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ORIGINAL ARTICLE

Evaluating Different Estimation methods of reference evapotranspiration with FAO Evaporation pan in both dry and Humid Climate of Caspian Sea Basin

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ABSTRACT
Estimation of reference evapotranspiration to estimate water needs, management of water project and drainage and time of watering plants are necessary in agricultural section. In this study to find best estimation model of reference evapotranspiration for Caspian Sea basin with both dry and humid climate using information of 264 climatologic stations, pluviometers and evaporation gauges, reference evapotranspiration resulted from evaporation pan is evaluated and compared with evapotranspiration derived from 8 evapotranspiration equations based on statistical parameters ,NRMSE, MAE, MBE, d, t, r. According to resulted outcome, methods of FAO-24 Blaney-Criddl, radiation FAO-24, Hargreavez -Samani, Turc 1961 and Makkink with regard to different time dimensions have best adjustment with reference evapotranspiration. The result shows in season scale in dry climate there is the least error (30%) in summer and with the most error of estimation (51%) in winter and in this time scale in humid climate in spring there is the least error (36%) and in winter with the most error of estimation(50%). In general month scale has less error than season scale. This result shows reduction in error estimation in little time scale.
Key words: *FAO-24 Blaney- Criddle, radiation FAO, Hargreavez-Samani, Turc, Makkink*

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INTRODUCTION

Growing population, needing to more food and use of limited water resources and soil reveals stability in agriculture development in climatic condition of Iran. So with regard to importance of agricultural section and used water in this section, determining need of water as one of Hydrology cycle is fundamental necessity in watering and drainage project. Estimation of potential evapotranspiration (ET_0) for levels of plants in order to water and increase function of agricultural products is necessary to determine water needs of plants. Evapotranspiration is an important component in water-balance and irrigation scheduling models[14]. Potential evapotranspiration is equal to maximum evapotranspiration from extensive plant covering without water limitation such as grass in one weather condition [7]. Different methods including methods of lysimeter are suggested in direct methods for measuring evapotranspiration. But use of lysimeter with spending a lot of money and time for the sake of taking data from them in all regions is not possible. So researchers try to use indirect methods of estimation ET_0 from evaporation pan or some climatologic data. Sing and colleagues evaluate estimation models ET_0 with evaporation pan in costal station of research center for potato cultivation in Canada [26]. Results suggest that model of evaporation pan estimates less ET_0 than relations of Penman-Monteith and Priestley-Taylor. Trajokovich and kolakovich [25] in Italy evaluate evaporationpan-based methods of simplification credit directly for estimation of ET_0 without needing to relative humid data and wind speed. In this study pan-based equations are compared with daily data of lysimeter (grass plant).In this study the success of Schneider equation in ET_0 estimation against Penman-Monteith equation is reported.

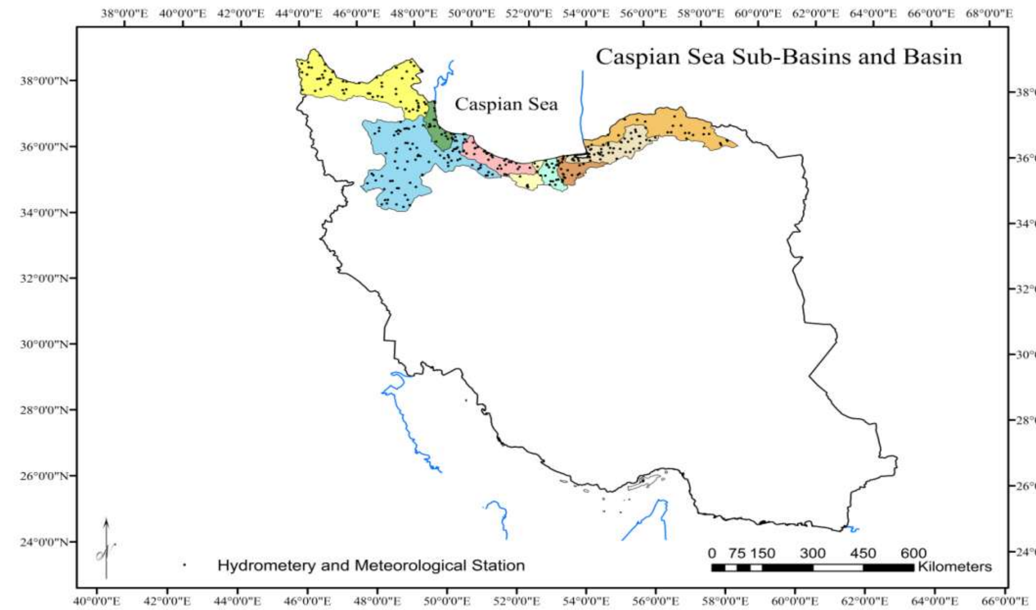
In 2012 Kaya Sebahtin and colleagues [18] in Egdir region of Turkey evaluate potential evapotranspiration of estimation with different equation of evaporation pan in comparison to FAO-

