Regional modification of the Hargreaves method for estimating reference evapotranspiration under semi-arid environment

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ABSTRACT

There are many regions of the globe where the metrological data is not accessible to evaluate standard Penman-Monteith (FAO-56 PM) ETo method. Hence, ablatives methods like Hargreaves method which require very small metrological data are used. The Hargreaves (HG) ETO method requires only air temperature as input data which is available in most of the weather stations of the world. The major drawback of the Hargreaves method is that it overestimates or underestimates the FAO-56 PM ETo method. Thus, it becomes compulsory to modify the HG ETo method according to the regional environment before it is being applied. The Hargreaves ETo method was assessed for monthly ETo estimation under cold and hot semi-arid environment of Quetta and Zhob weather stations using 9 years metrological data of each station against FAO-56PM ETo method. The HG ETo method overestimated PM ETo method at Zhob station by 15.82% and underestimated at Quetta station by 35.02%. The coefficient of HG ETo method was modified using a simple mathematical logic. The overestimation at Zhob station was reduced to 1.89% and underestimation at Quetta station reduced to 0.87% using modified HG (HGmod) ETo method. The variations of HG ETo method with PM method with root mean square error (RMSE) were 0.89 mm/day at Zhob station and 1.74 mm/day at Quetta station. The variations of HGmod ETo method with PM method with root mean square error (RMSE) were 0.27 mm/day at Zhob station and 0.29 mm/day at Quetta station.

Key words: Hargreaves, modified, semi-arid, ETo, environment.

INTRODUCTION

The use of fresh water for drinking has enlarged more than twice as the rate of public increase in the 20th century (Water, 2006). It is expected that in 2025 the rate in increase of new water extractions will rise and established countries will be 50 and 18%, respectively (Gough and Scott, 2007).

Evapotranspiration (ET) is a significant component of water-cycle of cultivated schemes. Evapotranspiration particulars are required in finding the capacity of water essential to overcome short period and seasonal water necessity for fields, plantations and irrigation developments. The improper approximation of the agrarian water necessity may lead to severe disasters in the structure performance and waste of valued water reservoirs. The Penman-Monteith (FAO-56 PM) method is currently recognized as a reference method for the estimation of ETo (Allen et al., 1998).

The Penman-Monteith (PM) method needs large amount of metrological data such as atmospheric temperature, relative humidity, sunshine duration and wind speed, which is not accessible to all metrological stations. When input metrological data for Penman-Monteith (PM) method is deficient particularly in developing states like Pakistan, then, the method established by Hargreaves and Samani can be applied with assurance after regional adjustment in parameters. The Hargreaves method requires very small
Many scholars tried to evaluate the accuracy of Hargreaves (HG) method by adjusting it according to regional environments (Bachour et al., 2013; Berti et al., 2014). Hargreaves and Allen (2003) recommended that Hargreaves method can be executed with assurance after calibration according to regional environments and provides the most accurate result for monthly time period because at routinely time period there are more variations in atmospheric temperature and wind speed etc. The Hargreaves method is executed after regional modification when all compulsory metrological data for Penman-Monteith (PM) method is not accessible (Fooladmand et al., 2008).

The objective of this investigation is to modify the Hargreaves (HG) method according to the regional semi-arid conditions of Quetta and Zhob, Baluchistan, Pakistan.

MATERIALS AND METHODS

Geographical location of the study area

The weather data of two metrological stations, that is, Quetta and Zhob stations were used to assess Hargreaves (HG) method for the estimation of monthly ETo. Both stations are located in Baluchistan Province, Pakistan. Table 1 shows 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.

ETo Methods

Penman-Monteith (FAO-56 PM) method

For the estimation of Penman-Monteith ETo computer model CROPWAT 8.0 was applied as suggested by FAO (Food and Agriculture organization). The input metrological data needed was minimum and maximum atmospheric temperature, relative humidity, wind speed and sunshine hour’s data. The monthly ETo was estimated by applying computer model (FAO CROPWAT 8.0, 2009), while the following PM method was applied as recommended by Allen et al. (1998) given as:

\[ ETo = 0.408\Delta (Rn - G) + \gamma(900/T + 27.3) U2 (VPD) \]
\[ \Delta + \gamma (1.34 U2) \]

Where: ETo is reference crop evapotranspiration (mm/day); \( \Delta \) 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-h air velocity at 2 m elevation (ms^{-1}); VPD is the vapor pressure debit (kPa); and \( \gamma \) is psychometric constant (kPa (°C)^{-1}). The computation of all data required for the calculation of the ETo followed the method of Allen et al. (1998).

Hargreaves (HG) method

The ETo calculated by applying Hargreaves method is given by Hargreaves and Samani (1985):

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

Where: ETo HG is reference evapotranspiration (mm/day); T represent Tmax and Tmin = average, maximum and minimum air temperature (°C), respectively.

Modification of Hargreaves (HG) method

The performance of Hargreaves (HG) method was improved by adjusting the parameter of the original HG method according to regional conditions. The HG method was modified by resulting new value of constant applying simple mathematical logic.

