Correction and sensitivity analysis of Hargreaves - Samani model in the estimation of the reference evapotranspiration (case study: Gonabab city in Iran)

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Abstract: According to the importance of evapotranspiration in water balance and supplying water requirement of the plant; this research aim to assess the corrective coefficients for Hargreaves-Samani model by using 22 years statistics of meteorological of synoptic station of Gonabad in Iran. The data series containing of 19 years were considered to estimate equations and remaining data (three years) was used to validate equations. Some equations including types of meteorological parameters were estimated by using SPSS software. equations that had better regression results were tested and two equations were selected among them which respectively with root mean squared error of 0.602 and 0.758 and Nash-Sutcliffe coefficient of 0.835, 0.711 and determination coefficient of 0.858, 0.776 showed that the close values to FAO Penman-Monteith than the Hargreaves methods. The first equation includes the average, maximum and minimum temperatures, actual hours of sunshine and maximum sunshine hours, the second equation has two parameters of temperature and wind speed in two meters height. In this research the two presented equations were analysed and the results showed that in the first model the evapotranspiration had relatively more sensitivity than the parameters of minimum and maximum temperatures and average temperature and in the second model both parameters of that were sensitive.

Key words: sensitivity analysis, evapotranspiration, corrective coefficient, FAO-Penman-Monteith, Gonabad

1. INTRODUCTION

Combining two separate processes which water has been removed from the soil surface as evaporation and from plant as transpiration, is called evapotranspiration. Because of evapotranspiration is one of basic components of hydrologic cycle, correct determination of that has high importance in water sciences such as hydrologic balance studies and water resources management. Evapotranspiration is estimated in direct methods of lysimeteric (pan evaporation) or indirect methods (empirical equations). In the case that it isn’t possible to reach accurate data, FAO Penman Monteith can be used as the standard method to evaluate results of other empirical methods (Qamarnia et al., 2012). The concept of evapotranspiration was propounded in the framework of hydrological, geographical, climatological, biological and agricultural meteorology studies and in order to evaluate dryness periods in the regional, continental and global scales (Gong et al., 2006). The purpose of that was presenting scales or indexes to compare and classify time series' values of meteorological and climatic variables. Using evapotranspiration of reference plant (ETo) has a special and useful place in hydrological, agro-hydrological and also agricultural meteorology discussions and yet many researchers have been conducted about this concept (Lu et al., 2005; Oudin et al., 2005; Donohoue et al., 2010; Weiss and Menzel, 2008; Pourali Baba and Shiri, 1991). The proper irrigation planning is one of ways to reduce water losses in the fields which its basis is accurate estimation of water requirements of plants. Equations that are used to calculate evapotranspiration of reference plant (ETo) are not suitable for all climatic conditions due to its empirical nature. So it is necessary was corrected the proper equation of each region (Pour Yazdankhah et al., 1991). Estimating evapotranspiration amount of reference plant is considered as one of very important cases in irrigation planning, determining water budget, planning farming
affairs and integrated management of agricultural systems (Pourali Baba and Shiri, 1991).

Based on the latest scientific information available in the world (Allen et al., 1998) the FAO-Penman-Monteith equation (FAO56-PM) is used as reference equation to estimate reference evaporation-transpiration and all models and different estimation equations and their accuracy are evaluated by values from this method (Pourali Baba and Shiri, 1991).

Many researches in all around the world have introduced the Penman-Monteith method as the most accurate method and a standard and valid method to calculate evapotranspiration of the reference plant (Suri, 2005). In another research they have evaluated models of evapotranspiration estimation for semi-arid regions with results of Lysimeter and they have suggested the Penman-Monteith model for these regions such as Karaj (Delghani Sanij et al., 2004). In this research the basis of measuring the accuracy of all used models will be the reference equation of Penman-Monteith-Fao which this evaluation is formed through using some statistical parameters.

The Hargreaves-Samani method is from the results of Hargreaves and Samani during 1975 to 1982. The mentioned equation has been developed by using 8 years data of Davis California. Different evaluations especially in regions such as Aspendal Australia, Lompoc California, Seabrook New Jersey, Arizona, Damin Haiti and also compared with the corrected Penman method in different regions of Bangladesh show that the above equation presents a good evolution from evapotranspiration of reference plant (Jacovides and Kontoiannis, 1995).

Some studies have been conducted in this field in Iran too, that it has corrected Hargreaves-Samani method based on the corrected Penman equation and Jensen Hayes for 64 regions of synoptic stations of Iran's Meteorological Organization. Evaluations show that correction of the mentioned equation with reference of Jensen Hayes for Isfahan industrial University station has suitable success (Khajezadeh, 1995; Najafi, 2006).

