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ESTIMATING REFERENCE EVAPOTRANSPIRATION BY HARGREAVES AND BLANEY-CRIDDLE METHODS IN HUMID SUBTROPICAL CONDITIONS

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ABSTRACT

Various methods are available to predict reference evapotranspiration (ETo) but the Penman-Monteith (PM) ETo method has been considered to be the most accurate ETo method to determine ETo. The PM ETo method can be solved by various weather parameters like atmospheric temperature, wind velocity, moisture content and net solar radiations. There are many weather stations in the world that have no complete set of weather parameters to predict ETo by applying PM ETo method. So alternative ETo methods like Hargreaves (HG) and Blaney-Criddle (BC) ETo methods are used which need only a fewer number of weather parameters. In this paper, two ETo methods, HG and BC are compared with PM ETo method in humid subtropical climatic conditions of Islamabad and Kakul (Abbottabad) weather stations. The study indicate that HG ETo method overestimated PM ETo method by 23.78% at Islamabad weather station and 28.47% at Kakul station. The BC ETo method overestimated PM ETo method by 37.93% at Islamabad weather station and by 22.68% at Kakul weather station. The dissimilarity of HG ETo method with PM ETo method with RMSE was 1.09 mm/day at Islamabad weather station and 1.17 mm/day at Kakul weather station. The dissimilarity of BC ETo method with PM ETo method has Root Mean Square Error (RMSE) of 2.86 mm/day at Islamabad weather station and 1.48 mm/day at Kakul weather station.

Contribution/Originality: The objective of this investigation is to compare ETo by HG and BC ETo methods with PM ETo method in humid subtropical climatic conditions of Pakistan.

1. INTRODUCTION

The usage of high calorie and meat-intensive food consumption are estimated to approximately twice by 2050 due to increasing of population to fulfill the diet security in the next decades, significant variations in agricultural water management are needed [1]. From January to April in 2010, a severe sacristy occur in southwest China, which thread more than sixty million public and produced greater than 23.66 billion financial fatalities [2]. In distinction to the increasing requirement on irrigated yield, water for agriculture has been decreased due to regular scarcities and struggle for water reservoirs among the different users [3]. 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 [4]. Pakistan lies in arid to semi-arid region where average annual rainfall is 254 to 356 mm against a potential demand (of water for maximum crop production) of 1778 mm. This gap between the demands and supplies is met through applying irrigation. Moreover, the country is facing threat of rapidly increasing population with the annual growth rate of 2.05 percent. It has been observed that water availability for agriculture is expected to decline globally to 62 percent by 2020 as was available (72%) in 1995 and from 87% to 73% in developing countries [5]. Land and water are two important factors, which are required for agricultural development and strong economy of a country. Pakistan is facing the problem of water scarcity and the demand of water for irrigation is also increased due to mounting demand of food and fiber [6]. As a result of increasing demand for water resources due to population growth, urbanization, and irrigated agriculture, optimizing the use of the limited available water especially in crop production systems is becoming more critical each year. Therefore, in order to manage and conserve increasingly scarce water resources, it is important to examine various methods that increase water use efficiency and reduce the excessive application of water. The knowledge of crop evapotranspiration (ET) is one of the most important factors in understanding crop water use, irrigation scheduling, proper water resources management, crop production, and water conservation. Generally, the estimation of crop ET involves calculating reference crop ET (ETo), and then multiplying the ETo by an appropriate crop coefficient [7]. ETo is defined as the evapotranspiration rate at which water would be removed from a reference surface where water is not limited or a limited factor [8]. The widely used ETo method , which have been developed to estimate ETo is Penman-Monteith ETo method as concluded by large number of studies including Allen, et al. [8]; Walter, et al. [9]; Howes, et al. [10]; Gurski, et al. [11]; Akumaga, et al. [12]; De Fraiture and Wichelns [13] and Gundalia and Dholakia [14]. Three significant practices (soil, plant and weather data based) applied for estimation of accurate irrigation schedule are soil, plant and weather data based, but weather data based practice has got consideration among the researchers because this practice requires no extra high value and specific detectors to calculate humidity of soil, atmospheric temperature and leaf area index [15].

Reference Evapotranspiration (ETo) is an important element of water-cycle of agricultural systems [16]. The exact figures about ETo rate are very significant for the weather data dependent practices to be used [17]. There are various ETo methods for the estimation of ETo. i-e Penman-Monteith (PM) ETo method [8] Blaney-Criddle ETo method [18] Priestley-Taylor (PT) ETo method [19] and Hargreaves –Samani ETo method [20] but the global researchers has accepted PM ETo as the most accurate method because of its accurate results when compared with other ETo methods in various climatic regions of the world [21]. Many researches have proved the correctness of the Penman-Monteith ETo method [8] when comparing it with lysimeter measurements particularly for daily ETo estimations [22]. The PM ETo method is widely used as the standard ETo method for estimating ETo [23]. The PM ETo method requires numerous meteorological variables for effective application which may be unavailable or missing in some locations, especially in developing countries [24]. Therefore, alternative approaches that require less weather parameters input are needed. The objective of this investigation is to compare ETo by HG and BC ETo methods with PM ETo method in humid subtropical climatic conditions of Pakistan.

