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RESEARCH PAPER

The effect of reference and crop evapotranspiration occurrence probability level on irrigation hydro-module (case study: Urmia, Iran)

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Key words: Evapotranspiration, Cropping Pattern, FAO Penman-Monteith, Hargreaves-Samani, Occurrence Probability.

Abstract

Evapotranspiration is a probable parameter. Thus, true estimation of plant evapotranspiration with certain probability level has an important role in agricultural water management. In this research, 24 years of meteorological data of Urmia synoptic station were used to compute reference and crop evapotranspiration. In order to investigate the effect of ET_o calculation method on its value and cropping pattern water requirement (CPWR), FAO Penman-Monteith (FPM) and Hargreaves-Samani (H-S) methods were selected. The daily ET_o values at different probability levels for each method were calculated. Based on dominant cropping pattern in region, wheat, apple and fine vegetables were chosen. Values of cropping pattern evapotranspiration were calculated on two methods: 1) 50% probability level for all the crops and 2) recommended probability levels (50% for wheat, 75% for apple and 90% for vegetables). Considering cropping pattern: wheat: 40%, apple: 30% and vegetables: 30%, and irrigation efficiency: 40%; the results showed that the values of CPWR on recommended probability level at irrigation intervals of 5 and 7 days in FPM method were 1.7 and 2.3 (lit/s/ha) which were 14% and 13% greater than 50% probability level, respectively. For the H-S method, the same values were 0.7 and 0.9 lit/s/ha (8% and 7%), respectively. The results showed that on 50% probability level and 5 and 7 days irrigation intervals the CPWR values for FPM method, were 2.3 and 3.1 (lit/s/ha) which were 21% and 21% greater than the same values from H-S method, respectively. For recommended levels, these values were 3.3 and 4.5 (lit/s/ha).

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Introduction

Crop evapotranspiration is one of the most important parameters in the hydrologic cycle. Evapotranspiration affects soil moisture condition and crop water requirement (Liang *et al.,* 2010). Accurate prediction of a crop evapotranspiration (ET_{crop}) has an essential role in agricultural water management especially in arid and semi-arid areas such as Iran (Dinpashoh, 2006). Whereas value and intensity of evapotranspiration affects moisture availability for crops, it plays an important role in water balance in agriculture (Petrone *et al.,* 2006). Also, crop growth and its yield depend on the evapotranspiration at crop growth period. Inaccurate estimation of evapotranspiration can lead to water stress and decreasing of crop yield in the case of less estimation or water loss in the case of more estimation (Shujiang *et al.,* 2009). Reaching to the actual evapotranspiration for a crop cover practically is very difficult, so, at first, reference evapotranspiration is calculated and, then, using it, crop evapotranspiration is estimated. Reference evapotranspiration is defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m (4.72 in), a fixed surface resistance of 70 s m^{-1} and an albedo coefficient of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground (Allen *et al.,* 1998). Taking into account the above explanations, it is concluded that accurate estimation of reference evapotranspiration is required for efficient irrigation scheduling, determination of channels capacity and correct optimum use of water resources (Dinpashoh, 2006). Lysimeters, Bowen ratio and energy balance methods are presently the most common methods for ET estimating, but they are very costly and complex (Gavilan and Castillo, 2009). Therefore, for reference evapotranspiration estimation, many empirical methods have been suggested which require recorded meteorological data. Considering multiplicity of presented relationships for reference evapotranspiration estimation, the existence of an accurate and standard method was sensed (Martinez and Tejero, 2004). Based on the results obtained from researches conducted all over the world, the superiority of FAO Penman–Monteith equation has been accepted as a standard method (Gavilan *et al.,* 2006). Evapotranspiration is a probable parameter and follows from statistical distributions. Common probability distribution that evapotranspiration data is fitted is known as normal distribution (Karamouz *et al.,* 2003; Alizadeh, 2004). Therefore at irrigation systems design, it is better to use evapotranspiration on a certain probability level. Effective factors on selection of evapotranspiration occurrence probability level for irrigation systems design are: crop type, soil texture and farmer risk. For valuable or less root zone depth crops, has been recommended using ET_0 values with 80% or 90% occurrence probability level (Jensen *et al.,* 1990). Also, for coarse texture soils which have less moisture retention capacity, ET_0 with more occurrence probability level has been suggested to be used (Wright and Jensen, 1972). The adoption of risk percentage by farmer is effective in selection of daily ET_0 occurrence probability level in irrigation systems design. For example, while an irrigation system is designed based on ET_0 with 90% occurrence probability level, in fact, farmer has accepted 10% risk. In other words, in this case, during 10 years of cultivation, there is one year when the yield in is less than the expected yield (Cuenca, 1989).