Panman-Monteith equation and report the superiority of Schneider methods. Yearly estimation of potential evapotranspiration based on two methods of Thornthwaite and Blaney-Criddle in Baluchistan region shows that method of Thornthwaite does not produce correct results for different seasons, but Blaney-Criddle method has good correlation with direct measurement (pan)[13]. Jahanbakhsh-asl and his colleagues [15] by using 20 years of long term statistics of Tabriz climatologic station evaluate potential evapotranspiration by use of combined, temperature, radiation, multi-correlation, and humid methods and compare by evaporation pan method. Their results show that Christian-Hargreavez method has better conformity in comparison to evaporation pan method. Shafiee-fasghandis and colleagues [21] evaluate estimation model of potential evapotranspiration for Ahar region against monthly potential evapotranspiration resulted from evaporation pan. According to resulted outcome appeared that methods of Turc, Thornthwaite, Christensen, Hargreavez and Blaney-Criddle after applying revised coefficienthave best adjustment with monthly ET_0 resulted from evaporation pan. Shahin-zadeh and colleagues [22] assess and compare potential evapotranspiration of Hofel region in Khuzestan province according to revised Blaney-Criddle methods, Penman-Monteith, Thornthwaite and evaporation pan. Attained results suggest that evaporation pan has more correlation coefficient with reference method of Penman-Monteith than other methods and priority of other methods against Penman-Monteith was Thornthwaite and Blaney-Criddl respectively.Karimi-koghary and Rezaee [17] estimate reference cropevapotranspiration and compare it with evaporation pan and state that there is high correlation coefficient between evapotranspiration resulted from method of Penman-Monteith and evaporation pan. Assessing resource represents importance of estimation of evapotranspiration with the least available data. Hence in this research methods of calculating evapotranspiration are evaluated and compared according to climatologic data and evapotranspiration resulted from evaporation pan.

MATERIALS AND METHODS

Geographical limit of basin

Studied region is one of five basins in north of Iran that its space is 172122.25 km^2 being 10 percent land of all country, located between meridians 44° 05' 00" E and 59° 00' 00" E ,and Parallel of latitude 35° 00' 00" N and 39° 45' 00". Highest point of this basin is Damavand summit with 5671m height and lowest point is coast of Caspian Sea with -29m height, thus height difference in this basin is estimated 5700m. above-mentioned basin includes 9 sub-basins including Aras (38578.75km^2), Atrak(25100km^2), Gorganrood (14119km^2), Sefidrood (60015km^2), Chalos(10407km^2), Neka-Tajan(7002.5km^2), Talesh-Anzali(6992.5km^2), Talar-Babelrood(5130km^2), and Haraz (4777.5 km^2). This basin is restricted from north to Turkmenistan, Azerbaijan, Armenia, from east to basin of ghare-ghom, from south to basins of Oman Sea and Persian Gulf and center and from the west to Oromeieh basin and Turkey. Figure 1 shows position of Caspian Sea basin along with dispersed stations based in this basin and figure 2 shows climatic regions of this basin according to classification method of De Martonne.



