Assessment of Hargreaves Equation for Estimating Monthly Reference Evapotranspiration in the South of Iran

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***Abstract*—**Evapotranspiration is one of the most important components of the hydrological cycle. Evapotranspiration (ETo) 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. Many researchers have a valid relationship, which is a function of climate factors, to estimate the potential evapotranspiration presented to the plant water stress or water loss, prevent. The FAO-Penman method (PM) had been recommended as a standard method. This method requires many data and these data are not available in every area of world. So, other methods should be evaluated for these conditions. When sufficient or reliable data to solve the PM equation are not available then Hargreaves equation can be used. The Hargreaves equation (HG) requires only daily mean, maximum and minimum air temperature extraterrestrial radiation .In this study, Hargreaves method (HG) were evaluated in 12 stations in the North West region of Iran. 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, Hargreaves equation, FAO-Penman method.

I. Introduction

THE Penman–Monteith (FAO-56 PM) equation is suggested as the standard method for estimating evapotranspiration (ET_0) by the International Irrigation and Drainage Committee and Food and Agriculture Organization (FAO). On the other hand, the Hargreaves–Samani (HS) equation is an alternative method compared with the FAO-56 PM equation.

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 [16]. Many researchers around the world Penman-Monteith lysimeters as compared to the standard method and the most accurate and reliable method for calculating reference evapotranspiration have been introduced [3]. Evapotranspiration (ETo) 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 [15]. Thus, most irrigation engineers use ETo and crop coefficients to estimate different crop water requirements [4]. The FAO-Penman method (PM) in estimating ETo had been recommended as a standard method [1]. This method requires many data and these data are not available in every area of world. The need for full weather data limits the widespread use of the Penman-Monteith [8], [13]. So, other methods that require fewer data should be evaluated for these conditions. In this research the equation of HG calibrate by Penman Monthis method.

Salako found that the daily means of PM ETo values were significantly correlated with those of the HG method ($P<0.0001$, r2 from 0.72-0.93) and pan ETo values ($P<0.0001$, r2 from 0.91-0.93). He also reported that the regression equations developed for three agroecological zones of Nigeria can be used to estimate PM ETo values for similar climatic zones where data requirements cannot be met but data for the HG or pan method are available [12].

Jabloun and Sahli evaluated the Hargreaves equation. They reported that the results obtained from the comparison of ETo daily estimates by the Hargreaves equation with FAO-56 PM, estimates taken as reference throughout different Tunisian locations showed a systematic overestimation at inland sites but that at coastal sites, the Hargreaves equation tends to underestimate ETo values. They suggested that further research would be required to adjust the Hargreaves coefficients to local conditions for obtaining better accuracy [7].

II. Material and Methods

The area under study was the North West region of Iran (Fars Province), between 27.2 and 31.2 N in latitude and between 51.9 and 54.4 E in longitude. This area covers approximately 2592890.16 hectares. The region is categorized as a semiarid climate based on different climate classification that show on Fig. 1. Measured weather data sets we obtained from 12 stations across the study area. The mean annual precipitation for the region ranges from 138 to 856 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 I.

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TABLE I
LOCALIZATION, METEOROLOGICAL DATA, AND CLIMATE OF THE 12 SELECTED STATIONS IN THIS STUDY

Station	Latitude (degree)	Longitude (degree)	Climate (De Martonne)	Elevation a.m.s.l (m)	Records Period	Percipitation (mm)	Tmax (°C)	Tmin (°C)	Tdew (°C)	U10 (Knot)	Rhmean (%)	n (hr)
Abadeh	31.166	52.616	Arid	2030	2005-2012	138.5	22	6.5	-3	16	35	9.3
Eghlid	30.883	52.716	Semi – Arid	2300	2008-2012	341	19.4	6.1	0.9	18	32	9.1
Boanat	30.45	53.633	Semi – Arid	2151	2003-2012	248.4	20.8	6.5	-2.5	16	34	9
Sepidan	30.283	51.983	Humid	2200	2005-2012	856.8	19.5	9.6	1	14	39	9.1
Mavdasht	29.933	52.883.	Semi – Arid	1620	2008-2012	504.7	23.9	11.5	-1	11	43	9
Izad Khast	31.55	52.116	Arid	2142	2006-2012	159.4	20.7	7.1	0	13	33	9.3
Fasa	28.95	53.65	Semi – Arid	1450	2004-2012	310.4	28	10.6	3.2	12	40	9.3
Lamerd	27.336	53.15	Arid	500	2009-2012	227.8	33.8	16.8	3.3	11	43	9.4
Lar	27.7	54.333	Arid	806	2007-2012	215.2	31.7	15.1	2.3	12	44	9.4
Neyriz	29.2	54.316	Arid	1795	2007-2012	213.3	25.7	13	3	11	36	9.8
Safashahr	30.616	53.166	Semi – Arid	2324	2002-2012	232	19.8	2.93	3.6	9.3	36.91	16.5
Zarghan	29.783	52.716	Semi – Arid	1600	2005-2012	338.7	24.6	7.3	2.5	11	42.5	9

