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REFERENCE EVAPOTRANSPIRATION BY HARGREAVES AND MODIFIED HARGREAVES EQUATIONS UNDER SEMI-ARID ENVIRONMENT

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ABSTRACT

The Penman-Monteith (FAO-56 PM) ETo equation is considered as the standard ETo equation to estimate reference evapotranspiration (ETo) under all the weather conditions of the world. But there are many regions of the globe where all the climatic data is not available to evaluate FAO-56 PM ETo equation. So, Hargreaves (HG) ETo equation can be used which required very small number of weather data. The HG ETo equation requires only air temperature as input data which is available at most of the weather stations of the world. But the major drawback of HG ETo equation is that it overestimates or underestimates FAO-56 PM ETo equation. So it becomes necessary to modify HG ETo Equation according to the local climatic conditions before it is being applied. The HGorg and modified HG ETo equations are assessed for ETo estimation under cold and hot semi-arid climatic conditions of Quetta and Zhob weather stations by using 9 years meteorological data of each weather station against FAO-56PM ETo equation. The original HG ETo equation overestimates FAO-56 PM ETo equation at Zhob weather station by giving percentage error of 15.82% and underestimate at Quetta weather station by giving percentage error of 35.02%. The coefficient of original HG ETo equation was modified by using a simple mathematical logic. The overestimation at Zhob weather station reduced to 1.89% and underestimation at Quetta station reduced to 0.87% by using modified HG ETo equation. The variations of original HG ETo equation with FAO-56 PM ETo equation has RMSE of 0.89 mm/day at Zhob weather station and 1.74 mm/day at Quetta weather station. The variations of modified HG ETo equation with FAO-56 PM ETo equation has RMSE of 0.27 mm/day at Zhob weather station and 0.29 mm/day at Quetta weather station.

Contribution/Originality: The objective of this research is to modify the Hargreaves (HG) ETo equation according to the regional semi-arid conditions of Quetta and Zhob weather stations of Baluchistan Province.

1. INTRODUCTION

Land and water are two important factors, which are required for agricultural development and strong economy of a country [1]. 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 [2]. The use of fresh water as drinking has enlarged at more than the two times as the rate of public increasing in the 20th century [3]. It is expected that in 2025 the rate in increase of new water extractions is rising and established countries will be 50% and 18%, respectively [4]. Reference evapotranspiration (ETo) is one of the most significant factor to design and manage water reservoirs [5]. The Penman-Monteith (FAO-56 PM) ETo equation currently recognized as a reference equation for the estimation of ETo [6]. The FAO-56 PM ETo equation needs large amount of meteorological data i-e; atmospheric temperature, relative humidity, sunshine duration and wind speed, which is not accessible for all meteorological stations. Therefore, it appears reasonably to substitute it by other ETo equations like Hargreaves (HG) ETo equation which requires small number of weather parameters [7]. When input meteorological parameters for FAO-56 PM equation is deficient particularly in developing countries like Pakistan, then equation established by Hargreaves and Samani can be applied with assurance after regional adjustment in parameters. The HG ETo equation needs very small meteorological input data i-e only temperature data. Many scholars tried to evaluate the accuracy of HG ETo equation by adjusting it according to regional environment conditions including Bachour, et al. [8] and Berti, et al. [6]. Hargreaves and Allen [9] recommended that Hargreaves ETo equation can be executed with assurance after modification according to regional environmental conditions and provides most accurate result for monthly estimation of ETo because at routinely time period there are more variation in atmospheric temperature, wind speed etc. The Hargreaves ETo equation is executed after regional modification when all compulsory metrological data for the evaluation of Penman-Monteith (FAO-56 PM) ETo equation is not accessible [10]. The objective of this research is to modify the Hargreaves (HG) ETo equation according to the regional semi-arid conditions of Quetta and Zhob weather stations of Baluchistan province, Pakistan.

2. MATERIALS AND METHODS

2.1. Geographical Location of the Study Area

The weather data of two weather stations i-e Quetta and Zhob weather stations is used to assess original Hargreaves (HGorg) ETo and modified Hargreaves (HGmod) ETo equations for the estimation of monthly ETo. Both stations are located in Baluchistan Province, Pakistan.

The environment of these metrological stations, GPS (Global positioning system) and period of average monthly weather data used for the modification of Hargreaves (HG) method are given below in Table 1.

Table-1. Geographical and climatic characteristics of selected weather stations.

