT 8.0 was utilized which was recommended by FAO (Food and Agriculture Organization). The input metrological parameters necessary were minimum and maximum atmospheric temperature, relative humidity, wind velocity and sunshine hours. Monthly ETo was approximated by means of computer model (Steduto *et al.*, 2009). Penman Monteith procedure applied as recommended by (Allen *et al.*, 1998) is stated as

$$ET_o = \frac{0.408\Delta\,(Rn - G) + \gamma\,(900/T + 273.3)\,U2\,(VPD)}{\Delta + \gamma\,(1.34\,U2)}$$

Where,

ETo is reference crop evapotranspiration (mm/day); Δ is slope of the saturation vapor pressure function (kPa $(°C)^{-1}$); Rn is net solar radiations (MJ $m^{-2}$ $day^{-1}$); G is earth heat flux thickness (MJ $m^{-2}$ $day^{-1}$); T is average atmospheric temperature (°C); U2 is the mean 24-hour air velocity at 2m elevation ($ms^{-1}$); VPD is the vapor pressure debit (kPa); and γ is psychometric constant (kPa $(°C)^{-1}$). The estimation of all weather data essential for calculation of ET0 followed the method of (Allen *et al.*, 1998).

#### 2.2.2. Hargreaves Method

The Hargreaves method is applied to estimate ETo when only air temperature is accessible (Hargreaves and Allen. 2003). ETo estimated by Hargreaves method (Hargreaves and Samani. 1985) is defined as:

$$ETo_{HG} = 0.0023\,Ra\,(T+17.8)\,(T_{max} - T_{min})$$

ETo is in mm $day^{-1}$; Ra (MJ $m^{-2}$ $d^{-1}$) is the extra-terrestrial solar radiation and $T_{mean}$ is mean monthly air temperatures (°C), respectively.

#### 2.2.3. Blaney-Criddle Method

The innovative method as designated by Blaney and Criddle (1950) is:

$$ETo = a+b\,[p\,(0.46\,T + 8.13)]$$

Where,

a =0.0043 (RH min)-n/N-1.41, b =0.82-0.0041 (RH min) +1.07 (n/N) + 0.066 (u d) - 0.006 (RH min) (n/N)-0.0006 (RH min) (ud), with T being the average monthly air temperature (°C) and p the monthly% of the yearly sunshine hours.

#### 2.2.4. Statistical Assessment

The following statistical tools were used to evaluate the performance of Hargreaves and Blaney-Criddle methods against standard Penman-Monteith method.

##### i. Coefficient of Determination ($R^2$)

The coefficient of determination was executed as:

$$R^2 = \frac{[\Sigma i^n = (x_i - \bar{x})\,(y_i - \bar{y})]^2}{\Sigma i^n = {}_1(x_i - \bar{x})^2\ \Sigma i^n = {}_1(y_i - \bar{y})^2}$$

Where,

yi = estimated ETo by Penman-Monteith method for day i (mm/day); xi= estimated ETo by Hargreaves and Blaney-Criddle methods for day i (mm/day).

##### ii. RMSE

The root mean square error (RMSE) was computed as:

$$RMSE = \sqrt{\frac{\Sigma i^n = {}_1(y_i - x_i)^2}{n}}$$

Where, yi= estimated ETo by PM method for day i (mm/day); xi= estimated ETo by Hargreaves and Blaney-Criddle methods for day i (mm/day); and n= total number of observation.

