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

Muhammad Hafeez
Zia Ahmad Chatha
Allah Bakhsh
Abdul Basit
Alamgir Akhtar Khan
Fatima Tahira

Department of Agricultural Engineering, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan.
Department of Food Engineering, Faculty of Agricultural Engineering, University of Agriculture, Faisalabad, Pakistan.
Department of Botany, Gujranwala University, Gujranwala, Pakistan.
Department of Agricultural Engineering, MNSUA, Multan, Pakistan.
Department of Mathematics, Institute of Southern Punjab, Multan, Pakistan.

Corresponding Author

ABSTRACT

The Penman-Monteith (FAO-56 PM) ET0 equation is considered as the standard ET0 equation to estimate reference evapotranspiration (ET0) 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 ET0 equation. So, Hargreaves (HG) ET0 equation can be used which required very small number of weather data. The HG ET0 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 ET0 equation is that it overestimates or underestimates FAO-56 PM ET0 equation. So it becomes necessary to modify HG ET0 Equation according to the local climatic conditions before it is being applied. The HGorg and modified HG ET0 equations are assessed for ET0 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-56 PM ET0 equation. The original HG ET0 equation overestimates FAO-56 PM ET0 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 ET0 equation was modified by using a simple mathematical logic. The overestimation at Zhob weather station reduced to 1.89% and underestimate at Quetta station reduced to 0.87% by using modified HG ET0 equation. The variations of original HG ET0 equation with FAO-56 PM ET0 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 ET0 equation with FAO-56 PM ET0 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) ET0 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 75% 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 ET0 equation can be executed with assurance after modification according to regional environmental conditions and provides most accurate result for monthly estimation of ET0 because at routinely time period there are more variation in atmospheric temperature, wind speed etc. The Hargreaves ET0 equation is executed after regional modification when all compulsory metrological data for the evaluation of Penman-Monteith (FAO-56 PM) ET0 equation is not accessible [10]. The objective of this research is to modify the Hargreaves (HG) ET0 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) ET0 and modified Hargreaves (HGmod) ET0 equations for the estimation of monthly ET0. 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.

| Station | Latitude | Longitude | Elevation | Date Period | Climate          |
|---------|----------|-----------|-----------|-------------|------------------|
| Quetta  | N 30°-05  | 66°-57 E  | 1719      | 2001-2009   | Cold semi-arid   |
| Zhob    | N 31°-21  | 66°-58 E  | 1405      | 2001-2009   | Hot semi-arid    |

## 2.2. Reference Evapotranspiration (ET0) Equations

### 2.2.1. Penman-Monteith (FAO-56 PM) ET0 Equation

For the estimation of Penman-Monteith (FAO-56 PM) ET0 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 ET0 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]:

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Where,

\[ E_{To} = \frac{0.408 (R_n - G) + 900 \gamma \left( \frac{U_z}{T + 273} \right) e_s - e_a}{\Delta + \gamma (1 + 0.34 U_z)} \]  

(1)

Where,  

- \( E_{To} \) = reference evapotranspiration (mm day\(^{-1}\));  
- \( R_n \) = net radiation at the crop surface (MJ m\(^{-2}\) day\(^{-1}\));  
- \( G \) = soil heat flux density (MJ m\(^{-2}\) day\(^{-1}\));  
- \( T \) = mean daily air temperature at 2 m height (°C);  
- \( U_z \) = wind speed at 2 m height (m/s);  
- \( e_s \) = saturation vapour pressure (kPa);  
- \( e_a \) = actual vapour pressure (kPa);  
- \( e_s - e_a \) = saturation vapour pressure deficit (kPa);  
- \( \Delta \) = slope vapour pressure curve (kPa/°C);  
- \( \gamma \) is the psychometric constant (kPa (°C)\(^{-1}\)).

The computation of all data required for the calculation of the \( E_{To} \) followed the method of Hargreaves and Allen [9].

2.2.2. Original Hargreaves (HG) \( E_{To} \) Equation

The \( E_{To} \) calculated by applying Hargreaves \( E_{To} \) equation is given by Hargreaves and Samani [12]:

\[ E_{To\ HG\ (org)} = 0.0023 \, R_a \, (T + 17.8)(T_{max} - T_{min})^{0.5} \]  

(2)

Where,

- \( E_{To\ HG\ (org)} \) = reference evapotranspiration (mm/day) by original \( E_{To} \) equation before modification;  
- \( T, T_{max} \) and \( T_{min} \) = average, maximum and minimum air temperature (°C) respectively.

2.2.3. Modified Hargreaves \( E_{To} \) Equation

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

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

The modified HG equation is in the form

\[ Y = MX \]

Where, \( Y = E_{To\ PM} \), \( X = R_a \, (T_{max} - T_{min})^{1/2} \, [T + 17.8] \). By the determined set of values of \( Y \) and \( X \), the constant \( M \) was calculated. The Hargreaves \( E_{To} \) 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 \( E_{To} \) 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 \( E_{To} \) methods.

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

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

\[
\%PE = \left( \frac{\bar{P} - \bar{O}}{\bar{O}} \right) \times 100
\]
Where, $P_i$ = ETo estimated by the PM ETo equation and $O_i$ = ETo estimated by different forms of HG method. $\bar{P}$ and $\bar{O}$ are the average of $P_i$ and $O_i$ 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

$$ETo \text{ HG mod} = 0.0031 \left( \frac{T_{\text{max}} - T_{\text{min}}}{T + 17.8} \right)^{1/2}$$

3.3. Modification at Zhob Station

$$ETo \text{ HG mod} = 0.0019 \left( \frac{T_{\text{max}} - T_{\text{min}}}{T + 17.8} \right)^{1/2}$$

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.

![Figure-1. Comparison of ETo by PM with (a) HG org and (b) HG mod methods at Quetta weather station.](image-url)
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 |

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 (HG$_{org}$) 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 (HG$_{mod}$) 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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