In the previous equation, ETo HG was set equal to ETo PM and the constant ‘0.0023’ was set as ‘M’ to be determined. Hence, the adjusted equation was written as:

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

The calibrated 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 method attained by means of above logic, that is, by varying the value of constant is written as HG mod equation. The value of Ra (extraterrestrial radiation) used in Hargreaves method was determined in research conducted by Samani and Hargreaves (1985).

Statistical evaluation

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

\[ RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \]
Table 1: Geographical and climatic characteristics of selected weather stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Data period</th>
<th>Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quetta</td>
<td>30° - 05' N</td>
<td>66° - 57' E</td>
<td>1719</td>
<td>2001-2009</td>
<td>Cold semi-arid</td>
</tr>
<tr>
<td>Zhob</td>
<td>31° - 21' N</td>
<td>66° - 58' E</td>
<td>1405</td>
<td>2001-2009</td>
<td>Hot semi-arid</td>
</tr>
</tbody>
</table>

Table 2: Statistical evaluation of HG_{org} and HG_{mod} compared with PM at Quetta station.

<table>
<thead>
<tr>
<th>Equation form</th>
<th>Percentage error</th>
<th>RMSE</th>
<th>R^2</th>
<th>SD</th>
<th>SEE</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>HG_{org}</td>
<td>35.02</td>
<td>1.74</td>
<td>0.98</td>
<td>2.05</td>
<td>0.31</td>
<td>4.50</td>
</tr>
<tr>
<td>HG_{mod}</td>
<td>0.87</td>
<td>0.29</td>
<td>0.98</td>
<td>2.79</td>
<td>0.31</td>
<td>6.14</td>
</tr>
</tbody>
</table>

Table 3: Statistical evaluation of HG_{org} and HG_{mod} compared with PM at Zhob station.

<table>
<thead>
<tr>
<th>Equation form</th>
<th>Percentage error</th>
<th>RMSE</th>
<th>R^2</th>
<th>SD</th>
<th>SEE</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>HG_{org}</td>
<td>15.82</td>
<td>0.81</td>
<td>0.97</td>
<td>2.00</td>
<td>0.27</td>
<td>4.61</td>
</tr>
<tr>
<td>HG_{mod}</td>
<td>1.89</td>
<td>0.27</td>
<td>0.97</td>
<td>1.65</td>
<td>0.27</td>
<td>3.81</td>
</tr>
</tbody>
</table>

Figure 1: Comparison of ETo by PM with (a) HG_{org} and (b) HG_{mod} methods at Quetta station.

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

\[ R^2 = \frac{\left[ \sum_{i=1}^{n} (x_i - \bar{x}) (y_i - \bar{y}) \right]^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2} \]

Where \( P \) is ETo estimated by the PM method and \( O \) is ETo estimated by different forms of HG method. \( \bar{P} \) and \( \bar{O} \) are the average of \( P \) and \( O \), and \( n \) is the total number of data.

RESULTS AND DISCUSSION

The original Hargreaves (HG) method was examined against standard Penman-Monteith (PM) method for monthly calculation of ETo. The HG_{org} method indicated...
underestimation of ETo by 35.02% for cold semi-arid conditions of Quetta and overestimation of ETo by 15.82% at hot semi-arid conditions of Zhob (Figures 1a and 2a) (Tables 2 and 3). Therefore, the HGorg method is not suggested for execution in cold and hot semi-arid conditions of Quetta and Zhob stations, respectively without being modified.

**Modification of Hargreaves (HG) method**

The modification to the Hargreaves (HG) method is by determining the value of constant term that lessen the RMSE and percentage error between ETo value calculated by standard Penman-Monteith (PM) method. The resultant modified HG (HGmod) equation arrangements are given as:

**Modification at Quetta station:**

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

**Modification at Zhob station:**

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

Many researchers have carried out researches to modify the Hargreaves method by altering the constant value (Bachour et al., 2013; Berti et al., 2014; Majeed et al., 2017). The ETo estimated by the modified Hargreaves (HG) method was again examined against the ETo calculated by the Penman-Monteith (PM) method. The monthly ETo was improved by the modified Hargreaves (HGmod) method. There was an improvement in RMSE and percentage error was also reduced (Tables 2 and 3). The calculation of ETo from that modified method reduced the percentage error to 0.87 and 1.89% with RMSE of 0.29 and 0.27 mm/day at Quetta and Zhob, respectively (Figures 1b and 2b) and (Tables 2 and 3).

**Conclusion**

The comparison of ETo by HG org and standard Penman-Monteith (PM) method showed that the original Hargreaves (HG org) method overestimated ETo in hot semi-arid environment of Zhob and underestimated ETo in cold semi-arid environment of Quetta. The modified Hargreaves (HG mod) showed better estimation of ETo at both stations. Hence, it is recommended that original Hargreaves method should be modified according to the regional environment before being applied.

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**REFERENCES**


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