

ORIGINAL ARTICLE

Evaluation of Hargreaves Equation for Calculating Daily Eto (Case Study: North West of Iran)

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ABSTRACT

Potential Evapotranspiration (ET₀) is one of the most important elements of water cycle that should be estimated in Irrigation, Drainage and hydrology studies. The FAO-Penman-Monteith (PM) method is recommended as the standard method by FAO (Food and Agriculture Organization) in the result of a comprehensive study. This method in calculating ET₀ requires numerous meteorological data and in many area of Iran the use of this method is limited due to lack of these data. In this study, Hargreaves method (HG), that requires only temperature and radiation data, were evaluated in 20 stations in the North West region of Iran. Modified form of Hargreaves method, called Modified Hargreaves equation (M.HG), was established by obtained calibration coefficients. At last, Results of HG and M.HG methods were compared with results of PM method. Statistical analysis of this comparison showed that calibration process has had significant effect on efficiency of Hargreaves method.

Keywords: Evapotranspiration, FAO-P-M, Hargreaves, calibration

Introduction

In arid areas, the lack of proper management of the erratic precipitation accentuates the problem of aridity. Agriculture should in the foreseeable future gain more value and momentum (Rockstrom, 1999; Hofwegen and Svendsen, 2000). Evapotranspiration (ET₀) is an important variable in water and energy balances on the earth's surface, and knowledge of the distribution of ET is a key factor in hydrology, climatology, agronomy and ecology studies (Rivas and Caselles, 2004). In most conditions, irrigation water use is calculated based on crop reference Evapotranspiration (ET₀). Thus, most irrigation engineers use ET₀ and crop coefficients to estimate different crop water requirements (Martinez-Cob and Tejedo-Juste, 2004). So it can be said that accurate understanding and estimating of this parameter is very important. The FAO-Penman method (PM) in estimating ET₀ had been recommended as a standard method (Allen *et al.*, 1998). This method requires many data and these data are not available in very area of world. The need for full weather data limits the widespread use of the Penman-Monteith (Pereira and Pruitt, 2004). So, other methods that require fewer data should be evaluated for these conditions.

Allen *et al.* (1998) have proposed that when sufficient or reliable data to solve the PM equation are not available then Hargreaves equation (Hargreaves *et al.*, 1985) can be used. This method was evaluated by lysimeter data for different climates (Hargreaves, 1994). The Hargreaves equation (HG) requires only daily mean, maximum and minimum air temperature extraterrestrial radiation (Droogers and Allen 2002). Extraterrestrial radiation can be calculated for a certain day and location, only minimum and maximum

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temperatures are the parameters that should be observed (Rahimi Khoob, 2007). Hargreaves method behaves best for weekly or longer prediction although some accurate ETo daily estimations have been reported in literature (Hargreaves and Allen, 2003). This method requires previous local calibration for acceptable performance (Gavilan *et al.*, 2006). Results of studies have showed that Hargreaves method in each condition requires specific type of calibration (Martinez-Cob and Tejero-Juste 2004). Fooladmand and Haghighat (2007) calibrated the Hargreaves equation for estimating monthly ETo in a semi arid region in Iran (Fars province) based on the Penman-Monteith method. The results indicated that the monthly ETo estimations with the Hargreaves equation was always less than monthly ETo estimations with the Penman-Monteith method in the study area. Today, the effect of precise design and management in efficiency of water projects, such as irrigation and drainage systems, is well known. Most area of Iran is characterized by low and erratic precipitation and so modified water management is very important for this condition. Daily values of ETo can be used for better and improved design and management of water projects. By considering this issue, evaluation of the Hargreaves method for ETo daily estimations have importance. The objective of this study was to evaluate the Hargreaves method for estimating daily ETo for the North West of Iran.

Materials and Methods

Study Area and Climate Data Set:

The area under study was the North West region of Iran, between 35.12 and 38.26 N in latitude and between 56.55 and 51.53 E in longitude. This area covers approximately 23970490 hectares. The region is categorized as a semiarid climate based on Koeppen climate classification. Measured weather data sets were obtained from 20 stations across the study area. The mean annual precipitation for the region ranges from 199 to 1853.5 mm. This climate variability is one of the major constraints facing dry land agriculture. The spatial distribution of selected stations can be seen from Fig. 1. Also, Information about the selected stations is shown in table 1.