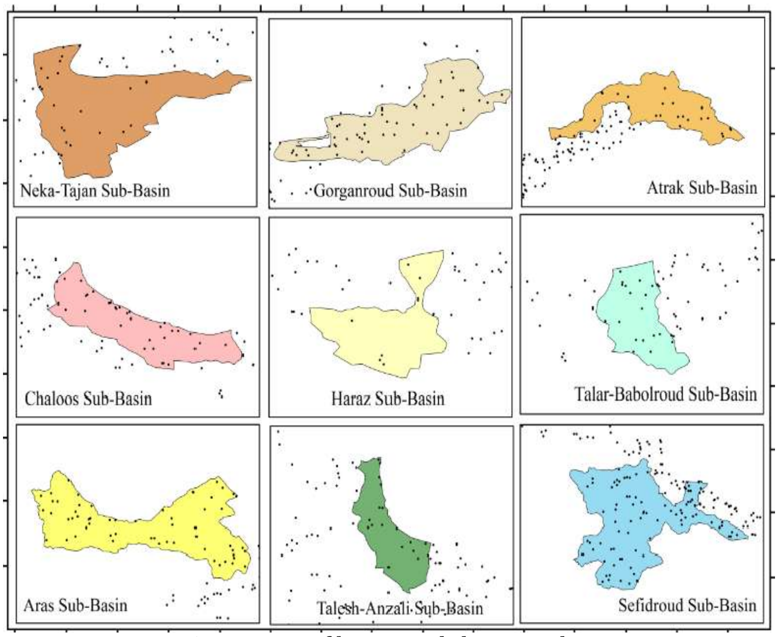


Figure1.Position of basin and their used stations

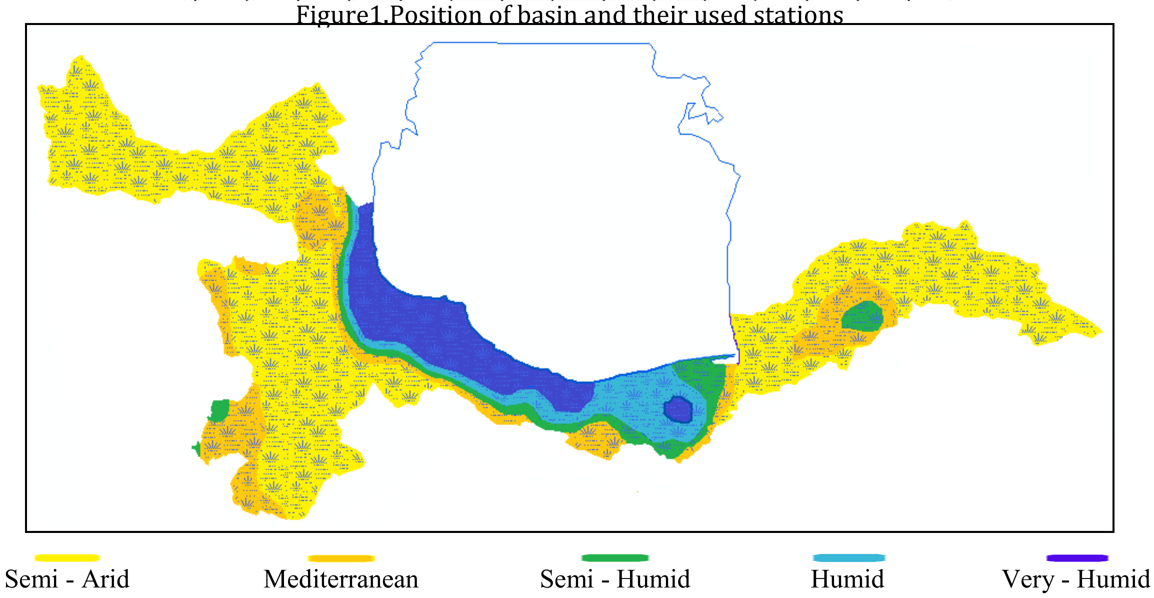


Figure2. climate Zonations of basin according to De Martonne method.

In general in this study information of 253 stations (150 stations in semi-Arid region and 114 stations in Mediterranean region till very humid) is selected from establishment to 2009. climatologic variables employed in this study are the minimum temperature, maximum temperature, average temperature, maximum-minimum-average relative humidity, daily wet temperature, daily dry temperature, daily dewpoint temperature, daily average wind speed in 2m height, data of evaporation pan, sunshine and monthly precipitation.In this basin in both regions maximum and minimum temperature, sunshine, and evaporation from pan occur in January and August respectively, in arid region relative minimum and maximum humidity in August and January and in humid climatic region in August and December respectively, minimum and maximum sunshine in dry region in January and August and in humid region minimum and maximum in December and June respectively, the least precipitation in both regions in August and maximum in dry region in May and in humid region in December, wind speed in dry region minimum in November and maximum in July and in humid region minimum in October and maximum in April. In dry climatic region changes domain in sun radiation, evaporation from pan and sunshine is more than humid region while changes domain of relative humidity and precipitation in humid region are more than other region. But change domain of temperature and wind speed in both regions is almost in the same condition. Changes in climatic parameters including temperature, sun radiation, evaporation from pan, precipitation, relative humidity and wind speed of regions based in the basin in figures (3 and 4) are depicted.After collecting data, assessing and controlling of data is done. To do this in every station every used parameter is assessed in congruity and normality, being in correct position, up and down extent, comparing with adjacent station and drawn diagram. Concerning deviated data, observation whose absolute value of standardized amount is bigger than 3, considered as deviated observation [9]. Also about coefficient of evaporation pan according to FAO journal, coefficient of evaporation pan bigger than one and evaporation from pan equal to zero are removed from data. Data processing is done by use of SPSS, Excel, Matlab, and Surfer software.