Pruitt *et al.,* (1972) for central California region, Nixon *et al.,* (1972) for coastal California region and Wright and Jensen (1972) for Kimberly region extracted daily ET_0 distribution curves with different occurrence probability. In Iran, evapotranspiration with different occurrence probabilities in Gorgan was calculated by FAO Penman–Monteith, Hargreaves-Samani and Jensen-Haise methods and then their values were compared to each other (Nikbakht and Sharifan, 2008). The results indicated the increase of occurrence probability level effect on ET_0 values. In their research, Hargreaves-Samani (H-S) and Jensen-Haise (J-H) methods estimated ET_0 more than FPM method at the same probabilities levels. In another research, crop evapotranspiration (ET_C) was calculated at different probability levels in Maragheh in Iran (Nikbakht *et al.,* 2007). Their findings showed that there was a difference in daily ET_C average at different average periods with different occurrence probability levels.

A simple simulation model for the design of microcatchment water harvesting systems for rain-fed tree cultures was developed based on the probability of annual rainfall and yearly ET_a. In this model the Type III Pearson distribution and Penman-FAO ET_0 was used to estimate the amount of actual evapotranspiration for different probabilities of occurrence. They results indicated that with 50 % probability of annual rainfall and yearly ET_a, the microcatchment area was estimated to be about 8.7 m^2 (Fooladmand and Sepaskhah, 2006).

Evapotranspiration and regional probabilities of soil moisture stress in rainfed crops included sorghum, pulses (mung bean, chickpea, soybean, pigeonpea) and oilseeds (safflower and sunflower), over the Krishna River basin in southern India (258,948 km^2) was mapped at 0.5° resolution. The results maps of soil moisture stress provided the basis for estimating the probability of drought and the benefits of supplemental irrigation (Biggs *et al.,* 2008).

Precipitation management under rice based rainfed cropping system was studied by in Varanasi district of Eastern Uttar Pradesh based on gamma probability, initial and conditional probability, probability of consecutive dry spells and wet spells, rainy days and weekly water balance. Through technical interventions like adoption of deep rooted crop (e.g. chickpea) or little drought tolerance genotypes accompanied with in-situ water harvesting plus provision for life saving irrigation may lead to efficient management under rainfed conditions (singh *et al.,* 2013).

Accurate estimation of crop water requirement is the basic step for designing and scheduling of irrigation and drainage projects. Evapotranspiration (ET) is a stochastic variable, therefore to reduce the risk level, it is needed to select and use proper evapotranspiration probability levels.

A comprehensive review of the related literature indicates that the effect of crop evapotranspiration occurrence probability level on irrigation hydro-module of dominant cropping pattern has not been investigated. With regard to importance of hydro-module in irrigation channels design and capacity of irrigation networks, it is an important factor to investigate for this region. Careless estimation and calculation of this factor leads to heavy damages to the irrigation facilities and channels.

Major research in association with evapotranspiration uncertainty, were conducted for reference crop. In this research uncertainty of evapotranspiration was done for cropping pattern evapotranspiration and cropping pattern hydro-module. More over in this, research two estimation methods of evapotranspiration includes: FPM and H-S were compared. Beside case study in this study was considered in a semi-arid region.