Hargreaves-Samani method is a simple method which needs few and common data in water resources projects in regions with no complete method statistic but despite suggestion of this model in some regions it doesn’t work in all climates. This issue is consistent according to this the Hargreaves-Samani method is thermal and effect of factors such as relative humidity, wind and sunshine duration and intensity have been not seen in it (Sharifan et al., 2012). In a research that 13 methods of potential evapotranspiration estimation were compared in synoptic station of Ardestan, results of evaluation indexes showed that best method is models of based on temperature and Hargreaves method (Ordibehesht and Samiei, 2013).

Two methods of Hargreaves-Samani and Jensen Hayes have a remarkable importance among different methods of estimation of reference evapotranspiration. Because in addition to they have a suitable relative accuracy in arid and semi-arid regions, also they need few meteorological data compared with other methods (Samani, 2000; Najafi, 2006).

Also with a research that was conducted in Santeh region in Kurdistan respectively Blaney Cradle, pan evaporation and Hargreaves methods have been determine suitable to estimate evaporation-transpiration (Mirzaei Takhtgahi and Ma'azed, 2006). A research that was conducted to calculate values of monthly ETo in different climatic conditions of Iran showed that Hargreaves-Samani model has suitable accuracy in climatic conditions of warm-wet and cold-arid while this model has weak results in cold-wet climate (Tabari, 2009; Mosaedi and Qbai Souq, 2013).

Estimation of water requirement is one of the most important stages of designing an irrigation system. Evaluating the effect of meteorology parameters in this estimation in addition to show the sensitivity of estimation models of evapotranspiration of reference plant can estimate water requirement of plants in different climatic conditions. Researches that have been conducted until now show that in various climatic conditions, responses (sensitivity) of evapotranspiration estimation models are not equal to meteorology parameters (Tafazzoli, 2006).

According to researches the sensitivity analysis of different models of ETo estimation especially Penman-Monteith- FAO model, the sensitivity had been relatively during year's days to various meteorology parameters and determination of coefficients (Allen et al., 1998; Estevez et al., 2009, Gong et al., 2006; McCuen, 1974; Qui et al., 1998). As the sample with sensitivity analysis of FAO-
Penman-Monteith, thermal Hargreaves, Priestly Taylor, torque and radiant Hargreaves models in three regions of ocean, subtropical and Mediterranean of France and to evaluate time changes of parameters of radiation, relative humidity, wind speed and temperature showed that time changes of climatic input parameters are strongly affected by type of climate.

Therefore empirical equations with related input data show different uncertainties in different under study regions (Ordibehesht and Samiei 2013; Bois et al., 2006). In another research sensitivity of data of temperature, relative humidity, solar radiation and wind speed were analyzed in standard equation of ASCE Penman-Monteith in 87 automatic stations in Andalusia Spain (Estevez et al., 2009).

Evaluations showed that a few studies have been conducted on correction of Hargreaves equation with above method in arid regions. The purpose of this research was determination of the most suitable correction coefficients for estimation of reference evapotranspiration with Hargreaves-Samani method to be able to use this relation with higher certainty and accuracy in evaporation measuring stations which number of quantitative parameters are measured. Of course these coefficients are not constant values but it is introduced an equation including meteorological parameters as the correction coefficient which its value is changed with climatic conditions. This coefficient can be used for climates similar to the case study which is presented here.

2. MATERIALS AND METHODS

Data of this research has been obtained from 22 series meteorological data (1992-2014) of synoptic station of Gonabad. Gonabad city is in the center of Razavi Khorasan in 265 km away of Mashhad; geographically it has longitude of 58 degrees and 41 minutes and latitude of 34 degrees 21 minutes. Gonabad region has arid and desert climate with warm summers and cold winters based on Domarten classification (Sokhanvar et al., 2013). The maximum temperature in this city is 47 degrees above zero in summer and its minimum is 17 degrees below zero in winter. Also the average annual precipitation is 140 mm in this region that it had been in oscillation between 48 to 240 mm in recent years (Sarvari et al., 2013).

From all available statistical period (22 years), 85% of data (19 years) were used for calibration and 15% of that (3 years) for test stage. According to meteorology data after determination of reference evapotranspiration for Hargreaves-Samani method (H.S) and also FAO-Penman-Monteith method (F.P.M); a relation of these two methods were calculated for all statistical data and for each day in calibration stage (k=(ETo F.P.M)/(ETo H.S)).