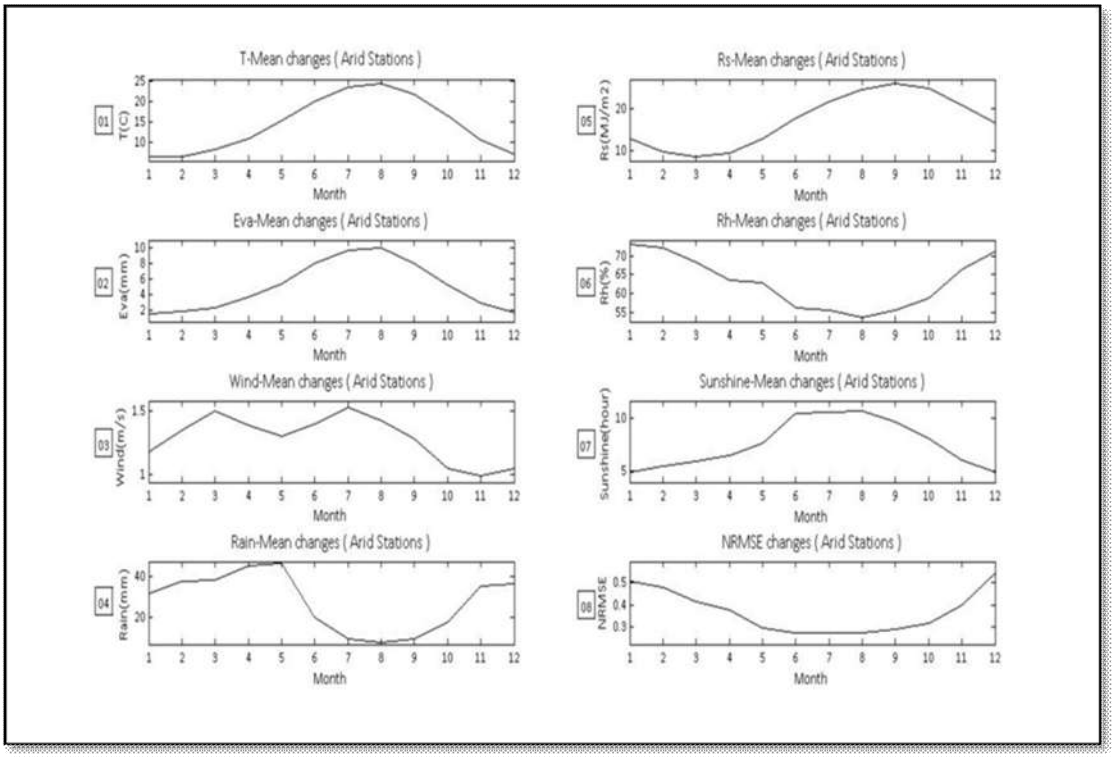


Figure 3: monthly changes of climatic parameters for arid region of Caspian Sea basin (1 ,2 ,3 ,4 ,5 ,6 ,7)-monthlyNRMSE changes (8).