ET Reference Methods:

There are many methods that be used in estimating and calculating ET reference (ETo). The FAO-Penman-Monteith equation has been introduced as a standard method after comprehensive study in world (Allen, 1992). This method has been used to evaluate and to calibrate other methods (Gavilan *et al.*, 2006; Rahimikhub, 2007; Fooladmand and Haghighat, 2007). The equation can be written as (Allen *et al.*, 1998):

$$ET_{oPM} = \frac{0.408 \Delta R_n + \gamma \frac{900}{T_a + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)} \quad (1)$$

where ET_{oPM} is the computed reference evapotranspiration by The FAO-Penman-Monteith equation (mm d^{-1}); Δ is the slope of saturation vapor pressure versus air temperature curve ($\text{kPa } ^\circ\text{C}^{-1}$); R_n is the daily net radiation ($\text{MJ m}^{-2} \text{d}^{-1}$); G is the soil heat flux ($\text{MJ m}^{-2} \text{d}^{-1}$); g is the psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$); T is the mean air temperature at 2 m height ($^\circ\text{C}$); U_2 is the daily mean of wind speed at 2 m height (m s^{-1}); e_s is the saturation vapor pressure (kPa); and e_a is the actual vapor pressure (kPa). All parameters were calculated using the equations provided by Allen *et al.* (1998). The soil heat flux (G) was assumed to be zero over the calculation time step period (24 h).

The Hargreaves equation (Hargreaves and Samani, 1985) can be written as:

$$ET_{oHG} = 0.0023 R_a (T + 17.8) \sqrt{T_{\max} - T_{\min}} \quad (2)$$

where ET_{oHG} is the computed reference evapotranspiration by Hargreaves equation (mm d^{-1}); R_a is the water equivalent of the extraterrestrial radiation (mm d^{-1}) and depends on day number in the year and latitude, it can be computed according to Allen *et al.* (1998); $T_{\max}$, $T_{\min}$ and T are the daily maximum, minimum and mean air temperature ($^\circ\text{C}$), with T calculated as the average of $T_{\max}$ and $T_{\min}$. 0.0023 is the original empirical coefficient proposed by Hargreaves and Samani (1985).

Validation and Calibration:

To calibrate the Hargreaves equation, based on the Penman-Monteith method and on a monthly basis, the following procedure is recommended (Allen *et al*, 1998):

$$ET_{oPN} = a + b ET_{oHG} \quad (3)$$

Where a and b are empirical coefficients, ET_{oPM} and ET_{oHG} are ETo estimates with the Penman-Monteith method and Hargreaves method respectively. In this study, equation (3) was used to calibrate and to evaluate daily ETo estimates. Therefore, a and b coefficients were determined for each day of year and for each station. Consequently, in each station, modified equations for Hargreaves method were established by obtain coefficients. The modified equations were called Modified Hargreaves equation (M.HG). At last, HG and M.HG results (ET_{oHG} and ET_{oMHG} estimates) were compared with PM results (ET_{oPM} estimates). Compared results in this step were the last year that required data have been available. This year was not used in calibrating HG method and obtaining empirical coefficients.

Statistical Analysis:

Using simple error analysis and linear regression, results of HG and M.HG methods were compared with results of PM method. For each station, the following parameters were computed (Willmott, 1982): Mean bias error (MBE)

$$MBE = \frac{\sum_{i=1}^n (y_i - x_i)}{n} \quad (4)$$

Root mean square error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - x_i)^2}{n}} \quad (5)$$

Ratio between both average ETo estimations (R)

$$R = \frac{y_{ave}}{x_{ave}} \quad (6)$$

Where n is the number of available days; x_i is the estimated ET_{oPM} ; y_i is the estimated ET_{oHG} or ET_{oMHG} ; x_{ave} is the average of ET_{oPM} and y_{ave} is the average of ET_{oHG} or ET_{oMHG} for a given site.

Results and discussion

ETo daily values for all the stations were estimated with FAO-Penman-Monteith (PM), Hargreaves (HG) and Modified Hargreaves (M.HG) methods. Results of HG and M.HG methods were compared with results of PM method. Statistical parameters for studied stations are listed in Table 2.

Table 1: Weather stations used in this study and annual mean values of meteorological variables at each station.