##### iii. % Error

Percentage error was determined as

$$PE = \left|\frac{\bar{P} - \bar{O}}{\bar{O}}\right| \times 100\%$$

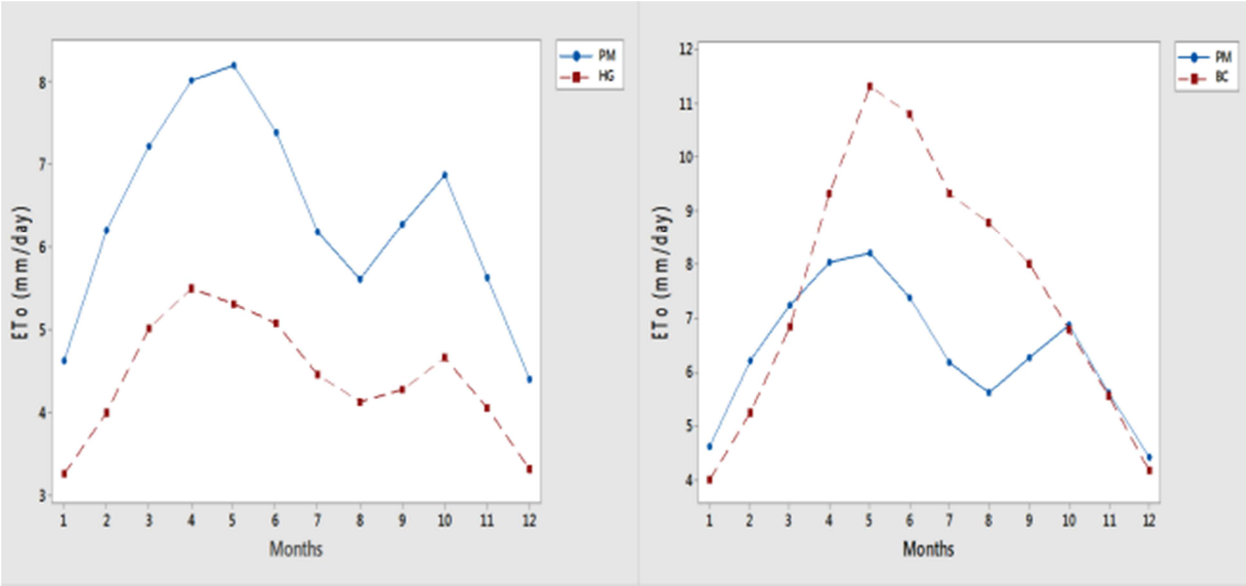
Where,

Pi and Oi are the projected and observed facts, respectively; P and Ō are the mean of Pi and Oi, and n is the whole number of figures

## 3. Results and Discussion

### 3.1. Performance Evaluation at Karachi Station

The Hargreaves (HG) and Blaney-Criddle methods are assessed against standard Penman-Monteith (PM) method in coastal arid region of Karachi (Sindh). The statistical performance indicated that the Hargreaves (HG) method underestimated ETo by 44.61% with coefficient of determination of 0.95 and root mean square error (RMSE) of 2.03 mm/day as shown in Figure 1 (a) and Table 2. The statistical performance of Blaney-Criddle method with standard Penman-Monteith (PM) method indicated that Blaney-Criddle (BC) method underestimated ETo in first 3 and last two months of the year and overestimated ETo in the remaining months by 14.91% with coefficient of determination of 0.59 and root mean square error of 1.98 mm/day as shown in Figure 1 (b) and in Table 2.




(a) (b)