2. MATERIALS AND METHODS

2.1. Experimental Area and Data Collection

The GPS (Global Positioning System) coordinates of Islamabad are 33.6844° N and 73.0479° E and elevation of 540 meters. The weather of Islamabad has a humid subtropical climate conditions. The GPS (Global Positioning System) Coordinates of Kakul (Abbottabad) are 34.1833° N and 73.2500° E and height of 1308 meters. Kakul has a humid subtropical climate conditions.

The mean monthly weather data of 10-years (2000-2009) of Islamabad weather station and 10-years (2001-2010) of Kakul weather stations is used to compare ETo by HG and BC ETo methods with the PM ETo method as stated in the Table 1.

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

Station	Latitude	Longitude	Elevation (m)	Climate
Islamabad	33.6844° N	73.0479° E	540	Humid subtropical
Kakul	34.1833° N	73.2500 ° E	1308	Humid subtropical

2.2. Evapotranspiration Estimation Methods

2.2.1. Estimation of ETo by Penman-Monteith Method

Allen, et al. [8] presented the Penman–Monteith (PM) method as:

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

Where, ETo is the reference crop evapotranspiration (mm d^{-1}) by PM ETo method ; Δ is the slope of the saturation vapor pressure function (kPa $(°C)^{-1}$); Rn is the net radiation (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean air temperature (°C); U_2 is the average 24-hour wind speed at 2-meter height (m s^{-1}); (e_s-e_a) is the vapor pressure deficit (kPa); and γ is the psychometric constant (kPa $°C^{-1}$). The computation of all data required for the calculation of ETo followed the method suggested by Allen, et al. [8].

2.3. Estimation of ETo by Hargreaves Method

ETo calculated by applying Hargreaves ETo Method [20] is given as:

$$ET_o\ HG = 0.0023 R_a\,(T_{mean} + 17.8)\,(T_{max} - T_{min})^{(0.5)} \quad (2)$$

Where, ET_o HG is in mm day^{-1} and T_{mean} is mean monthly air temperatures (°C). A coefficient of 0.408 is used to convert MJm^{-2} day^{-1} into mmd^{-1} as concluded by Allen, et al. [8] and 0.0023 is the original coefficient of the HG ETo method as suggested by Hargreaves and Samani [20].

Due to the small number of climatic data requirement, it is often applied under conditions where less climatic data is available, and especially, when only air temperatures are available [25].

2.4. Estimation of ETo by Blaney-Criddle Method

The original model as described by Blaney and Criddle [18] is:

$$ET_o = a + b\,[\,\rho(0.46 T_{mean} + 8.13)] \quad (3)$$

Where,

$$a = 0.0043\,(RH_{min}) - n/N - 1.41 \quad (4)$$

$b = 0.82 - 0.0041(RH_{min}) + 1.07\,(n/N) + 0.066(u_d) - 0.006\,(RH_{min})\,(n/N) - 0.0006\,(RH_{min})\,(u_d)$ (5)

with T being the mean monthly temperature (°C) and p the monthly percentage of the annual daytime hours.

2.5. Evaluation Criteria

In this study, the root mean square error (RMSE), percentage error of estimate (PE), mean bias error (MBE) and coefficient of determination (R^2) are used for the evaluation of ETo methods. The RMSE, PE, MBE and R^2 are defined in Equations 6, 7, 8 and 9.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Pi - O_i)^2}{n}} \quad (6)$$

$$\%PE = \left|\frac{\bar{P} - \bar{O}}{\bar{O}}\right| \times 100 \quad (7)$$

$$MBE = \frac{\sum_{i=1}^{n} (P_i - O_i)}{n} \quad (8)$$

$$R^2 = \frac{[\sum_{i=1}^{n} (P_i - \bar{P})(O_i - \bar{O})]^2}{\sum_{i=1}^{n} (P_i - \bar{P})^2 \sum_{i=1}^{n} (O_i - \bar{O})^2} \quad (9)$$

Where,

Pi are predicted values and Oi are observed values, $\bar{P}$ and $\bar{O}$ are the average values of Pi and Oi, and n is the total number of data.