Then the equations were estimated in SPSS software in a form that in each stage various meteorology parameters such as relative humidity, wind speed, minimum and maximum temperatures and...as independent variables and K relation as the dependent variable, it presented us some equations based on these parameters. After this the obtained equations were multiplied in ETo H.S to obtain ETo values such as F.P.M. In the next stage the new ETos were compared by using F.P.M method as radix by using statistical indexes. Equations that had closer results remained and others were removed (Table 1).

The equations were corrected in test stage in Excel and in linear method and again the statistical indexes were evaluated, two equations that had better results than the H.S method were selected as correction coefficients. The used statistical indexes have been mentioned in Table 1.

In Table 1, N is number of data and $S_i$ is the predicted values of evapotranspiration and $Q_i$ is real values of evapotranspiration and $S$ is average of the predicted values of evapotranspiration and $Q_i$ is average of real values of evapotranspiration. In this research the two presented equations were analysed in graph method. In this method the relative changes of independent variable (such as various meteorology parameters) are drawn to relative changes of dependent variables (reference evapotranspiration). The values of changes of independent variable were considered ±50%, ±40%, ±30%, ±20%, ±10% and 0%.
Table 1. The used statistical indexes in equations

<table>
<thead>
<tr>
<th>Statistical parameter</th>
<th>Formula</th>
<th>Range</th>
<th>Ideal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>( \sqrt{\frac{\sum_{i=1}^{N}(S_i - Q_i)^2}{\sum_{i=1}^{N}S_i^2}} )</td>
<td>Infinity to 0</td>
<td>0</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>( \frac{(\sum_{i=1}^{N}(S_i - \bar{S})(Q_i - \bar{Q}))^2}{\sum_{i=1}^{N}(S_i - \bar{S})^2 \sum_{i=1}^{N}(Q_i - \bar{Q})^2} )</td>
<td>1 to 1</td>
<td>1</td>
</tr>
<tr>
<td>NS</td>
<td>( 1 - \frac{\sum_{i=1}^{N}(S_i - Q_i)^2}{\sum_{i=1}^{N}(Q_i - \bar{Q})^2} )</td>
<td>1 to infinity</td>
<td>-1</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The obtained daily ETo values from H-S method were multiplied in the obtained coefficients in SPSS in order to evaluate the equations and then they compared with obtained daily ETo values from standard method (F-P-M). In Table 2, the first row is related to H-S method and other rows cover estimating equations. It should be noted that the available equations in Table 2 were selected among other equations because they had more desirable statistical results; means less RMSE and more NS than the H-S method. All available equations in Table 2 were corrected again in test stage in linear method and the results were evaluated.

Table 2. The corrected equations in validation period

<table>
<thead>
<tr>
<th>NS</th>
<th>( R^2 )</th>
<th>RMSE</th>
<th>Equations</th>
<th>Equations Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6.24</td>
<td>0.53</td>
<td>1.80</td>
<td>( 0.0135 \left( 0.075 \times \frac{100 (\frac{U_2}{N})}{\sqrt{T_{\text{max}} - T_{\text{min}}}} \right) \times \text{Ra} \times \sqrt{T_{\text{max}} - T_{\text{min}}} \times (\text{Tmean} + 17.8) )</td>
<td>H-S</td>
</tr>
<tr>
<td>0.71</td>
<td>0.77</td>
<td>0.75</td>
<td>( 0.5055 \times \left( \text{ETo} \times \left( 0.0867 \text{Tmean} + 0.053U_2^2 \right) \right) + 0.6387 )</td>
<td>FPM-1*</td>
</tr>
<tr>
<td>-11.10</td>
<td>0.85</td>
<td>1.49</td>
<td>( 0.3674 \times \left( \text{ETo} \times (0.0677 \text{Tmean} + 0.052U_2^2 + \text{RH}) \right) + 0.989 )</td>
<td>FPM-2*</td>
</tr>
<tr>
<td>0.51</td>
<td>0.67</td>
<td>0.91</td>
<td>( 0.5706 \times \left( \text{ETo} \times (0.0667 \text{Tmean} + 0.052U_2^2 + 1.05 \text{RH}) \right) ) + 0.4745</td>
<td>FPM-3*</td>
</tr>
<tr>
<td>0.58</td>
<td>0.70</td>
<td>0.86</td>
<td>( 0.5489 \times \left( \text{ETo} \times (0.075 \text{Tmean} + 0.052U_2^2 + 1.344 \text{RH}^2) \right) ) + 0.5107</td>
<td>FPM-4*</td>
</tr>
<tr>
<td>0.66</td>
<td>0.74</td>
<td>0.80</td>
<td>( 0.5222 \times \left( \text{ETo} \times (0.0937 \text{Tmean} + 0.049U_2^2 + 1.594 \text{RH}^2 - 0.036n) \right) ) + 0.5544</td>
<td>FPM-5*</td>
</tr>
<tr>
<td>-21.04</td>
<td>0.04</td>
<td>1.56</td>
<td>( 0.0215 \times \left( \text{ETo} \times \left( 0.071T_{\text{max}} + 0.002T_{\text{min}}\text{in}^2 - 2.554 \times 10^{-6}T_{\text{mean}}^4 \right. \right. ) ) + 1.66 ( \text{RH}^5 + 1.281 \times 10^{-5}U_2^2 ) + 2.4851</td>
<td>FPM-6*</td>
</tr>
<tr>
<td>0.83</td>
<td>0.85</td>
<td>0.60</td>
<td>( 1.2666 \times \left( \text{ETo} \times \left( 0.055 \left( T_{\text{max}} - T_{\text{min}} \right) - 0.323 \left( \frac{G_{\text{Si}}}{R^2} \right) + 0.147 \left( \text{Tmean} + 17.8 \right) \right) \right) ) + 0.1062</td>
<td>FPM-7*</td>
</tr>
</tbody>
</table>