***Figure 1.*** *Monthly comparison of ETo _ PM with (a) HG and (b) BC at Karachi station.*

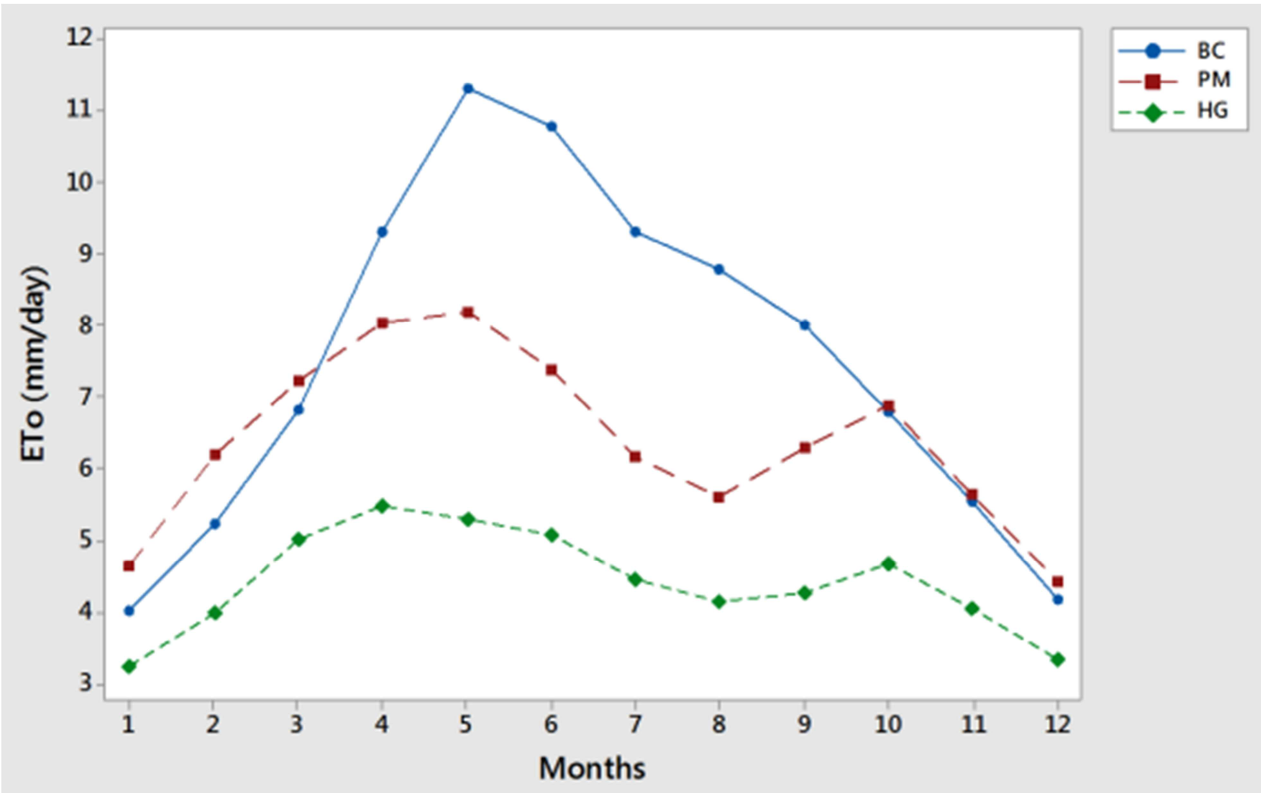



***Figure 2.*** *Monthly comparison of ETo _ PM with HG and BC at Karachi station.*

***Table 2.*** *Statistical performance of PM with HG and BC at Karachi Stat.*

| Method | RMSE | $R^2$ | % Error |
|---|---|---|---|
| Hargreaves | 2.03 | 0.95 | 44.61 |
| Blaney- Criddle | 1.98 | 0.59 | 14.91 |

### *3.2. Performance Evaluation at Gawadar Station*

The Hargreaves (HG) and Blaney-Criddle (BC) methods are evaluated against standard Penman-Monteith (PM) method in hot and arid region of Gawadar (Baluchistan). The statistical evaluation showed that the Hargreaves (HG) method underestimated ETo at Gawadar station by 30.86% with coefficient of determination of 0.92 and root mean square error (RMSE) of 1.46 mm/day as shown in Figure 3 (a) and in Table 3. The Blaney-Criddle (BC) method overestimated ETo by 23.98% with coefficient of determination of 0.78 and root mean square error (RMSE) of 2.42 mm/day as shown in Figure 3 (b) and in Table 3.

