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COMPARATIVE ANALYSIS OF REFERENCE EVAPOTRANSPIRATION BY HARGREAVES AND BLANEY-CRIDDLE EQUATIONS IN SEMI-ARID CLIMATIC CONDITIONS

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ABSTRACT

There are various equations for calculation of reference evapotranspiration (ETo), but the Penman-Monteith (PM FAO-56) equation has been considered as the standard ETo equation. The key problem of PM FAO-56 equation is that it uses large number of weather parameters like air temperature, wind velocity, humidity and sun radiation as input. These weather parameters are not accessible at all weather stations of the world especially in developing countries. So, ablatives ETo equations like Hargreaves (HG) and Blaney-Criddle (BC) equations are used for estimation of ETo which required very small number of weather parameters that are readily available at most of the weather stations of the world. A research is conducted to compare HG and BC ETo equations for estimation of monthly ETo under semi-arid climatic regions of Lahore, Faisalabad and Peshawar, Pakistan. The PM FAO-56 ETo equation is considered as reference ETo equation for the assessment of HG ETo and BC ETo equation. The statistical results indicate that HG ETo equation overestimates PM FAO-56 ETo method by 7.91% at Lahore weather station, 5.59 % at Faisalabad weather station and 11.95% at Peshawar weather station. The BC ETo equation overestimates PM FAO-56 ETo equation by 34.345% at Lahore weather station, 28.637% at Faisalabad weather station and 21.44% at Peshawar weather station. The variation of HG ETo equation with PM FAO-56 ETo equation with RMSE of 0.487 mm/day at Lahore weather station, 0.521 mm/day at Faisalabad weather station and 0.985 at Peshawar weather station is noted. The variation of BC ETo equation with PM FAO-56 ETo equation having RMSE of 3.03 at Lahore weather station, 2.58 at Faisalabad weather station and 1.96 at Peshawar weather station is noted.

Contribution/Originality: The objectives of this study is to compare the HG ETo and BC) ETo equations against FAO-56 PM ETo equation in semi-arid climatic conditions.

1. INTRODUCTION

Pakistan is under the problem of water shortage and the demand of water for irrigation is also increased due to mounting demand of food and fiber [1]. Pakistan is in between the arid to semi-arid region [2]. The knowledge of

ETo is a key element for the management of water resources [3]. Numerous researchers have argued that Penmen–Monteith (FAO-56 PM) ETo method can be applied as a reference ETo method as compared to the other experimental ETo methods [4-7]. The PM ETo method requires large number of weather parameters i-e atmospheric temperature, relative humidity, solar radiation, wind velocity etc. But, availability of these weather parameters is not accessible at all the weather stations of the globe specially in developing country like Pakistan. Therefore, it appears reasonably to substitute it by other ETo methods which require small number of weather parameters [8]. The accuracy of a particular ETo method depends greatly on the climatic situations of the research area [9]. The objectives of this study are to compare the HG ETo and BC) ETo equations against FAO-56 PM ETo equation in semi-arid climatic conditions.

2. MATERIALS AND METHODS

2.1. Study Area

The data of three meteorological weather stations Lahore, Faisalabad and Peshawar are used to estimate the reference evapotranspiration (ETo). The GPS (Global Positioning system) coordinates of Lahore are 31.33° N and 74.20° E and height of 214 m from the ocean. Lahore sorts semi-dry climatic conditions. The GPS (Global Positioning System) coordinates of Faisalabad are 31.26° N and 73.08° E and elevation of 185.6 meters. The weather of Faisalabad sorts semi-arid climatic conditions with very warm and moist midsummers and arid cold wintertime. The GPS (Global Positioning System) coordinates of Peshawar are 34.02° N, 71.56° E and elevation of 327 m from the sea. It has warm semi-arid weather conditions with very thirsty summers and slight winters-time. The mean monthly weather data period, climate conditions and Global Positioning System (GPS) of weather stations used in the study are given in Table 1.

Table-1. Global Positioning System and climate of weather stations of study regions.