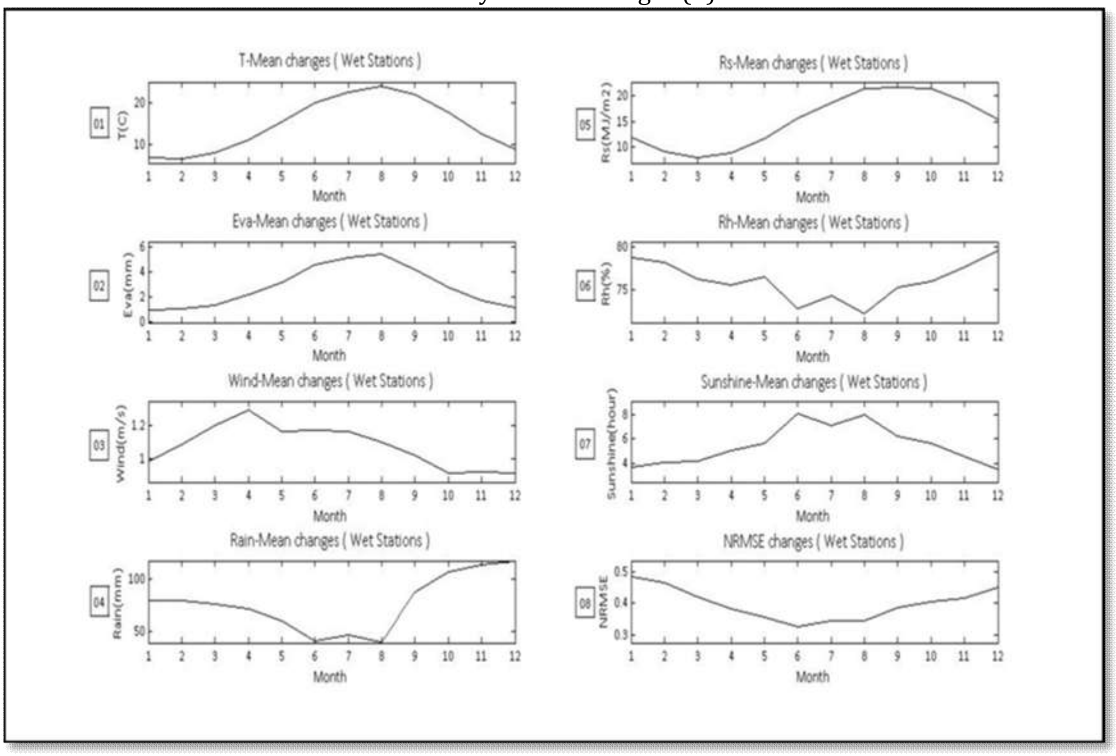


Figure 4: monthly changes of climatic parameters for humid region of Caspian Sea basin (1 ,2 ,3 ,4 ,5 ,6 ,7)-monthlyNRMSE changes (8).

Then amount of ET_o for every station by use of Ref-ET software is calculated. In this software calculating methods with regard to kinds of input (minimum temperature, maximum temperature, daily average temperature, relative minimum humidity, relative maximum humidity, daily relative average humidity, wind speed, rate of precipitation, height, and geographical coordinates of every station) include 7 combined methods based on Penman, two temperature methods, one radiation method and three combined radiation-temperature methods. In this study two combined method FAO-56 Penman-Monteith and Kimberly-Penman, two temperature methods of FAO-24 Blaney-Criddle and Hargreavez-Samani, three radiation-temperature methods including Priestley- Taylor, Makkink(1957) , Turc(1961) equations and FAO-24 radiation method are used. Finally method of FAO-24 of evaporation pan is used as calculating equation of $ET_\circ$. Every calculating methods are shown in table 1.

Table 1. Calculating methods of reference evapotranspiration and required parameters.

Equation Form	**Calculating Method Name ($ET_\circ$)**
$ET_\circ = k_p . E_{pan}$	FAO-24 of evaporation pan
$ET_\circ = 0.0023 R_n (T_{mean} + 17.8) T_D^{\ 0.5}$	Hargreavez-Samani
$ET_\circ = a + b[P(0.46T_{mean} + 8.13)]$	FAO-24 Blaney-Criddle
$ET_\circ = 0.61 \frac{\Delta}{\Delta + \gamma} . \frac{R_s}{2.45} - 0.12$	Makkink(1957)
$ET_\circ = a_T \times 0.013 \frac{T_{mean}}{T_{mean} + 15} \times \frac{23.8856 R_s + 50}{\lambda}$	Turc(1961)
$ET_\circ = 1.26 \frac{\Delta}{\Delta + \gamma} . \frac{R_n - G}{\lambda}$	Priestley- Taylor
$ET_\circ = \frac{0.408 \Delta (R_n - G) + \gamma (\frac{890}{T + 273}) [u_2 (e_a - e_d)]}{\Delta + \gamma (1 + 0.34 u_2)}$	FAO-56 Penman- Monteith
$ET_\circ = \frac{\Delta}{\Delta + \gamma} (R_n - G) + k_w \frac{\gamma}{\gamma + \Delta} (a_w + b_w u_2)(e_s - e_a) / \lambda$	Kimberly Penman(1982)
$ET_\circ = a + b \left(\frac{\Delta}{\Delta + \gamma} . R_s \right)$	FAO-24 radiation

Used parameter in their equation and unit measurement	
R_s : daily solar radiation ($\frac{MJ}{m^2.day}$)	K_p : coefficient of evaporation pan
$ET_\circ$: reference evapotranspiration ($\frac{mm}{day}$)	Δ : slop of the saturation vapor pressure temprature relationship($\frac{kp_a}{^oc}$)
γ : psychrometric constant ($\frac{kp_a}{^oc}$)	$e_a - e_d$: saturation vapor pressure deficit (kp_a)
P : atmospheric pressure (kp_a)	G : soil heat flux ($\frac{MJ}{m^2.day}$)
λ : latent heat of vaporization ($\frac{MJ}{kg}$)	k_w : stable coefficient equal to 6.43 for $ET_\circ$ in terms of mm/day
T_{mean} : mean daily air temprature ($^\circ c$)	$u2$: mean daily wind speed at 2-m height ($\frac{m}{s}$)
T_D : Difference between Minimum and maximum temprature ($^\circ c$)	R_{nl} : outgoing net longwave radiation ($\frac{MJ}{m^2.day}$)
R_n : net radiation (mm)	a_w , b_w : Empirical coefficient are according to primitive suggestion of Penman if wind speed is in terms of m/s, their numerical amounts are equal to unit and 0.537 respectively.
P : Average hour light in every day of desired month divided into total hour light of year then multiplied by 100	