Station	Latitude	Longitude	Elevation	Date Period	Climate
Quetta	30^0 -05$'$ N	66^0-57$'$ E	1719	2001-2009	Cold semi-arid
Zhob	31^0–21$'$ N	66^0-58$'$ E	1405	2001-2009	Hot semi-arid

2.2. Reference Evapotranspiration (ETo) Equations

2.2.1. Penman-Monteith (FAO-56 PM) ETo Equation

For the estimation of Penman-Monteith (FAO-56 PM) ETo computer model CROPWAT 8.0 is applied which was suggested by FAO (Food and Agriculture organization). The input meteorological data needed are minimum and maximum air temperature, relative humidity, wind speed and sunshine hours. The monthly ETo is estimated by applying computer model (FAO CROPWAT 8.0, 2009) the following FAO-56 PM equation is applied as recommended by Gough and Scott [11]:

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

Where,

ETo = reference evapotranspiration (mm day^{-1}); Rn = net radiation at the crop surface (MJm^{-2} /day); G =soil heat flux density (MJ m^2/day); T = mean daily air temperature at 2 m height (°C); U2 = wind speed at 2 m height (m/s); es =saturation vapour pressure (kPa); ea = actual vapour pressure (kPa); es-ea = saturation vapour pressure deficit (kPa); Δ = slope vapour pressure curve (kPa/ °C); γ is the psychometric constant (kPa (°C)$^{-1}$) The computation of all data required for the calculation of the ET_o followed the method of Hargreaves and Allen [9].

2.2.2. Original Hargreaves (HG) ETo Equation

The ETo calculated by applying Hargreaves ETo equation is given by Hargreaves and Samani [12]:

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

Where,

ETo HG (org) = reference evapotranspiration (mm/day) by original ETo equation before modification ; T, Tmax and Tmin= average, maximum and minimum air temperature (° C) respectively.

2.2.3. Modified Hargreaves ETo Equation

The performance of original Hargreaves (HGorg) ETo equation is improved by adjusting the parameter of the original HG ETo equation method according to regional weather conditions. The original HG ETo equation is modified by resulting new value of constant by applying simple mathematical logic. In the original HG ETo equation, ETo HG (org) was set equal to ETo PM and the constant '0.0023' was set as 'M' to be determined. Hence, the modified Hargreaves (HGmod) ETo equation can written as:

$$ETo_{\,HG\,mod} = ETo_{\,PM} = M\ Ra\ (T_{max} - T_{\,min})^{\,1/2}\ [T + 17.8]$$

The modified HG equation is in the form

Y = MX

Where, $Y = ETo_{\,PM}$; $X = Ra\ (T_{max} - T_{\,min})^{\,1/2}\ [T + 17.8]$. By the determined set of values of Y and X, the constant M was calculated. The Hargreaves ETo equation attained by means of above logic i-e by varying the value of constant has been written as HGmod equation. The value of Ra (extraterrestrial radiation) used in original Hargreaves ETo equation has been determined in research conducted by Hargreaves and Samani [12].

2.2.4. Statistical Evaluation

In this study, the roots mean square error (RMSE), percentage error of estimate (PE), standard error of estimation (SEE) and coefficient of determination (R^2) are used for the evaluation of ETo methods.

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

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

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

Where, *Pi= ETo estimated by the PM ETo equation and Oi= ETo estimated by different forms of HG method.* $\overline{P}$ and $\overline{O}$ are the average of *Pi* and *Oi*, and *n* is the total number of data.

3. RESULTS AND DISCUSSION

The original Hargreaves (HGorg) ETo equation has been by standard Penman-Monteith (FAO-56 PM) ETo equation for monthly calculation of ETo in semi-arid weather conditions of Quetta and Zhob. The HGorg ETo equation indicated underestimation of ETo by 35.02% for cold semi-arid climatic conditions of Quetta weather station and overestimation of ETo by 15.82% at hot semi-arid climatic conditions of Zhob weather as shown in Figure 1 (a) and 2 (a) and also in Tables 2 and 3. Therefore, the original Hargreaves (HGorg) ETo equation cannot be suggested for the estimation of ETo in cold and hot semi-arid climatic conditions of Quetta and Zhob weather stations, respectively without being modified.

3.1. Modification of Original Hargreaves (HGorg) Equation

The modification of original Hargreaves (HGorg) ETo equation is done by determining value of constant term that lessen the RMSE and Percentage error between ETo value calculated by standard Penman-Monteith (FAO-56 PM) and modified Hargreaves (HGmod) ETo equations. The resultant modified Hargreaves (HGmod) ETo equation arrangements are given below.