Materials and methods

Evapotranspiration models

In this research, hydro-module was calculated by two methods. The first method was to use the average of meteorological data in reference evapotranspiration calculations. The second method was the determination of reference evapotranspiration with recommended probabilities levels at references and using it for calculation of cropping pattern hydro-module. To investigate the effect of ET_0 calculation method on hydro-module, two methods of FPM as standard method (equation 1) and Hargreaves-Samani (H-S) (equation 2) were used. The latter method needs a few meteorological data.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{(T+273)} u_2(e_a - e_d)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where ET_0 is reference evapotranspiration (mm/day), Δ is slope of the vapor pressure curve (kPa/°C), R_n is net radiation at the crop surface (MJ/m²/day), G is the soil heat flux density (MJ/m²/day), γ is the psychometric constant (kPa/°C), T is the average of daily air temperature (°C), u_2 is the wind speed at 2 m height above the ground surface (m/s), $[e_a - e_d]$ indicates saturation air vapor pressure deficit (kPa), 900 coefficient for reference crop (kg°k/kJ/day) and 0.34 stands for wind coefficient for reference crop (s/m) (Allen *et al.,* 1998).

$$ET_0 = 0.0023 R_a (T_{mean} + 17.8) TD^{0.5} \quad (2)$$

Where ET_0 is reference evapotranspiration (mm/day), R_a indicates Extraterrestrial radiation (MJ/m²/day), T_{mean} refers to daily temperature average (°C), TD shows difference of daily maximum and minimum temperature (°C) (Hargreaves, 1994).

Study area

In this study, to calculate the reference evapotranspiration, daily recorded meteorology data of Urmia airport synoptic station were used. This station has a longitude of 45°5', latitude of 37°32' and with elevation about 1313 m. Table 1 shows the long-term average of meteorological parameters of Urmia synoptic station.

Table 1. Climatological characteristics of Urmia synoptic station.

Applied statistical period	1985 to 2008 (24 years)
Average of daily minimum temperature (°C)	5.1
Average of daily maximum temperature (°C)	17.6
Average of daily temperature (°C)	11.4
Average of relative humidity (%)	59
Average of daily sunshine (hr)	7.9
Wind speed average at height of 2 m (km/hr)	22

Assumptions and structure of calculation

In this research, first, daily ET_0 with different probabilities levels was calculated by FPM and H-S methods. To determine daily ET_0 with different probability levels, daily ET_0 for all the days of statistical period (24 years) were calculated. Then, daily ET_0 for each Julian day were separated. Therefore, for each Julian day, 24 numbers were calculated. Amounts of average and standard deviation for data's of each day were calculated. Using normal distribution relationship (equation 3), daily ET_0 with different probability levels for all the days throughout the year was obtained.

$$X = \overline{X} + K.S \quad (3)$$

Where X is random variable amount (reference evapotranspiration) with different occurrence probability, $\overline{X}$ stands for sample average, S is the sample standard deviation and K is the abundance coefficient of normal distribution that depend on random variable occurrence probability (reference evapotranspiration) (Karamouz *et al.,* 2003; Alizadeh, 1995).

Daily ET_0 annual distribution diagram in different occurrence probability levels were drown. Then, through relationship 4, daily ET_c of cropping pattern with different probabilities levels was determined.

$$ET_c = ET_0 \times K_c \quad (4)$$

Where ET_c is crop evapotranspiration (mm/day), ET_0 is reference evapotranspiration (mm/day) and K_c is the crop coefficient.

To calculate ET_c for the area under study, it was necessary to choose the cropping pattern. To determine the cropping pattern, the information was obtained from Agriculture Jihad Organization of West Azerbaijan province. Based on the existing information, wheat (from cereal family), apple (from trees family) and fine vegetables (from vegetable family), were chosen as the cropping pattern. Dates of implant, removal and crop density of tillage pattern crops are presented in Table 2.

Table 2. Planting date, harvesting date and crop density of cropping pattern.

Crop	Planting date	harvesting date	Crop density (%)
wheat	Third decade of October	Third decade of June	40
Apple *	second decade of April	Third decade of September	30
fine vegetables	Third decade of March	Third decade of June	30

* Planting date of apple is beginning of growth period

Tables 3 and 4 show the length of growth period and crop coefficient of crops, respectively. Based on FAO recommendation, after extracting of $K_{C\text{-}Mid}$ and $K_{C\text{-}End}$ amounts, their amount should be corrected with attention to region meteorological information through relationships 5 and 6 (Allen *et al.,* 1998).

Table 3. Different stages length of Growth period: Each tillage pattern crop shown (day) (Allen *et al.,* 1998).

Crop	Initial stage	Second stage	Third stage	fourth stage	Total
wheat	30	140	40	30	240
Apple	20	60	80	20	180
fine vegetables	20	30	40	10	100

Table 4. Amounts of crop coefficient and maximum crop height (Allen *et al.,* 1998).