Tmin=minimum air temperature, Tmax=maximum air temperature, Tdew=dew point temperature, U10=wind speed at 10 m height, RHmean=mean relative humidity, n=mean monthly total sunshine hours. **The classification of the climatic regions based on De Martonne method

Fig. 1 Meteorological stations used in the study

To calculate wind speed at two-meter height, the equation proposed by Allen et al. (1998) was used [1]:

$$u_2 = \frac{4.87 . u_{10}}{\ln(67.8.10 - 5.42)} \quad (1)$$

where U_2 is the average 24-hour wind speed at a height of 2 m and U_{10} is average 24-hour wind speed at a height of 10 m.

The solar radiation was calculated by using:

$$R_s = \left(0.25 + 0.5\frac{n}{N}\right) . R_a \quad (2)$$

where R_s is the net solar radiation (MJ m^{-2} day^{-1}), N is the maximum possible sunshine hours (h), n is the number of actual sunshine hours (h), and R_a is the extraterrestrial radiation (MJ $m^{-2}day^{-1}$).

Allen proposed the FAO-Penman-Monteith method as a standard method to estimate, evaluate and calibrate the ET reference value. This method has been used by many researchers [2], [4], [9]-[11] and the equation can be rewritten as:

$$ET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_{10}(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3)$$

where ETo is the reference evapotranspiration (mm day^{-1}), Rn, G, and T are net radiation values at the crop surface (MJ m^{-2} day^{-1}), soil heat flux density (MJ m^{-2} day^{-1}), and mean daily air temperature at 2 m height (°C), respectively. Also, u2, es ea ,(es - ea), Δ, and γ are wind speed at 2 m height (m s^{-1}), saturation vapor pressure (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), slope of the saturation vapor pressure curve (kPa/°C), and psychrometric constant (kPa/°C), respectively.

The Hargreaves equation can be written as [5], [6]:

$$ETo = C(Tmin + 17.8)(Tmax - Tmin)^{0.5}R_a \quad (4)$$

where Tmean, Tmax and Tmin are mean, maximum and minimum temperatures (°C), respectively, and *Ra* is extraterrestrial radiation (MJ m^{-2} day^{-1}) converted to equivalent evaporation in mm day^{-1} with a factor of 0.408.

The climate of each region was determined by using the De Martonne model as [14]:

$$I = \frac{P}{T+10} \quad (5)$$

where P is mean of annual precipitation (mm) T (°C) is mean of annual temperature, I is the Demartonne drought index.

To estimates by the PM and HG models were compared using simple error analysis and the linear regression method. Both methods were compared before and after adjustments were applied. For each location, the following parameters were also calculated [13]: root mean square error (RMSE).

$$RMSE = \left[\frac{\sum_{i=1}^{n}(X_{Harg} - X_{PM})^2}{n}\right]^{1/2} \quad (6)$$

where X_{Harg}, X_{pm}, and n are the evaporation values estimated by the Hargreaves and Penman- Monteith methods and data number, respectively.

III. Results and Discussion

Monthly ETo values for all the stations were estimated by the FAO-Penman-Monteith (PM) and Hargreavess-Samani (HG) methods, and the results were compared. Table II shows the monthly and annual values of RMSE. A comparison shows that the lowest monthly RMSE index belonged to the Sepidan Station, with humid climate and with a value of 0.095 in December. The highest RMSE, with a value of 3.132, was recorded at the Fasa Station under a Semi-Arid climate in April. Annually, the highest and lowest RMSE values of 1.407 and 0.467 were at the Eghlid and Abadeh stations, with Semi-Arid and Arid climates, respectively. The results showed that the RMSE values in warm months were higher than those as presented in Table III, the monthly and yearly values of the C coefficients in the HG method were estimated. For the monthly results, the lowest value of C was 0.0018 for (Zarghan) Station in October, while it was for (Izadkhast) Station in Jan. Zarghan were located in semi-arid climate and Izadkhast were located in arid climate. Also, as shown in Table III, the highest C value, 0.0042, was obtained for Lar Station under an arid climate in April.