3. RESULTS AND DISCUSSION

3.1. Comparison at Islamabad Station

The HG and BC ETo methods are compared with PM ETo method for monthly ETo assessments in humid sub-tropical climatic region of Islamabad. The HG ETo method indicated overestimation of ETo by 23.78% as compared to the PM ETo method at Islamabad weather station as shown in Figure 1 (a) and also in Table 2. The overestimation of ETo by HG ETo method in humid subtropical region is similar as concluded by Droogers and Allen [26]; Rojas and Sheffield [27] and Ashraf, et al. [28]. The BC ETo method indicated an overestimation of ETo by 37.93% as compared to the PM ETo method at Islamabad weather station as shown in Figure 1 (b) and also in the Table 2. The overestimation of ETo by BC ETo method as compared with the PM ETo method in humid subtropical climatic region is similar as stated by Tabari, et al. [29].

Table-2. Summary results of HG and BC ETo methods compared with PM ETo method at Islamabad station.

Sr.no	Station	Method	RMSE	R^2	%Error	Mean	SD	MBE
1	Islamabad	Hargreaves	1.09	0.98	23.78	4.49	1.8	-1.097
2	Islamabad	Blaney-Criddle	2.86	0.94	37.93	5.51	3.65	-2.092

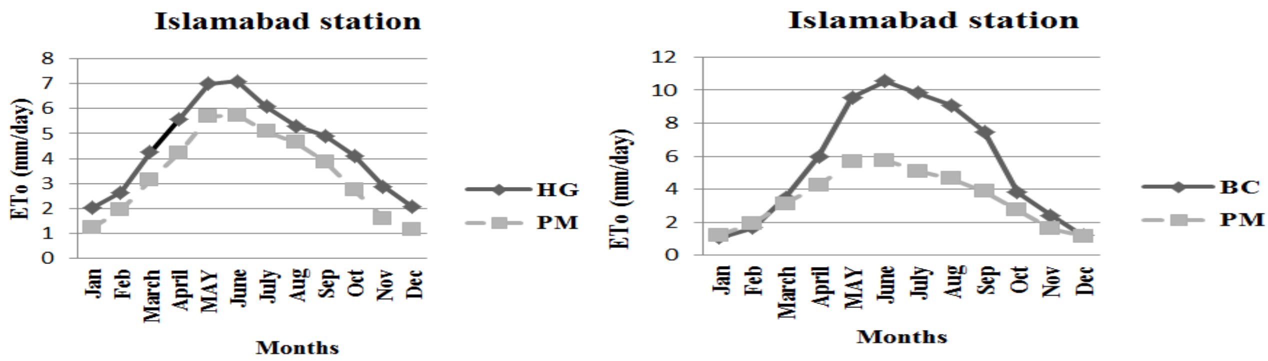

Figure-1. Monthly comparison of ETo _ PM with (a) HG and (b) BC at Islamabad station.

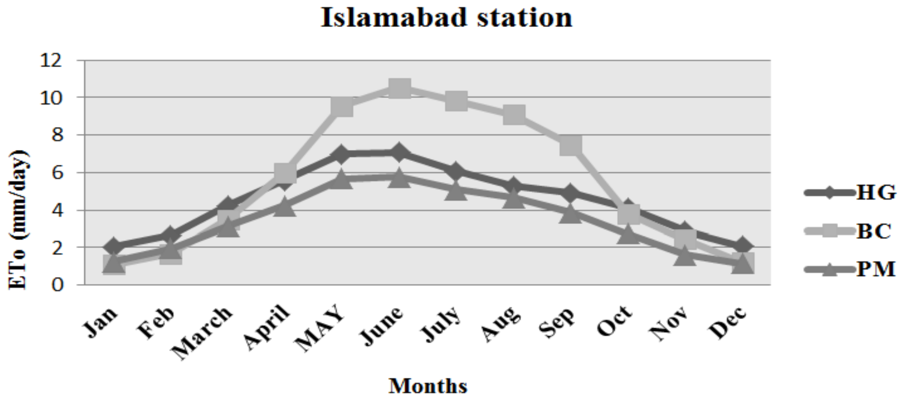

Figure-2. Monthly comparison of ETo _ PM with HG and BC at Islamabad station.

The statistical results indicate that HG ETo method overestimate ETo as compare to the PM ETo method at Islamabad weather station with R^2 0.98, MBE of -1.097 and RMSE of 1.09 mm/day as shown in the Table 2. The BC ETo method show overestimation of ETo when compare with PM ETo method at Islamabad weather station with R^2 0.94, MBE of -2.092 and RMSE of 2.86 mm/day, as shown in Table 2.