In Table 2, number of actual hours of sunshine is \( N \), the maximum possible sunshine hours is \( T_{\text{max}} \), maximum temperature (centigrade grade), \( T_{\text{min}} \) is minimum temperature (centigrade grade), \( \text{Ra} \) is the radiation entry into the atmosphere (mm/day), \( \text{Tmean} \) is average temperature (centigrade grade), \( U_2 \) is wind speed in height of two meters in (meter on second) and \( \text{RH} \) is relative humidity. It is resulted from statistical results of available equations in Table 3 that FPM-7* equation has the most accuracy. This equation has less RMSE value than the others and although it has less \( R^2 \) than some models but due to more NS that has than the other equations the slight difference of its \( R^2 \) with other equations can be ignored. The same conditions are applied for FPM-1* equation but it is situated in the second priority with very close difference than the FPM-7* equation. From this perspective equations of FPM-3*, FPM-4* and FPM-5* are situated in next classes. Equations of FPM-6* and FPM-2* and H-S have the least accuracy than the other equations due to high RMSE and very low \( R^2 \) and NS that they have. So two equations of FPM-1* and FPM-7* were presented to correct the Hargreaves-Samani method. According to sensitivity graph of Figures 1 and 2 it is
observed that in FPM-7* parameters of maximum and minimum temperatures and average temperature; both parameters of that have more sensitivity means average temperature and wind speed in height of two meters due to high slope that they have. The positive slope of changes of FPM-7* model in front of changes of maximum temperature and average temperature (Tmean) show the direct relationship of the model with these two parameters. The negative slope of changes of FPM-7* model in front of changes of minimum temperature parameter and sunshine hours (N) show the inverse relationship of the model with these two parameters. In other words the evapotranspiration intensity of FPM-7* model is increased by increase of maximum temperature and average temperature and its intensity is reduces by increase of minimum temperature and sunshine hours.

![Figure 1. Sensitivity graph of FPM-7* model](image)

In sensitivity graph of Figure 2, positive slope of changes of FPM-1* in front of temperature changes and wind speed in height of two meters shows the direct relationship of the model with its parameters. In fact whatever these two parameters to be increased the evapotranspiration intensity of the model is increased. The wind speed parameter has more effect on increase of evapotranspiration intensity due to the more slopes that it has.

![Figure 2. Sensitivity graph of FPM-1* model](image)

### 4. CONCLUSION

Using FPM-7* and FPM-1* is suggested instead of Hargreaves-Samani model to calculate water
requirement of reference plant in Gonabad region with warm and arid climate, this model can be used in other similar region to this climate. The proposal FPM-7*model has more accuracy than the proposal FPM-1*model but the advantage of proposal FPM-1*model is that needs less data to calculate evapotranspiration. FPM-1*model is sensitive to parameters of wind speed and temperature and it has direct relationship with these two. FPM-7* model is sensitive respectively to parameters of maximum temperature, average temperature, minimum temperature and sunshine hours. Of course this sensitivity is very few about sunshine hours. FPM-1*model has direct relationship with maximum temperature and average temperature and it has inverse relationship with sunshine hours.

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