Function statistics of models

To compare methods of $ET_\circ$ estimation, outcomes resulted from every method against evaporation pan method are drawn. Then mentioned methods are assessed and analyzed by taking regression between reference evapotranspiration obtained from every evapotranspiration method and evapotranspiration resulted from evaporation pan. *MAE, MBE, NRMSE, d, t* criteria [25] are applied in Analyzing result of

Pearson correlation coefficient (r), determining coefficient (R^2) and meaningful test of this statistic (relations from 1 to 5).

) 1

$$NRMSE = \frac{\sqrt{\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}}}{\overline{O}}$$

) 2

$$MAE = \frac{\sum_{i=1}^{N}\left|p_i - O_i\right|}{N}$$

) 3

$$d = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|)^2}$$

) 4

$$t = \sqrt{\frac{(N-1)MBE^2}{RMSE^2 - MBE^2}}$$

) 5

$$MBE = \frac{\sum_{i=1}^{N}(P_i - O_i)}{N}$$

In above mentioned relation, Pi: estimation of evapotranspiration, O_i: measured amount by evaporationpan, N: number of observation, $\overline{O}$: Average amount of measured evapotranspirationby evaporation pan, t: Jacovides index

Mentioned optimal state of statistic is as follow:

$RMSE \quad , MAE \quad , MBE \quad , t \rightarrow 0$

$d \, , r \rightarrow 1$

RESULT AND DISSECTION

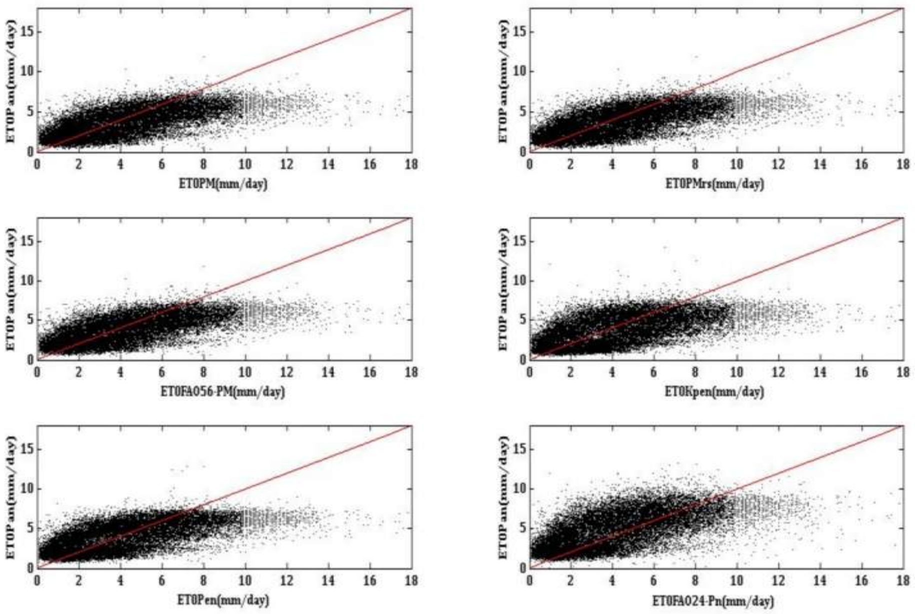
Assessing different estimation methods of evapotranspiration in dry region:

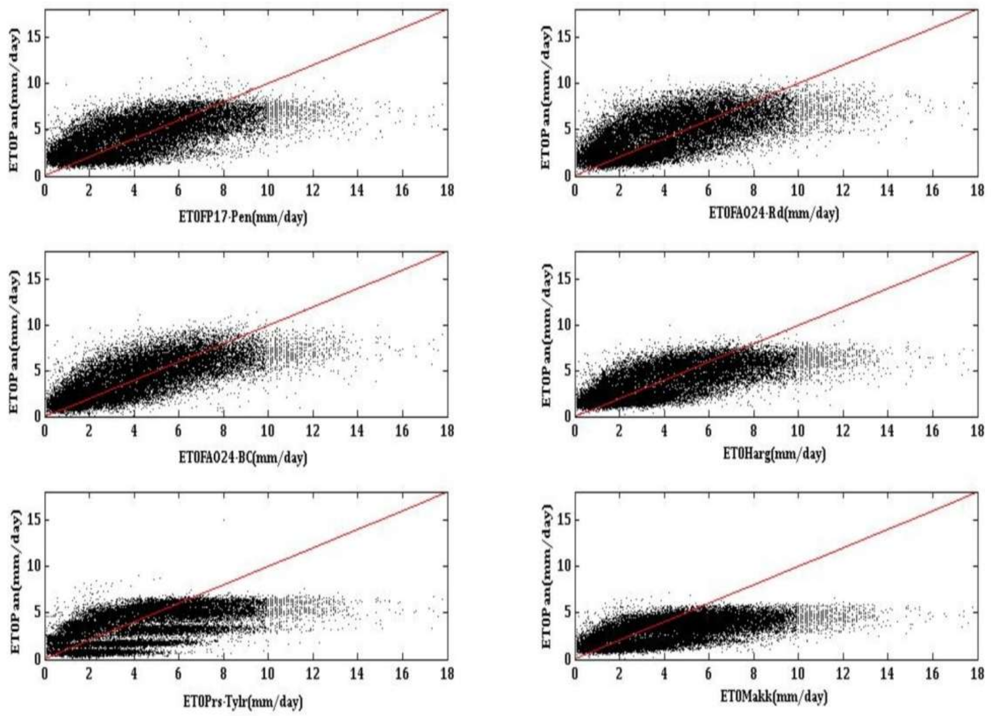
Assessing different estimation methods of evapotranspiration in dry region (150 stations) in three monthly, seasonal, and yearly scales in table 2 represent that in monthly scale, method of Blaney-Criddle has best adjustment with estimated evapotranspiration from pan evaporation. The least *NRMSE* error in June till August that is 0.27 has occurred that in this region has highest temperature. The result shows this point that in warm months in dry region estimated evapotranspiration by temperature methods are more trustful and has less error. The most error in January and December that the least temperature dominated the region is visible (*NRMSE*=0.51-0.55). Also figure (3-8) shows monthly changes of NRMSE according to amount of this statistics in table 2. The results of seasonal scale become convergent with monthly scale. As you see in table 2 with time movement from spring to winter, the amount of error increases. Hence the least error in summer and the most error in winter are considered. In six-month time scale, second six months of year that is warm period of year less error is seen and temperature method of Blaney-Criddl is good responsive for this time dimension. This method in yearly scale reveals estimation with 0.41 errors than evaporation pan. As table 2 shows in spring amount resulted from FAO radiational method, in autumn Hargreaves method and in yearly, and six-month time dimensions Blaney-Criddle method show high correlation coefficient with evapotranspiration resulted from evaporation pan. In other word in this region, methods of FAO radiation, Hargreavez temperature and Blaney-Criddle show good correlation coefficient with outcome resulted from pan evaporation. This suggests harmonious ups and downs in result diagram of these methods with available ups and downs in result method of evaporation pan and in this region spring and summer seasons show less domain of *NRMSE* (0.30 - 0.31) than autumn and winter(.42 - .51). Figure 5 shows outcome resulted from different estimation methods of reference evapotranspiration against outcome resulted from FAO evaporation pan.

Table 2: equations that have the most adjustment according to statistical parameters applied with reference evapotranspiration by method of FAO evaporation pan - Dry stations

Time	*ET0 Calculate Methods*	*r*	*NRMSE*	*MAE* (mm/day)	*MBE* (mm/day)	*d*	*t*
Jan	Turc-1961	0.4314	0.5071	0.3988	-4.59E-16	0.5416	2.59E-14
Feb	Turc-1961	0.4386	0.4806	0.3586	-2.27E-16	0.5493	1.34E-14
Mar	Turc-1961	0.4670	0.4175	0.3161	2.36E-16	0.5822	1.78E-14
Apr	FAO24-Rd	0.3071	0.3778	0.2954	2.58E-16	0.3936	3.25E-14
May	FAO24-Rd	0.3483	0.2955	0.2326	-3.89E-16	0.4426	6.71E-14
Jun	FAO24-BC	0.4032	0.2743	0.2142	2.90E-16	0.5070	5.42E-14
Jul	FAO24-BC	0.4612	0.2755	0.2185	2.79E-15	0.5746	5.21E-13