Station	Latitude	Longitude	Elevation (m)	Data Period	Climate
Lahore	31.33° N	74.20° E	214.0	2000-2010	hot semi-arid
Faisalabad	31.26° N	73.08° E	185.6	2001-2015	hot semi-arid
Peshawar	34.02° N	71.56° E	327.0	2000-2009	hot semi-arid

2.2. Reference Evapotranspiration (ETo) Methods

2.2.1. FAO-56 Penman-Monteith ETo Method

For estimation of ETo by FAO-56 PM equation Computer model [10] is used. The input data required are minimum and maximum air temperatures, relative humidity, wind velocity and sunshine hours. The following FAO-56 PM equation is suggested by Majeed, et al. [10].

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

Where, ETo is the reference evapotranspiration (mm d^{-1}); 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 the ET_0 followed the equation given by Allen, et al. [11].

2.3. Hargreaves ETo Equation

ETo calculated by applying Hargreaves ETo equation suggested by Hargreaves and Samani [12] is given as

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

Where, ETo_{HG} is in mm day^{-1} and T_{mean} is mean air temperatures (^0C). A coefficient of 0.408 is used to convert MJm^{-2} day^{-1} into mmd^{-1} suggested by Allen, et al. [11] and 0.0023 is the original coefficient of the Hargreaves ETo equation given by Hargreaves and Samani [13]. Due to the low data requirement, it is often applied under conditions where less data is available and especially, when only air temperature is available [14].

2.4. Blaney-Criddle ETo Equation

The original equation as described by Blaney and Criddle [1] is given as:

$$ET_0 = a + b[p(0.46T + 8.13)] \quad (3)$$

Where,

$a = 0.0043(RH\ min) - n/N - 1.41$, (4)

$b = 0.82 - 0.0041(RH\ min) + 1.07(n/N) + 0.066(u\ d) - 0.006(RH\ min)(n/N) - 0.0006(RH\ min)(ud)$ (5)

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

2.5. Statistical Analysis

The RMSE, PE and R^2 are defined in Equations 6, 7 and 8.

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

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

$$R^2 = \frac{\left[\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \bar{O})\right]^2}{\sum_{i=1}^{n}(P_i - \bar{P})^2 \sum_{i}^{n}(O_i - \bar{O})^2} \quad (8)$$

3. RESULTS AND DISCUSSION

The Hargreaves (HG) ETo equation and Blaney-Criddle (BC) ETo equation compared with the standard Penman-Monteith (FAO-56 PM) ETo equation for monthly estimation of ETo in semi-arid climatic conditions of Lahore, Faisalabad and Peshawar, Pakistan. The Hargreaves (HG) ETo equation overestimated FAO-56 PM ETo equation by 7.91% at Lahore weather station as shown in Figure 1 and in Table 2.

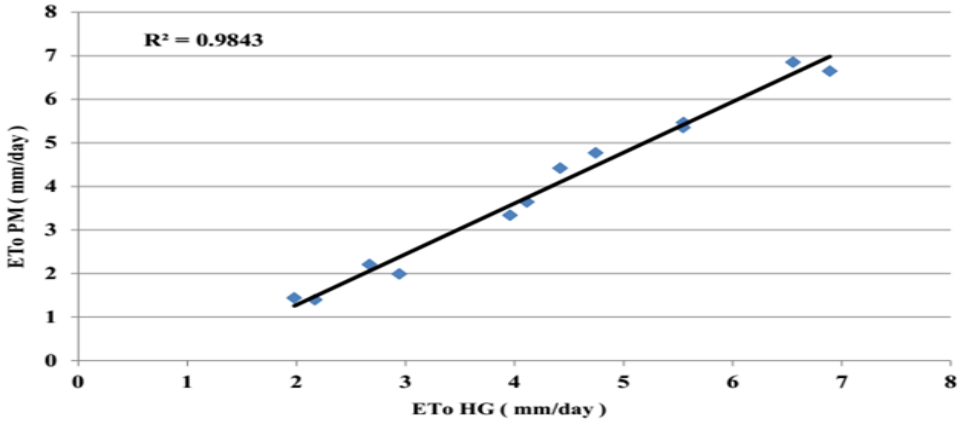

Figure-1. Monthly comparison of ETo_PM with HG at Lahore station.

Table-2. Statistical analysis of HG and BC ETo Equations compared with FAO-56 PM ETo equation at Lahore station.