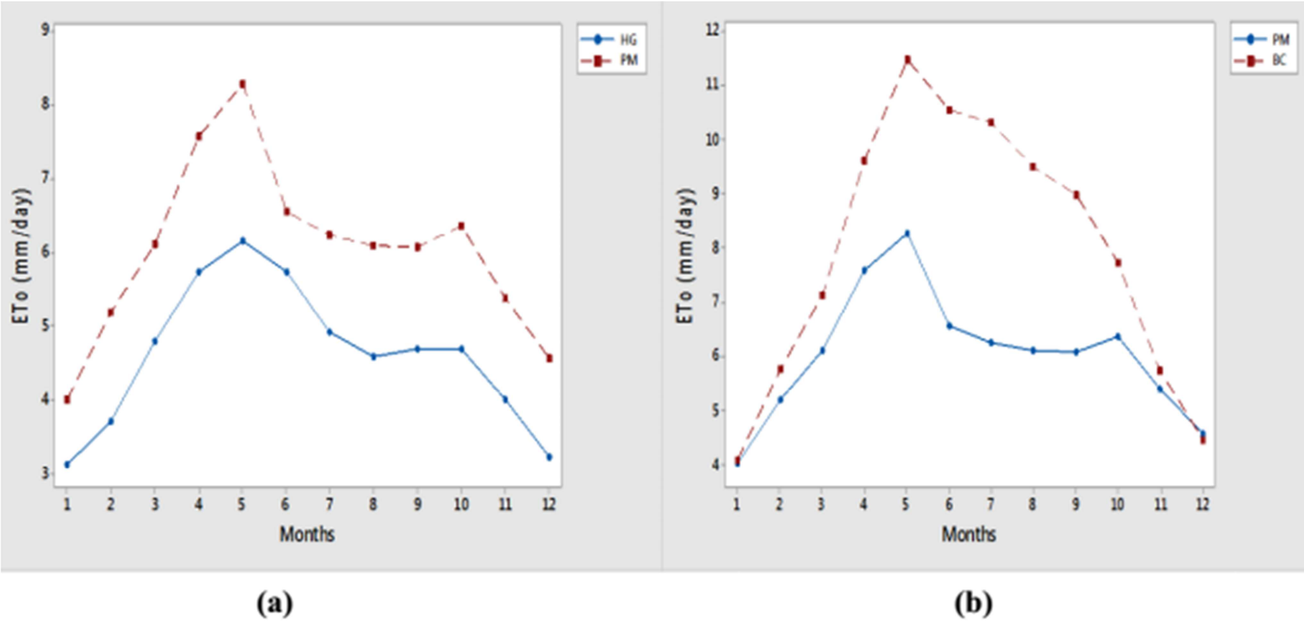



***Figure 3.*** *Monthly comparison of ETo _ PM with (a) HG and (b) BC at Gawadar station.*

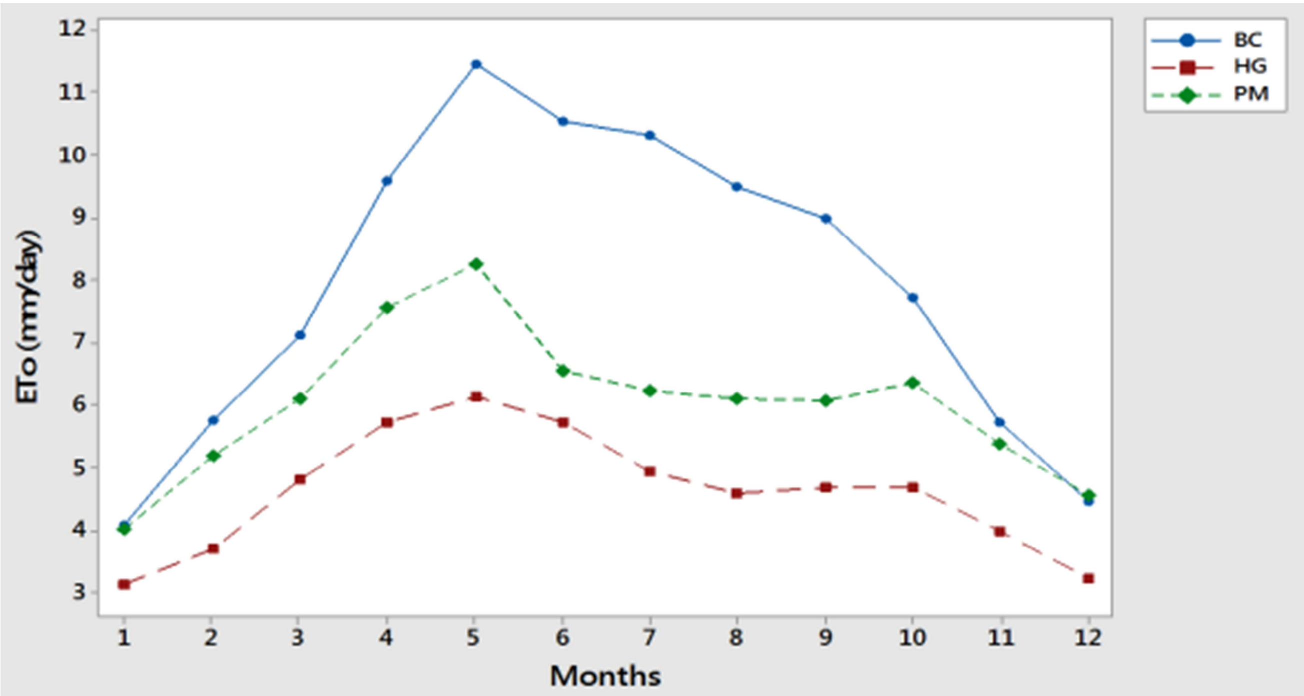


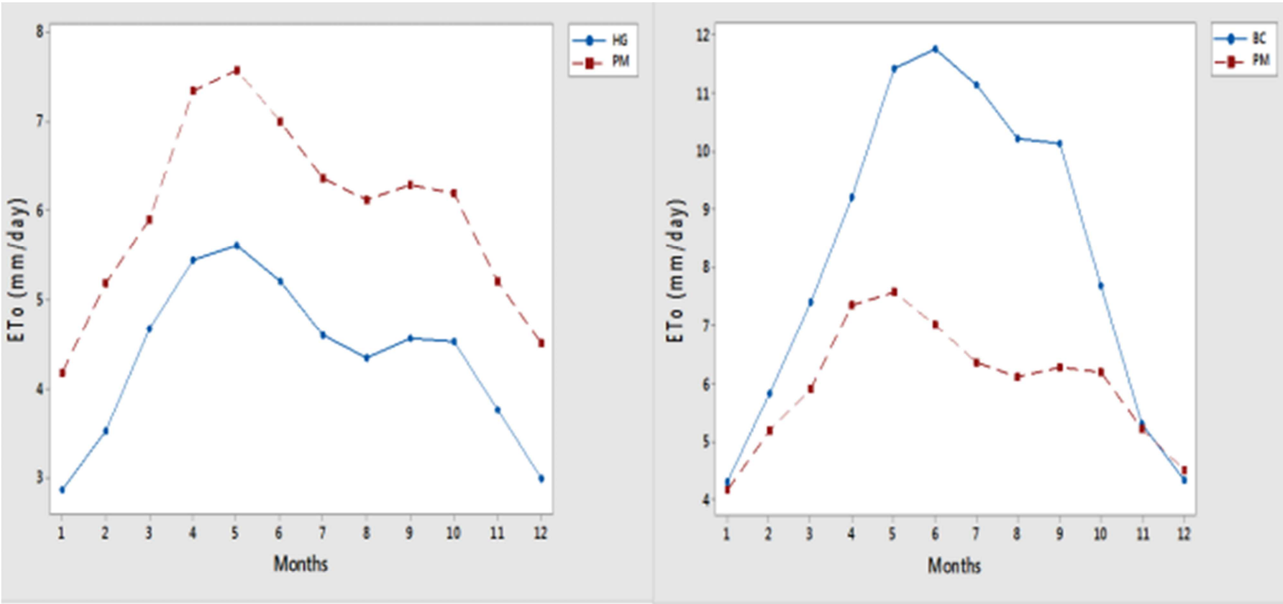

***Figure 4.*** *Monthly comparison of ETo _ PM with HG and BC at Gawadar station.*

***Table 3.*** *Statistical performance of PM with HG and BC at Gawadar Station.*

| Method | RMSE | $R^2$ | % Error |
|---|---|---|---|
| Hargreaves | 1.46 | 0.92 | 30.86 |
| Blaney- Criddle | 2.42 | 0.78 | 23.98 |

### *3.3. Performance Evaluation at Jiwani Station*

The statistical evaluation of Hargreaves (HG) method against standard Penman-Monteith method indicted that the Hargreaves (HG) method underestimated ETo at Jiwani station by 27.03% with coefficient of determination ($R^2$) of 0.89 and root mean square error (RMSE) of 1.21 mm/day as shown in Figure 5 (a) and in Table 4. The assessment of Blaney-Criddle (BC) method indicated underestimation of ETo in January and December and overestimation of ETo in remaining months at Jiwani station as shown in Figure 5 (b) and in Table 4.