Crop name	$K_{C\text{-}Ini}$	$K_{C\text{-}Mid}$	$K_{C\text{-}End}$	Maximum crop height (h) (m)
Wheat	0.4	1.15	0.4	1.0
Apple	0.45	0.95	0.7	4.0
fine vegetables	0.7	1.05	0.95	0.3

$$K_{C-mid} = K_{C-Mid-table} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)][\frac{h}{3}]^{0.3} \quad (5)$$

$$K_{C-end} = K_{C-End-table} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)][\frac{h}{3}]^{0.3} \quad (6)$$

Where $K_{C\text{-}Mid\text{-}table}$ stands for crop coefficient for mid-season growth stage, $K_{C\text{-}End\text{-}table}$ shows crop coefficient for end point of end-season growth stage, h *is* maximum crop height (m), u_2 shows wind speed at height of 2 m (m/s), RH_{min} is the minimum relative humidity (%) (Allen *et al.,* 1998). To determine cropping pattern hydro-module in growth period length, crop water requirement was calculated in two states. First, using equation 4, with multiplying corrected amounts of K_C to ET_0 with 50% probability level, ET_C for each of tillage pattern crops with 50% probability level were estimated. The reason of this state application is to use long-term average of meteorological data in irrigation network design in usual. In this condition, probability level of ET_0 will be 50% (Nikbakh *et al.,* 2007). Second, in line with the recommendations made by Jensen *et al.*, (1990) and Cuenca *et al.*, (1992), ET_C of wheat, apple and fine vegetables were calculated with probability levels of 50%, 75% and 90%, respectively.

To investigate the effect of frequency length on the hydro-module, it was calculated for 3, 5, 7 and 10 days frequency periods. To this end, using obtained ET_C at previous stages, daily ET_C average of 3, 5, 7 and 10 days frequency periods for each of cropping pattern with 50% and recommended probability levels were calculated. Then, by viewpoint of crop density of crops at cropping pattern and 40% efficiency for surface irrigation in region, irrigation hydro-module for different frequency periods were calculated.

Results and discussion

Occurrence probability levels of evapotranspiration

Fig.1 shows daily ET_o distribution curves (calculated by FPM method) at different occurrence probability levels includes: 99, 95, 90, 75, 50 and 25 percent. In the Fig. 2 the daily ET_o distribution was compared together for the different occurrence probability levels by FPM method.