Equation	% Error	RMSE	R^2		Mean	SD
Hargreaves	7.91	0.487	0.984		4.29	1.64
Blaney-Criddle	34.345	3.03	0.8		6.02	4.04

When the Blaney-Criddle ETo equation is compared with the standard FA0-56 PM ETo equation, it overestimated FAO-56 PM ETo equation by 34.34% at Lahore weather station as shown in Table 2 and Figure 2.

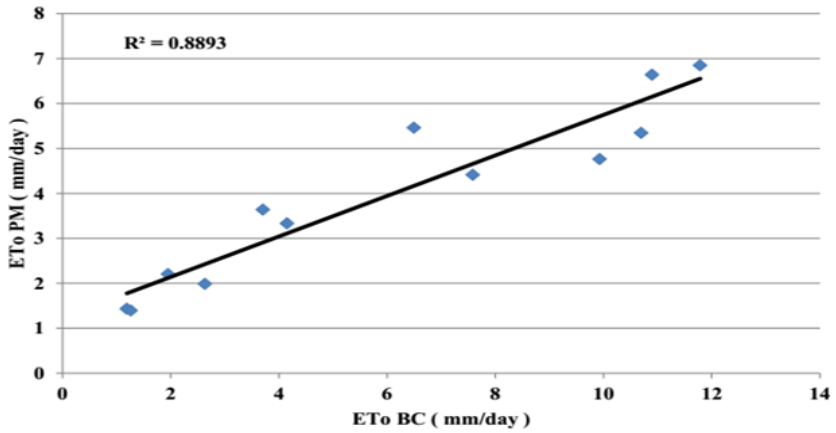

Figure-2. Monthly comparison of ETo_PM with BC at Lahore station.

The Hargreaves (HG) ETo equation is compared with standard Penman-Monteith (FAO-56 PM) ETo equation in semi-arid climatic conditions of Faisalabad. The HG ETo equation overestimates in winter and underestimates in summer by 5.59% when compared with FAO-56 PM ETo equation at Faisalabad as shown in Figure 3 and Table 3. The underestimation of ETo at Faisalabad weather station by Hargreaves (HG) ETo equation over FAO-56 PM ETo equation in summer is due to blowing of high speed wind in summer and underestimation is due blowing of low speed wind in winter. The Penman-Monteith (FAO-56 PM) ETo equation uses wind speed parameter in its execution but Hargreaves (HG) ETo equation does not use it that is why the FAO-56 PM ETo equation results more ETo values in summer and low ETo values in winter than HG ETo equation. The R^2 between HG ETo equation and FAO-56 PM ETo equation is 0.98.

Table-3. Statistical analysis of HG and BC ETo Equations compared with FAO-56 PM ETo equation at Faisalabad station.

Equation	% Error	RMSE	R2	Mean	SD
Hargreaves	5.59	0.521	0.98	4.64	1.76
Blaney-Criddle	28.63	2.58	0.93	6.13	3.99

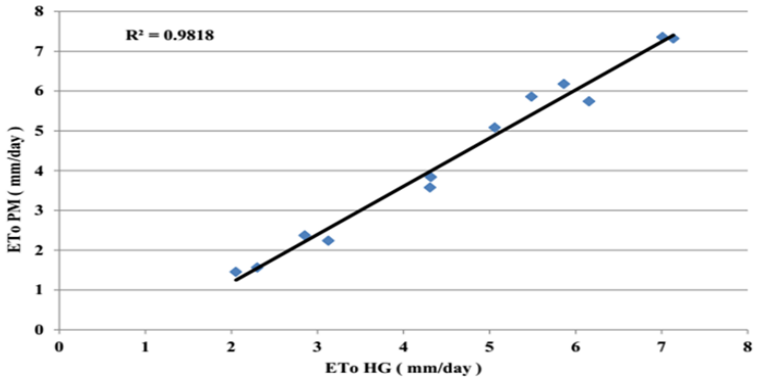

Figure-3. Monthly comparison of ETo _ PM with HG at Faisalabad station.

The BC ETo equation overestimates PM FAO-56 ETo equation by 28.637% at Faisalabad weather station when compared with FAO-56 PM ETo equation as shown in Figure 4 and Table 3.