**(a)** **(b)**

***Figure 5.*** *Monthly comparison of ETo _ PM with (a) HG and (b) BC at Jiwani station.*

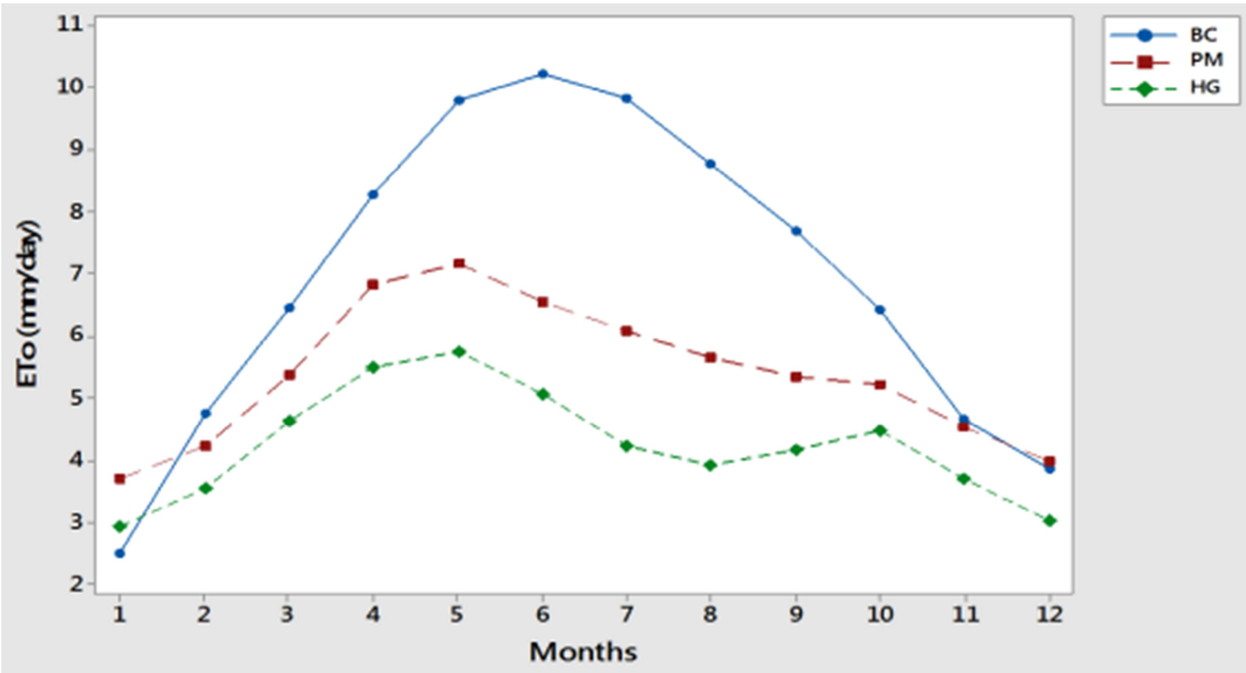



***Figure 6.*** *Monthly comparison of ETo _ PM with HG and BC at Jiwani station.*

***Table 4.*** *Statistical performance of PM with HG and BC at Jiwani Station.*

| Method | RMSE | $R^2$ | % Error |
|---|---|---|---|
| Hargreaves | 1.46 | 0.92 | 30.86 |
| Blaney- Criddle | 2.42 | 0.78 | 23.98 |

### *3.4. Performance Evaluation at Pasni Station*

The comparison of Hargreaves (HG) method with the standard Penman-Monteith method showed underestimation of ETo at Pasni station by 37.8% with coefficient of determination ($R^2$) of 0.97 and root mean square error (RMSE) of 1.65 mm/day as shown in Figure 7 (a) and in Table 5. The evaluation of Blaney-Criddle (BC) method indicated underestimation of ETo in December and overestimation of ETo in all remaining months by 25.27% with coefficient of determination ($R^2$) of 0.78 and root mean square error (RMSE) of 2.89 mm/day as shown in Figure 7 (b) and in Table 5.