3.2. Comparison at Kakul Station

The HG ETo and BC ETo methods are compared with PM ETo method in humid subtropical climatic conditions of Kakul (Abbottabad) weather station. The statistical results show that the HG ETo method overestimated ETo by 28.47% as compare to the PM ETo method at Kakul weather station as shown in Figure 3 (a). The overestimation of ETo by HG ETo method in humid subtropical climatic conditions are similar as concluded by Dinpashoh [30]; Droogers and Allen [26]; Rojas and Sheffield [27] and Ashraf, et al. [28]. The BC ETo method also show overestimation of ETo by 22.68% as compare to PM ETo method at Kakul station Figure 3 (b). The overestimation of ETo by BC method under humid subtropical conditions is similar as concluded by Tabari, et al. [29].

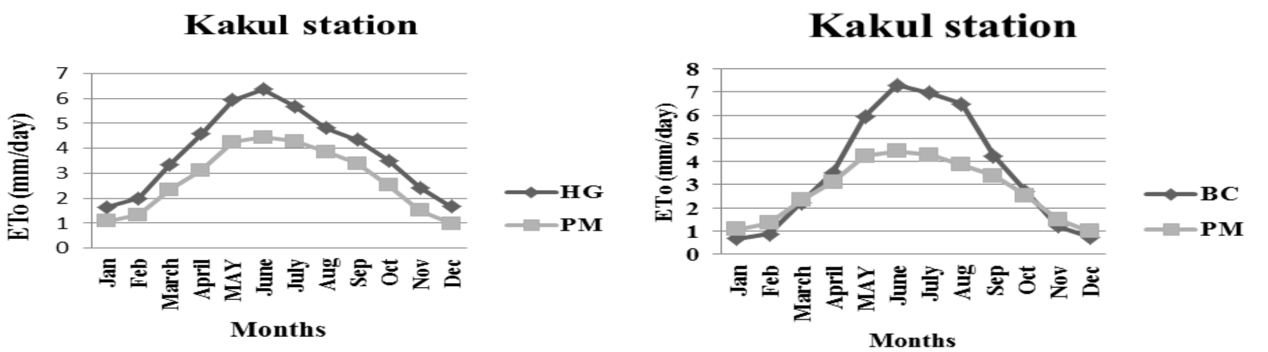

Figure-3. Monthly comparison of ETo _ PM with (a) HG and (b) BC at Kakul station.

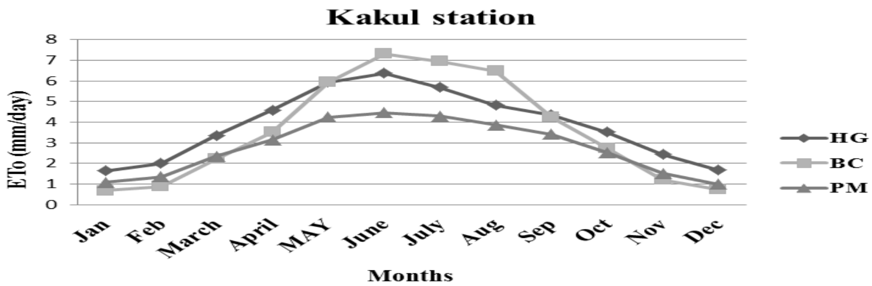

Figure-4. Monthly comparison of ETo _ PM with HG and BC at Kakul station.

Table-3. Summary results of hargreaves and blaney-criddle methods compared with penman-monteith method at kakul station.

Sr.no	Station	Method	RMSE	R^2	%Error	Mean	SD	MBE
1	Kakul	Hargreaves	1.17	0.98	28.47	3.86	1.68	-1.10
2	Kakul	Blaney-Criddle	1.48	0.95	22.68	3.57	2.55	-0.81

The statistical results which indicate that the HG ETo method overestimated PM ETo method with RMSE of 1.17 mm/day, MBE of -1.10 and R^2 0.98 at Kakul station in humid subtropical climatic conditions as shown in Table 3. The BC ETo method also overestimate PM ETo method with RMSE of 1.48 mm/day, MBE of -0.81 and R^2 0.95 at Kakul station in humid subtropical climatic conditions as shown in Table 3.

4. CONCLUSION

This study is conducted to compare the accuracy HG ETo BC ETo methods against PM ETo method in humid sub-tropical climatic conditions of Islamabad and Kakul regions. The results of both the ETo methods are obtained on the basis of statistical analysis. The statistical analysis averagely show over all twelve months overestimation of ETo by HG and BC ETo methods as compared to the PM ETo method. The PM ETo method is considered as the standard ETo method all over the world due to its accurate ETo estimation as concluded by Gundalia and Dholakia [14]; Afzaal, et al. [31]; Trajkovic, et al. [32] that's why in present study this ETo method is taken as standard method for the comparison of both HG and BC ETo methods. The comparison show that both HG ETo method and BC ETo method indicate overestimation of ETo as compared to the PM ETo method at Islamabad and Kakul weather stations.

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