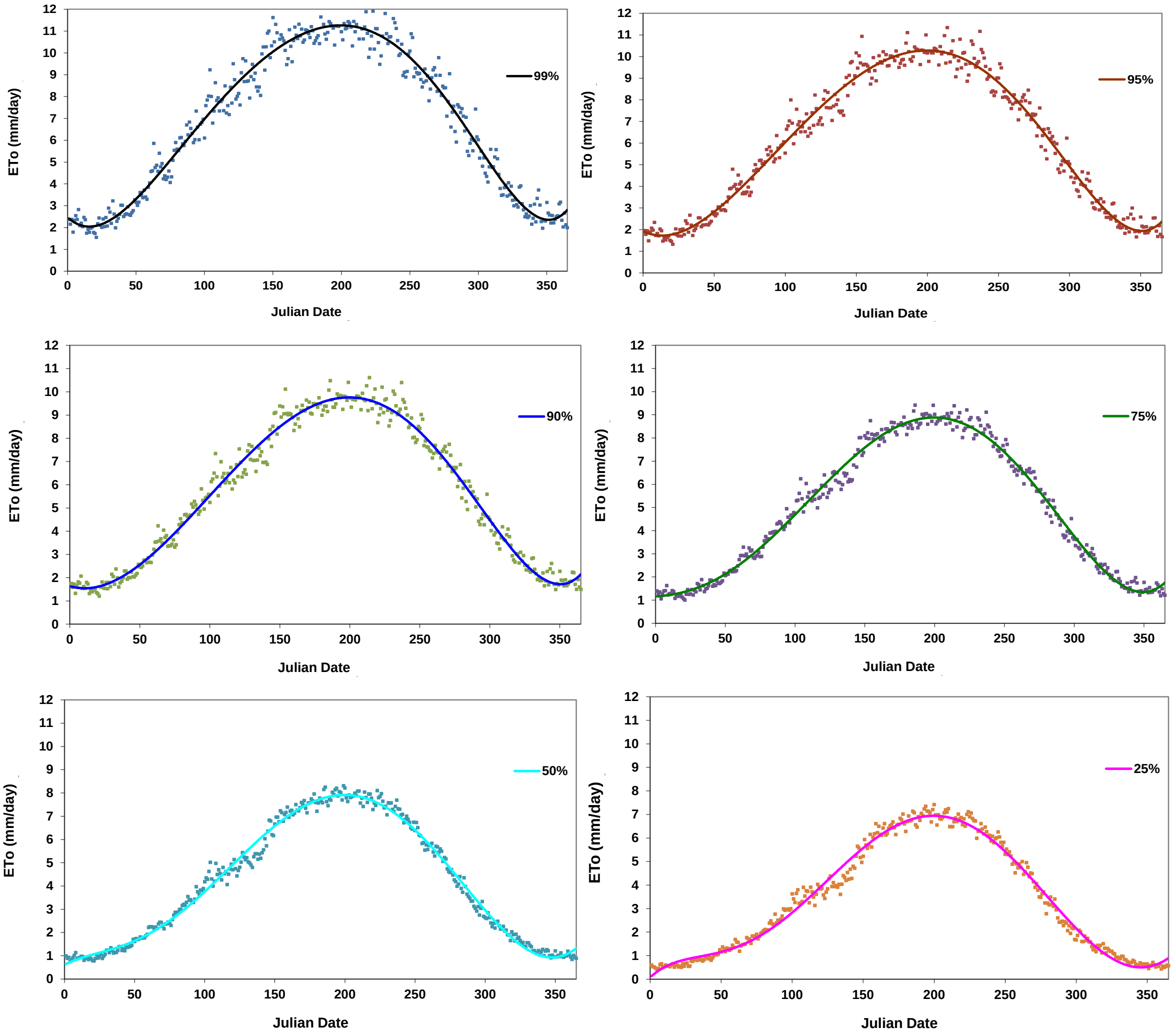

Fig.1. Daily ET_o distribution curves (calculated by FPM method) for different occurrence probability levels.

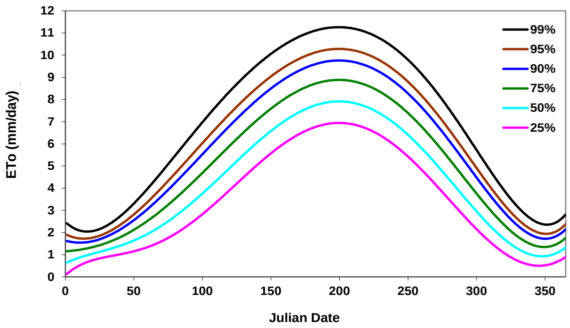

Fig. 2. Comparison of daily ET_o distribution that calculated by FPM method for different occurrence probability levels.

The same procedure was repeated to calculate daily ET_o by H-S method. Fig. 3 shows daily ET_o distribution curves for 99, 95, 90, 75, 50 and 25 percent occurrence probability levels that calculated by H-S method. Comparison of daily ET_o distribution that calculated by H-S method for different occurrence probability levels was presented in Fig. 4.