The annual results showed that the lowest and highest C values were obtained for Boanat and Lar Stations, 0.0023 and 0.0029, respectively. According to Table III annual C coeifficent was different for each station. The lowest C value was obtained at Zarghan Station with a value of 0.0018 in a Semi-Arid, while the greatest difference was obtained at Lar, Safashahr, Neyriz, Abadeh Stations, with a Different values. The climate at the Lar Station is Arid, which of Zarghan is semi-arid. As Table III shows, C coefficients were lower than 0.0023 for Izadkhast, Zarghan, Marvdasht, safashahr, and Lamerd Stations, all with arid climate, and Sepidan station with humid climate. This implies that the ETo values estimated by the Hargreaves method were higher than those by the Penman-Monteith method. For stations with C coefficient higher than 0.0023, the ETo values estimated by the Hargreaves method were lower than those by Penman-Monteith method.

TABLE II
The Values of RMSE between ETO-HARG and ETO-PM

Station	jan	feb	mar	apr	may	june	july	aug	sep	Oct	nov	dec	yearly
Abadeh	0.142	0.489	0.377	0.422	0.486	0.625	0.457	1.015	0.268	0.387	0.309	0.179	0.467
Eghlid	0.154	0.672	0.253	0.98	0.771	0.717	0.468	0.869	0.358	0.637	0.464	0.27	1.047
Boanat	0.291	0.767	0.228	1.294	1.082	0.748	0.958	0.915	0.662	0.844	0.507	0.482	0.918
Sepidan	0.142	0.154	0.291	0.384	0.499	0.815	0.714	00.682	0.623	0.537	0.15	0.095	0.489
Mavdasht	0.499	1.198	0.494	2.862	1.438	1.018	1.405	0.406	1.058	1.037	1.208	1.167	0.991
Izad Khast	0.815	1.554	0.491	2.575	1.14	1.158	1.414	0.463	1.237	0.782	1.348	1.492	0.857
Fasa	0.714	1.835	0.309	3.132	1.428	1.214	1.316	0.646	0.817	1.027	1.264	1.463	0.707
Lamerd	0.682	1.754	0.35	3.026	1.65	1.431	1.018	1.482	0.605	1.246	1.21	0.722	0.688
Lar	0.623	1.494	0.492	2.121	1.352	1.351	0.912	0.747	0.548	1.089	0.84	0.458	0.826
Neyriz	0.537	0.825	0.134	0.971	0.794	0.851	0.619	0.496	0.362	0.576	0.447	0.289	0.955
Safashahr	0.15	0.586	0.116	0.572	0.456	0.656	0.354	0.808	0.29	0.371	0.198	0.221	0.606
Zarghan	0.095	1.15	0.334	1.946	1.101	0.968	0.952	0.89	0.684	0.826	0.849	0.799	0.724

TABLE III
The Monthly C values in the HG Method for Different Months for Investigated Station

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	yearly
Abadeh	0.0021	0.003	0.0025	0.0032	0.0034	0.0032	0.0025	0.0034	0.0023	0.0022	0.0029	0.0028	0.0025
Eghlid	0.0023	0.0029	0.0024	0.0034	0.0032	0.003	0.0024	0.0031	0.0022	0.0021	0.0029	0.0027	0.0024
Boanat	0.0024	0.0027	0.0023	0.0033	0.0031	0.0027	0.0024	0.0028	0.0021	0.002	0.0027	0.0027	0.0023
Sepidan	0.0021	0.0027	0.0023	0.0032	0.0029	0.0026	0.0023	0.0027	0.0021	0.002	0.0026	0.0028	0.0024
Mavdasht	0.0021	0.0027	0.0022	0.0035	0.0028	0.0026	0.0024	0.0025	0.0021	0.0019	0.0027	0.0026	0.0026
Izad Khast	0.002	0.0027	0.0022	0.0033	0.0027	0.0027	0.0024	0.0024	0.0022	0.0019	0.0026	0.0026	0.0029
Fasa	0.0021	0.0029	0.0022	0.0035	0.0028	0.0027	0.0023	0.0024	0.0022	0.0019	0.0027	0.0025	0.0029
Lamerd	0.0021	0.0031	0.0022	0.0039	0.0032	0.0029	0.0024	0.0025	0.0023	0.0019	0.0029	0.0028	0.0028
Lar	0.0023	0.0034	0.0026	0.0042	0.0035	0.0032	0.0025	0.0032	0.0023	0.0021	0.0034	0.0033	0.0029
Neyriz	0.0025	0.0034	0.0023	0.004	0.0037	0.0034	0.0025	0.0032	0.0023	0.002	0.0033	0.0032	0.0027
Safashahr	0.0024	0.0034	0.0022	0.0038	0.0036	0.0035	0.0023	0.0033	0.0022	0.0019	0.003	0.0025	0.0023
Zarghan	0.0022	0.0028	0.0023	0.0035	0.0029	0.0027	0.0024	0.0026	0.0028	0.0018	0.0028	0.0027	0.0027