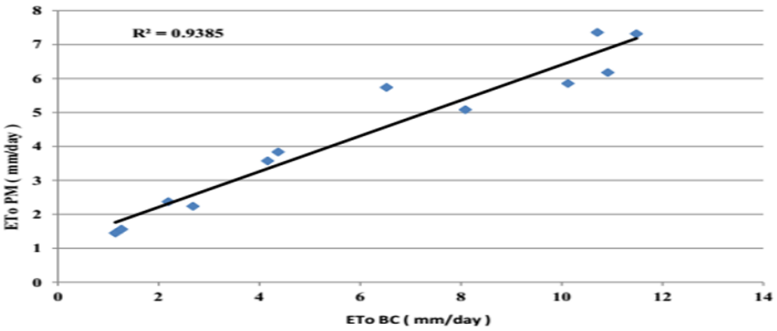

Figure-4. Monthly comparison of ETo _ PM with BC at Faisalabad station.

The HG ETo equation overestimates the FAO-56 PM ETo equation in winter and underestimates in summer by 11.95% when compared with FAO-56 PM ETo equation at Peshawar weather station as shown in Figure 5 and Table 4.

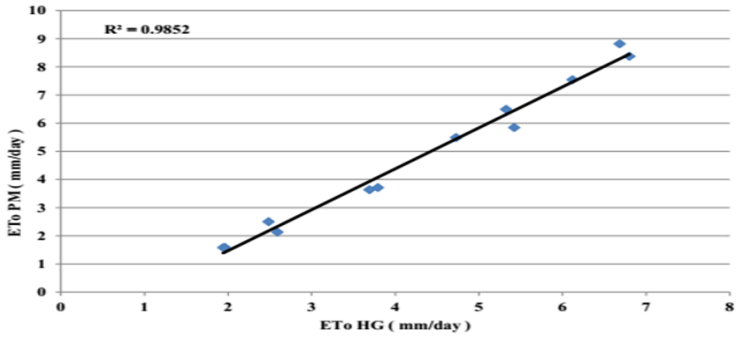

Figure-5. Monthly comparison of ETo _ PM with HG at Peshawar station.

Table-4. Statistical analysis of HG and BC ETo Equations compared with FAO-56 PM ETo equation at Peshawar station.

Equation	% Error	RMSE	R^2	Mean	SD
Hargreaves	11.95	0.985	0.98	4.29	1.79
Blaney-Criddle	21.44	1.96	0.96	6.18	4.03

The BC ETo equation overestimates FAO-56 PM ETo equation by 21.44% at Peshawar weather station of semi-arid climatic region as shown in Figure 6 and Table 4.

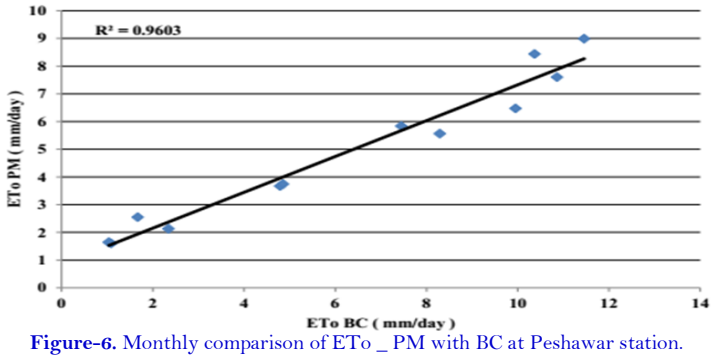

Figure-6. Monthly comparison of ETo _ PM with BC at Peshawar station.

4. CONCLUSION

This study is conducted to assess the performance of Hargreaves (HG) and Blaney-Criddle (BC) ETo equations against standard Penman-Monteith (FAO-56 PM) ETo equation in semi-arid climatic regions of Lahore, Faisalabad and Peshawar. The comparison showed that Hargreaves (HG) ETo equation underestimates and overestimates FAO-56 PM ETo equation while Blaney-Criddle (BC) ETo equation overestimates the FAO-56 PM ETo equation in all the semi-arid climatic regions of Lahore, Faisalabad and Peshawar.

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