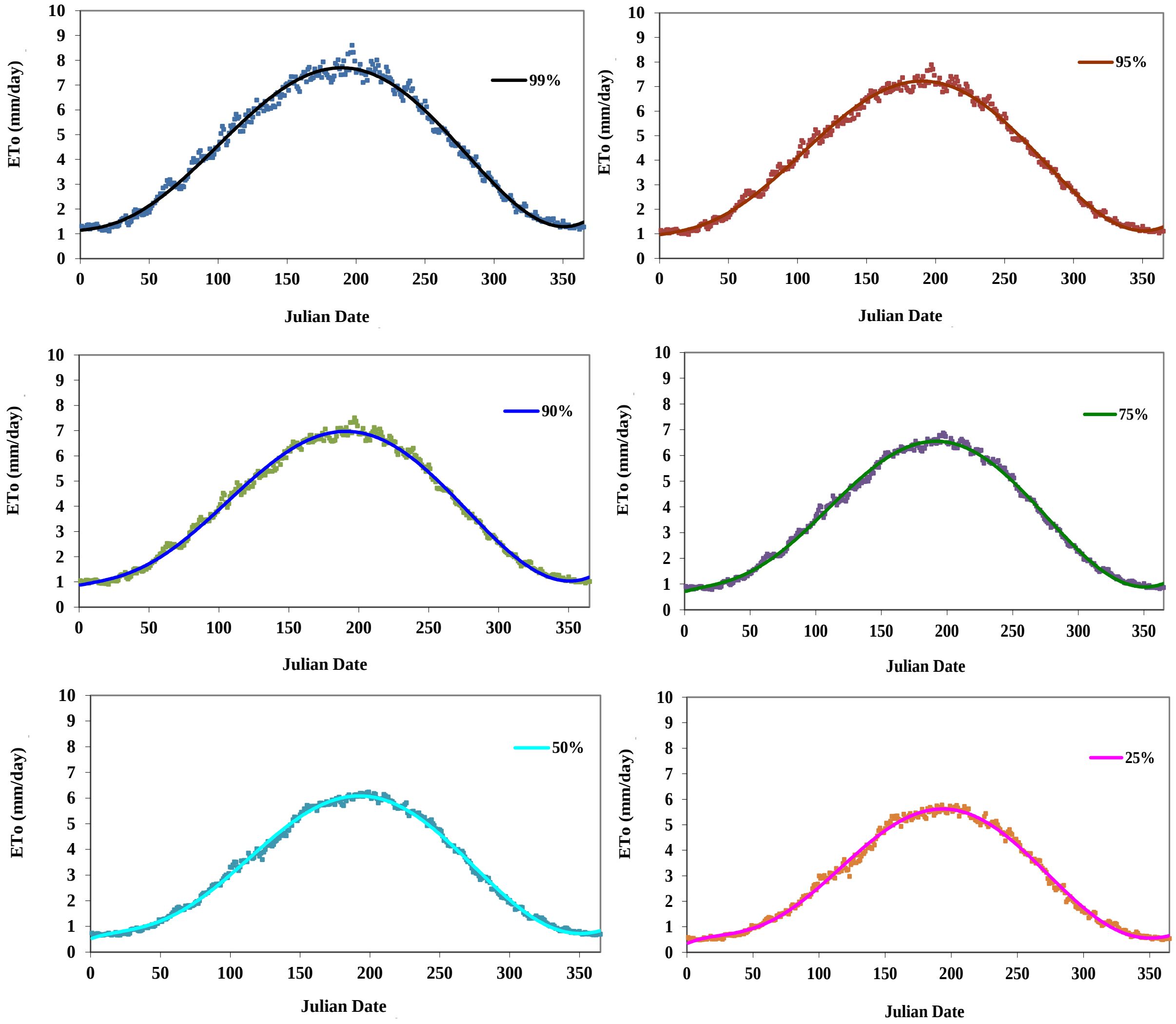

Fig 3. Daily ET$_o$ distribution curve (calculated by H-S method) for different occurrence probability levels.

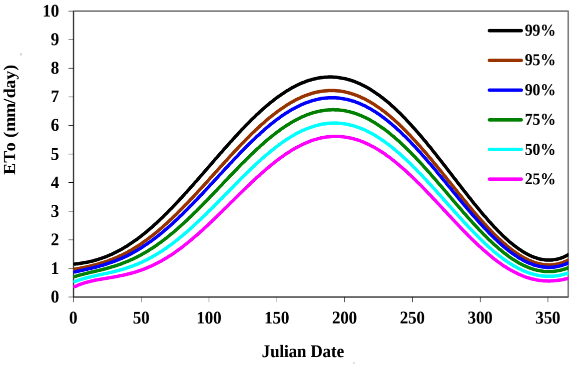

Fig. 4. Comparison of daily ET$_o$ distribution that calculated by H-S method for different occurrence probability levels.

Based on Sharifan and Alizadeh (2009) results, Jensen-Haise (J-H) method overestimate ET$_c$ compare to Hargreaves-Samany (H-S) method. The difference was more in 3 days period of irrigation than 5 days period. Also for wheat and barley H-S method estimated higher value of ET$_c$ compared with J-H method. Based results of this research, amount of ET$_c$ by FPM method were more than by H-S method for all crops.