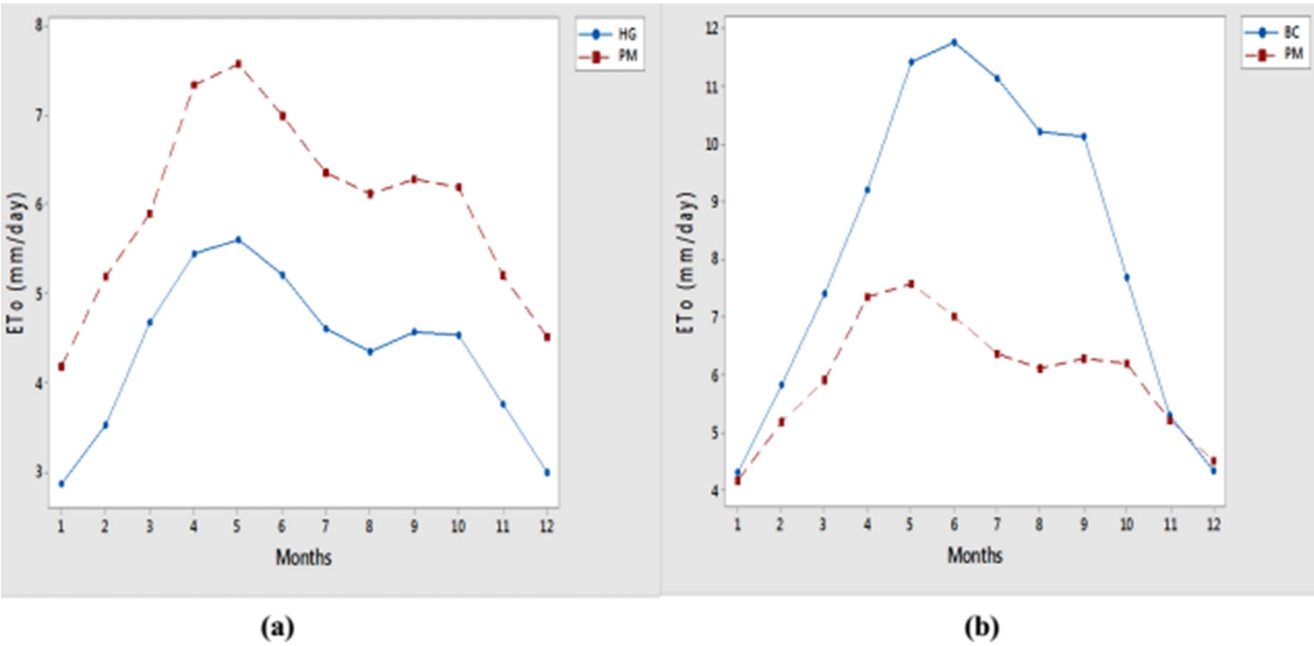



***Figure 7.*** *Monthly comparison of ETo _ PM with (a) HG and (b) BC at Pasni station.*

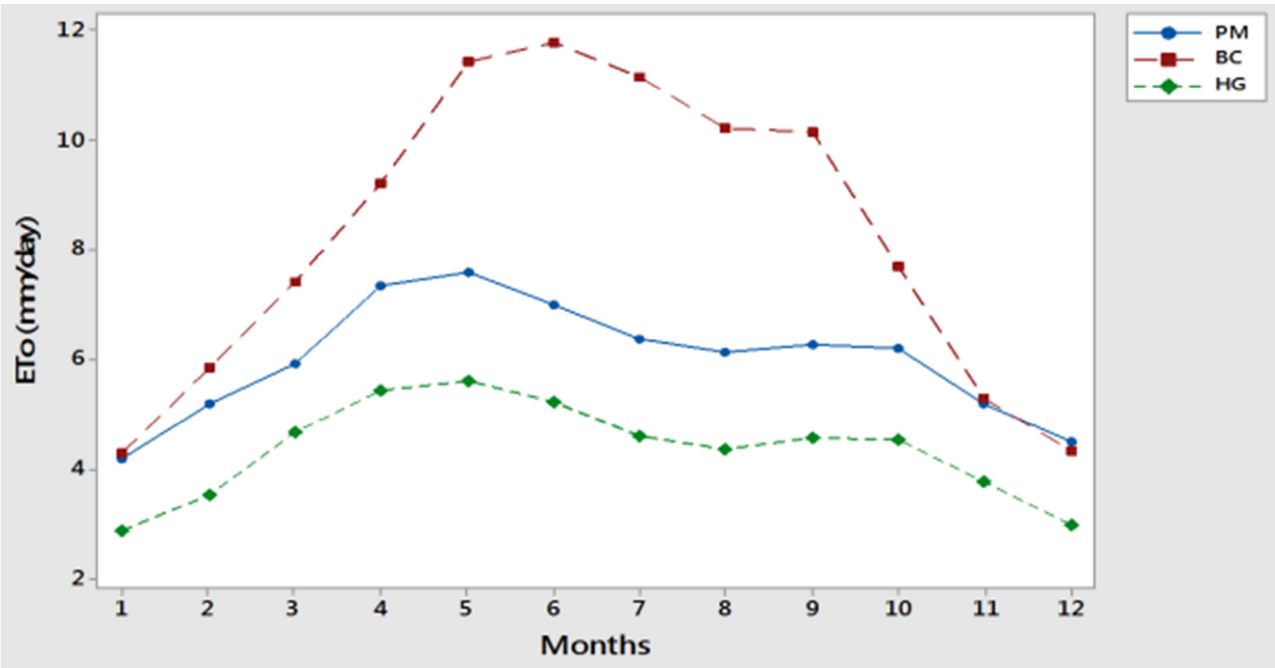



***Figure 8.*** *Monthly comparison of ETo _ PM with BC and HG at Pasni station.*

***Table 5.*** *Statistical performance of PM with HG and BC at Pasni Station.*

| Method | RMSE | $R^2$ | % Error |
|---|---|---|---|
| Hargreaves | 1.65 | 0.97 | 37.8 |
| Blaney- Criddle | 2.89 | 0.78 | 27.25 |

## 4. Conclusion

The Hargreaves (HG) and Blaney-Criddle (BC) methods are compared with standard Penman-Monteith (FAO-56 PM) under coastal climatic conditions. The results of research indicated that Hargreaves (HG) method underestimated the standard PM method at all the metrological stations of coastal conditions and the Blaney-Criddle (BC) method overestimated PM method at all the metrological stations of coastal conditions. So it is suggested that these methods must be modified according to the local conditions.

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