The result of this investigation indicated that both monthly and yearly means by the Hargreaves method were significantly correlated with those of the Penman-Monteith method at all available recording stations in North of Fars Province Iran); hence, it is possible to predict monthly and yearly ETo values precisely in other areas where the required data for the Penman-Monteith estimations are unavailable and only maximum and minimum air temperatures have been recorded.

References

[1] Allen, R. G., Pereira, L.S., Reas, D., and Smith, M. (1998). "Crop Evapotranspiration." FAO Irrigation and Drainage Paper 56, Rome, 300.

[2] Fooladmand, H. R., and Haghighat, M. (2007). "Spatial and temporal calibration of Hargreaves equation for calculating monthly ETo based on Penman-Monteith method." Irrig. And Drain, 56, 439–449.
[3] Fooladmand, H.R., and Sepaskhah A. R. (2005). "Regional calibration of Hargreaves equation in a semiarid region." Iran-Water Recourses Research, 1(2), 1-6. (In persion).
[4] Gavila´n, P., Lorite, I.J., Tornero, S., Berengena, J. (2006). "Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment." Agric. Water Manag., 81(3), 257–281.
[5] Hargreaves, G. H., and Samani, Z. A. (1985). "Reference crop evapotranspiration from ambient air temperature", Paper No. 85-2517. American society of agricultural engineers. Chicago, IL.
[6] Hargreaves, G. H., and Allen, R. G. (2003). "History and evaluation of Hargreaves evapotranspiration equation." J. Irrig. Drain. Eng., 129(1), 53-63.
[7] Jabloun, M., and Sahli, A. (2008). "Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data Application to Tunisia." Agric. Water Manag., 95(6), 707 – 715.
[8] Martinez-Cob, A. and Tejero-Juste, M. (2004). "A wind-based qualitative calibration of the Hargreaves ETo estimation equation in semiarid regions." Agric. Water Manag., 64(3), 251–264.
[9] Noori Mohammadieh, M., Mohammadi, M., Helali, J., Nazari, B., and Sohrabi, T. (2009). "Evaluation of Hargreaves equation for calculating daily ETo (Case study: North West of Iran)". Advances in Natural and Applied Sciences, 3(2), 273-278.
[10] Rahimi Khoob, A. (2008). "Comparative study of Hargreaves's and artificial neural network's methodologies in estimating reference evapotranspiration in a semiarid environment." Irrig. Sci., 26, 253-259.
[11] Sabziparvar, A. A., and Tabari, H. (2010). "Regional Estimation of Reference Evapotranspiration in Arid and Semiarid Regions." J. Irrig. Drain. Eng., 136(10), 724–731.
[12] Salako, F. K. (2008). "Estimation of Evapotranspiration with FAO-56 Penman-Monteith equation for three Agroecological zones of Nigeria." ASSET, an International Journal, 8(2), 134-149.
[13] Sentelhas, P. C., Gillespie, T. J., and Santos, E. A. (2010). "Evaluation of FAO Penman –Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada." Agric. Water Manag., 97(5), 635–644.
[14] De Martonne, Emmanuel. 1926. A~"me et lnc:Uce artldite. Comptel Rendus de L'Acad. BeL, Paris 182: 1396-1398.
[15] Rivas, R., & Caselles, V. (2004). A simplified equation to estimate spatial reference evaporation from remote sensing-based surface temperature and local meteorological data. Remote Sensing of Environment, 83, 68−76
[16] Hofwegen van, P., Svensen, M., 2000. A Vision of Water for Food and Rural Development. World Water Council (sector division documents)