Also Similar to other research by increasing the probability level, the difference between calculated ET$_c$ by FPM and H-S decreased significantly.

Hydro-module of cropping pattern

Table 5 shows the maximum daily hydro-module in growth period length of cropping pattern and daily ET$_c$ of cropping pattern corresponding to maximum hydro-module. The data presented in this table were calculated with reference to crop density and 40% irrigation efficiency (presented by Agriculture Jihad Organization) using FPM and H-S methods. Table 6 shows the maximum calculated hydro-module amounts in growth period length of tillage pattern crops.

Table 5. Daily ET_c amounts and hydro-module of tillage pattern crops for different probability levels.

Crop	ET_c by FPM method		ET_c by H-S method	
	Probability level		Probability level	
	50%	Recommended	50%	Recommended
Wheat	3.1	3.1	2.4	2.4
Apple	2.0	2.4	1.6	1.6
Fine vegetables	2.6	3.6	2.0	2.3
Hydro-module	2.2	2.6	1.7	1.8

Table 6. Maximum calculated hydro-module amounts in growth period length.

ET_0 calculation method	Probability level	Irrigation interval			
		3 days	5 days	7 days	10 days
FPM method	50%	6.4	10.7	14.9	21.3
	Recommended	7.5	12.4	17.2	24.4
H-S method	50%	5.1	8.4	11.8	16.9
	Recommended	5.5	9.1	12.7	18.1

Table 7 shows the difference of hydro-module with 50% and recommended probability level at different irrigation interval in FPM and H-S methods. For example, it can be seen from Table 7 that at 5 days irrigation interval, irrigation channel capacity in FPM with respect to recommended probability level 14% has been increased to 50% probability level. The same value for H-S method is 8%.

Table 7. Difference of maximum amounts of tillage pattern hydro-module at recommended probability level into 50%.

Irrigation interval	FPM method		H-S method	
	(lit/s/ha)	(%)	(lit/s/ha)	(%)
1 day	0.4	15	0.1	6
3 days	1.1	15	0.4	7
5 days	1.7	14	0.7	8
7 days	2.3	13	0.9	7
10 days	3.1	13	1.2	7

This state leads to increase irrigation channel capacity and their executive costs, but system risk decreases and prevents creating economic and social damages.

The effect of ET_0 calculation method on hydro-module values at the same probability levels is shown in tables 5 and 6. Table 8 shows the difference of maximum calculated hydro-module values at probability levels of 50% and recommended with FPM and H-S methods. Based on results summarized in Table 8, maximum hydro-module values by H-S method were less than FPM method at 50% and recommended probability levels. For example, at 50% probability level and 7 days irrigation interval, the maximum hydro-module difference of FPM method with H-S method was 3.1(lit/s/ha) and the same value at recommended probability level was 4.5 (lit/s/ha).

Table 8. Difference of maximum calculated hydro-module amounts by FPM method into H-S method at different probability levels.

Irrigation interval	50% probability Level		Recommended probability level	
	(lit/s/ha)	(%)	(lit/s/ha)	(%)
1 day	0.5	23	0.8	31
3 days	1.3	20	2.0	27
5 days	2.3	21	3.3	27
7 days	3.1	21	4.5	26
10 days	4.4	21	6.3	26

Considering the results obtained from this study, one can come to the conclusion that, 1: To decrease the risk at irrigation system, using recommended

probability levels in calculating hydro-module is suitable, 2: In case of existing of sufficient meteorological data, the use of FPM method is preferred.
The results of Fooladmand and Sepaskhah (2006), showed that the amounts of ET_a for grape vine during the growing season and whole year of the years 1984-1987 were 373 and 496 mm and varied between the ranges determined for probabilities of occurrence of 90 to 10 %. Also they suggested, 50 % probability of yearly ET_a is the most appropriate situation for building squared microcatchments, which is in agreement with the vine spacing (3 m × 3 m) that local farmers use in the Bajgah area.

Based on previous research, FPM is the standard method of estimating reference evapotranspiration and cropping pattern hydro-module in this region and the values of FPM method for hydro-module is recommended.

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