Station	Elevation (m)	Latitude (Degree)	Longitude (Degree)	Precipitation (mm)	T mean (°C)	RH (%)
Abali	2465	35° 45'	5° 53'	534	8.4	49
Ahar	1391	38° 26'	47° 7'	292.2	10.8	60
Ardebil	1332	38° 15'	48° 17'	303.9	9	71
Astara	-18	38° 25'	48° 52'	1381	15.2	82
Ghazvin	1279	36° 15'	50° 3'	316	14	51
karaj	1313	35° 55'	50° 54'	243.8	14.9	47
Khalkhal	1796	37° 38'	48° 31'	384.6	8	65
Khorram dareh	1575	36° 11'	49° 11'	301.1	11.9	51
Manjil	333	36° 44'	49° 24'	209.3	17.6	59
Maragheh	1478	37° 24'	46° 16'	322.4	12.9	49
Meshkin shahr	1569	38° 23'	47° 40'	367.8	10.6	67
Mianeh	1110	37° 27'	47° 42'	282.1	13.7	51
Noushahr	-20.9	36° 39'	51° 30'	1294	16.1	83
Nowzheh	1680	35° 12'	48° 43'	334.7	11	53
Ramsar	-20	36° 54'	50° 40'	1218	16	83
Sanandaj	1373	35° 20'	47° 0'	458.4	13.4	47
Sarab	1682	37° 56'	47° 32'	243.6	8.6	61
Tabriz	1361	38° 5'	46° 17'	288.9	12.5	54
Zanjan	1663	36° 41'	48° 29'	458.4	13.4	47
Zarrine obato	2143	36° 4'	46° 55'	394.8	7.9	53

Table 2: Summary of statistics from comparison between HG, MHG and PM method.

Station	Hargreaves Method			Modified Hargreaves Method		
	RMSE (mm/day)	MBE (mm/day)	R	RMSE (mm/day)	MBE (mm/day)	R
Abali	0.69	-0.42	0.86	0.49	-0.12	0.96
Ahar	0.58	0.28	1.10	0.44	-0.06	0.98
Ardebil	0.95	0.72	1.32	0.42	0.11	1.05
Astara	0.52	0.32	1.15	0.45	0.04	1.02
Ghazvin	0.70	0.27	1.08	0.69	-0.11	0.97
Karaj	0.92	-0.38	0.91	0.91	-0.05	0.99
Khalkhal	0.65	0.27	1.11	0.41	-0.06	0.98
Khorram dareh	1.49	-0.96	0.76	1.21	-0.50	0.88
Manjil	0.88	0.15	1.05	0.69	-0.01	1.00
Maragheh	0.60	-0.08	0.98	0.57	-0.17	0.95
Meshkin shahr	0.57	-0.02	0.99	0.58	-0.10	0.96
Mianeh	0.83	0.45	1.14	0.56	-0.07	0.98
Noushahr	0.58	0.35	1.16	0.43	0.01	1.00
Nowzheh	0.71	0.04	1.01	0.77	0.13	1.04
Ramsar	0.50	0.19	1.09	0.46	-0.10	0.95
Sanandaj	1.21	0.83	1.26	0.49	0.03	1.01
Sarab	0.78	0.53	1.21	0.36	-0.04	0.99
Tabriz	0.55	0.00	1.00	0.54	-0.08	0.97
Zanjan	0.69	0.46	1.16	0.38	0.04	1.01
Zarrine obato	1.14	-0.72	0.80	0.82	-0.04	0.99
Average	0.78	0.11	1.06	0.58	-0.06	0.98

In the case of the HG Method, results indicated that minimum RMSE and maximum RMSE were obtained in Ramsar and Khoramdareh, 0.50 and 1.49 (mm/day), respectively. On the other hand, the average value of RMSE for all stations was 0.78 (mm/day). Therefore, the difference between the estimated ET_{PM} and ET_{HG} was considerable. Also, the results showed that the minimum MBE and the maximum MBE were obtained in Khoramdareh (-0.96) and Sanandaj (+0.83), respectively. Negative and positive values of MBA show underestimating and overestimating state, respectively. Ratios between ET_{HG} and ET_{PM} mean values (R) showed that maximum overestimation produced was as high as 32% and, in Ardebil station, and the maximum underestimation found amounted to 20%, in Zarrine obato station. 12 locations significantly overestimated daily ETo with respect to PM and three locations clearly underestimated it. The method provided satisfactorily good ETo estimations for five locations (under- or over-estimations were smaller than 5%). Daily values of a and b coefficients for all the stations were calculated for obtaining calibrated form of Hargreaves equation which is called as the Modified Hargreaves (M.HG) equation. In each station, all available data except data of the 2006 year were used for extracting above coefficients. 2006 year data were used for evaluating of M.HG equation results.