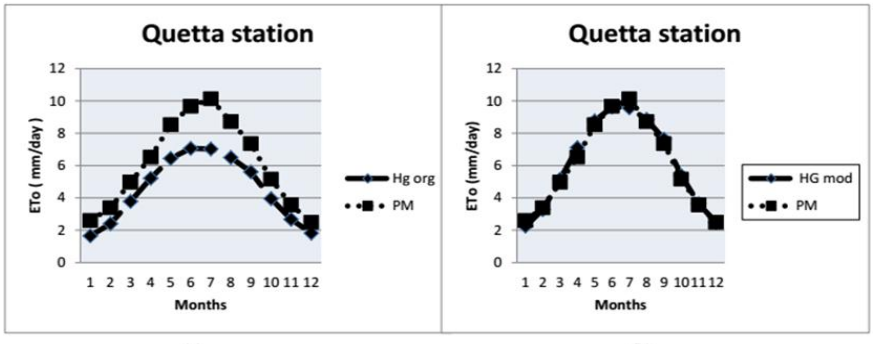
3.2. Modification at Quetta Station

$$ETo\ HG\ mod = 0.0031\ Ra\ (T_{max} - T_{min})^{1/2}\ [T + 17.8] \quad (3)$$

3.3. Modification at Zhob Station

$$ETo\ HG\ mod = 0.0019\ Ra\ (T_{max} - T_{min})^{1/2}\ [T + 17.8] \quad (4)$$

Many researchers including Bachour, et al. [8]; Berti, et al. [6] and Majeed, et al. [13] have done research to modify the original Hargreaves ETo equation by altering the constant value. The ETo estimated by modified Hargreaves (HGmod) ETo equation is again examined against the ETo calculated by the Penman-Monteith (FAO-56 PM) ETo equation. The monthly ETo has been improved by the modified Hargreaves (HGmod) ETo equation. The RMSE and percentage error are also reduced as shown in the Table 1 and 2. The calculation of ETo from that modified Hargreaves ETo method reduced the percentage error up to 0.87% and 1.89% with RMSE of 0.29 mm/day and 0.27 mm/day at Quetta and Zhob weather stations, respectively as shown in the Figure 1 (b) and 2 (b) and also in the Tables 2 and 3.

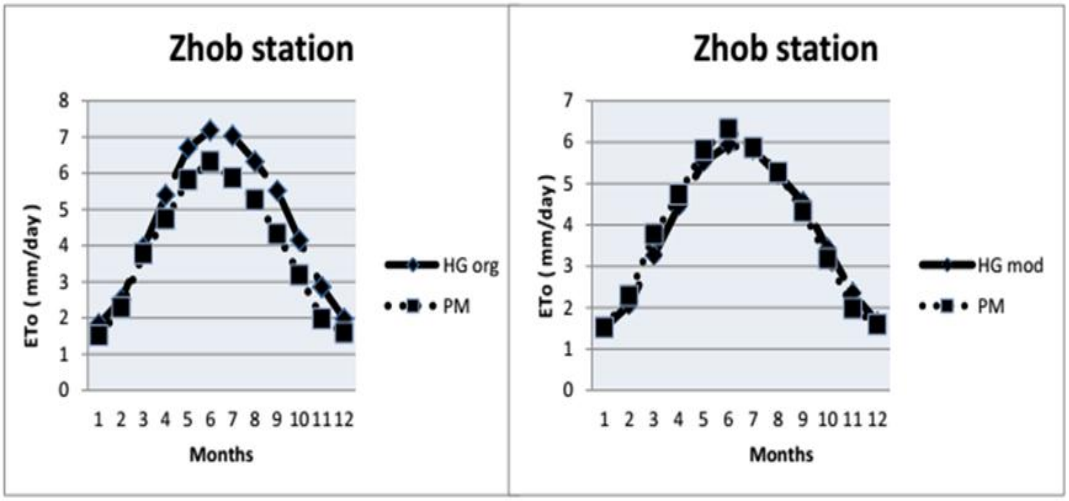


(a) (b)

Figure-1. Comparison of ETo by PM with (a) HG org and (b) HG mod methods at Quetta weather station.

Table-2. Statistical evaluations of HG_{org} and HG_{mod} compared with FAO-56 PM at Quetta weather station.

Equation Form	Percentage Error	RMSE	R^2	SD	SEE	Mean
HG_{org}	35.02	1.74	0.98	2.05	0.31	4.50
HG_{mod}	0.87	0.29	0.98	2.79	0.31	6.14



(a) (b)

Figure-2. Comparison of ETo by PM with (a) HG org and (b) HG mod methods at Zhob weather station.

Table-3. Statistical evaluations of HG_{org} and HG_{cal} compared with PM at Zhob weather station.

Equation form	Percentage Error	RMSE	R^2	SD	SEE	Mean
HG_{org}	15.82	0.81	0.97	2.00	0.27	4.61
HG_{mod}	1.89	0.27	0.97	1.65	0.27	3.81

4. CONCLUSION

The comparison of reference evapotranspiration (ETo) by original Hargreaves (HGorg) ETo equation and standard Penman-Monteith (FAO-56 PM) ETo equation show that the original Hargreaves (HG org) ETo equation overestimate FAO-56 PM ETo equation in hot semi-arid environment of Zhob weather station and underestimate FAO-56 PM ETo equation in cold semi-arid environment of Quetta weather station. The modified Hargreaves (HGmod) equation shows better estimation of ETo at both the weather stations. So, it is suggested that before using original Hargreaves equation it must be modified according to the local regional environment conditions.

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