In the case of the M.HG equation, results minimum RMSE and maximum RMSE were obtained in Sarab and Khoramdareh, respectively 0.36 and 1.21 (mm/day). Also, the average value of RMSE for all stations for this method was 0.58 (mm/day). The minimum MBE and the maximum MBE were found in Khoramdareh (-0.50) and Nowzheh (+0.13). Ratios between ET_{MHG} and ET_{PM} mean values (R) showed that maximum overestimation produced was as high as 5% and, in Ardebil station, and the maximum underestimation found amounted to 12%, in Khoramdareh station. One location significantly overestimated daily ETo with respect to PM and one location clearly underestimated it. The method provided satisfactorily good ETo estimations for 18 locations (under- or over-estimations were smaller than 5%).

Conclusion:

The objective of this study was to evaluate Hargreaves method for estimating daily ETo for the North West part of Iran. For this purpose, daily data were used for calculating daily ETo values by Hargreaves method (HG). In this study, considering the objective of daily ETo estimating, calibration process was carried out on a daily basis. Calibration coefficients, that determine M.GH equation forms, were achieved for each station. All available data except data of the 2006 year were used for extracting above coefficients. 2006 year data were used for evaluating of HG and M.HG methods. For better comparison of HG and M.HG methods efficiency, MBE values are presented in Fig 2. Calibration process clearly has had good consequence.

As mentioned in the results section, the Hargreaves and the Modified Hargreaves method provided satisfactorily good ETo estimations for five and 18 locations, respectively. This implies that calibration process has had significant effect on efficiency of Hargreaves method. So, it can be concluded that, calibration of Hargreaves method improves its efficiency.

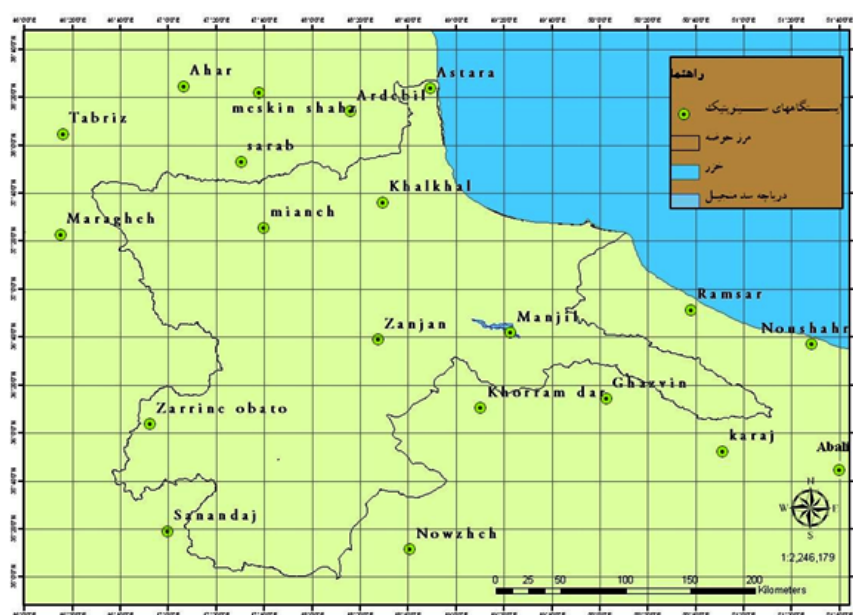


Fig. 1: Spatial distribution of studied stations.

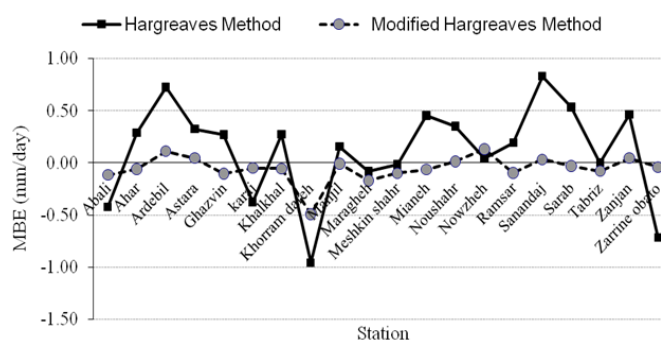


Fig. 2: MBE values of HG and M.HG methods results.

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