Aug	FAO24-BC	0.3922	0.2769	0.2205	8.76E-16	0.4996	1.62E-13
Sep	FAO24-BC	0.3891	0.2896	0.2319	8.73E-16	0.4941	1.55E-13
Oct	FAO24-BC	0.2510	0.3181	0.2543	-3.95E-16	0.3247	6.30E-14
Nov	FAO24-BC	0.2803	0.4010	0.3187	2.74E-16	0.3640	3.34E-14
Dec	Turc-1961	0.4301	0.5456	0.4164	1.25E-15	0.5504	8.60E-14
Spring	FAO24-Rd	0.7054	0.3124	0.2411	-9.50E-16	0.8092	2.63E-13
Summer	FAO24-BC	0.3645	0.3002	0.2379	-3.42E-15	0.4653	1.01E-12
Autumn	Harg-1985	0.6747	0.4193	0.3234	1.08E-15	0.7835	2.07E-13
Winter	Turc-1961	0.3365	0.5113	0.3960	3.80E-15	0.4322	3.80E-13
Half-Yearly (1)	FAO24-BC	0.6957	0.4502	0.3458	1.22E-15	0.8011	2.58E-13
Half-Yearly (2)	FAO24-BC	0.6774	0.3174	0.2455	-1.79E-16	0.7852	7.01E-14
Yearly	FAO24-BC	0.7310	0.4128	0.3222	-9.03E-15	0.8290	3.42E-12





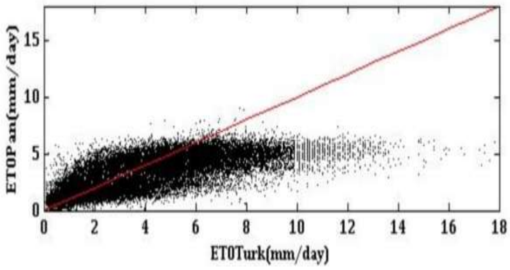


Figure 5: changes in different estimation methods of reference evapotranspiration (x) against estimation of reference evapotranspiration by method of FAO evaporation pan (y) - dry region

Assessing different estimation methods of evapotranspiration in humid region:

For this region of basin like dry region, assessing different estimation methods of evapotranspiration in stations with humid climate is done including 114 stations in three monthly, seasonal and yearly scales. Table 3 represents that in monthly scale of 24-FAO radiation method there is better adjustment with estimated evapotranspiration from pan evaporation. Little amount of NRMSE error in June, July, and August (0.34-0.31) has occurred that in this region like dry region, months with high temperature have little NRMSE. Also figure (4-8) shows monthly changes of NRMSE according to statistics in table 3. In seasonal scale as it is observed from table 3, in cold season of year (i.e. autumn and winter) amount of error increases. Hence in autumn error of NRMSE belongs to Makkink method and highest amount of error is for Blaney-Criddle in winter. But spring and summer show less error. In yearly scale it is observed that by increase in time dimension, amount of error increases. While in monthly scale amount of NRMSE is less. But if we look in the inserted correlation coefficient in table 2, in this region highest correlation coefficient is related to yearly time dimension, but in this region correlation coefficient is less than dry region and this suggest that available ups and downs in result diagram of evaporation pan haveless adjustment with Blaney- Criddle method. In this region like arid region, spring and summer have lesschange domain than autumn and winter. But in this region change domain are bigger than dry region. Figure 6 shows outcome resulted from different estimation methods of reference evapotranspiration against outcome resulted from FAO evaporation pan.

Table 3: equations that have the most adjustment according to statistical parameters appliedwith reference evapotranspiration by method of FAO evaporation pan - humid stations

Time	*ET0 Calculate Methods*	*r*	*NRMSE*	*MAE* (mm/day)	*MBE* (mm/day)	*d*	*t*
Jan	Turc-1961	0.3021	0.4746	0.3666	6.84E-16	0.3802	4.85E-14
Feb	Harg-1985	0.3292	0.4640	0.3577	2.57E-15	0.4253	1.87E-13
Mar	Harg-1985	0.5044	0.4190	0.3138	-2.09E-15	0.6218	1.71E-13
Apr	FAO24-Rd	0.3963	0.3777	0.2973	1.83E-15	0.5041	1.78E-13
May	FAO24-Rd	0.2644	0.3563	0.2806	-1.10E-15	0.3335	1.19E-13
Jun	FAO24-Rd	0.2923	0.3247	0.2539	-1.39E-15	0.3779	1.67E-13
Jul	FAO24-Rd	0.4429	0.3436	0.2645	7.76E-17	0.5586	8.79E-15
Aug	FAO24-Rd	0.4110	0.3418	0.2616	5.19E-16	0.5193	5.91E-14
Sep	FAO24-Rd	0.4974	0.3887	0.2982	3.08E-15	0.6117	3.07E-13
Oct	FAO24-Rd	0.3803	0.4069	0.3188	8.39E-16	0.4786	7.93E-14
Nov	Makk-1957	0.2828	0.4213	0.3295	4.62E-16	0.3506	4.16E-14
Dec	FAO24-Pn	0.2613	0.4460	0.3418	-1.10E-16	0.3275	8.67E-15
Spring	FAO24-Rd	0.6066	0.3615	0.2783	-4.34E-15	0.7252	7.93E-13
Summer	FAO24-Rd	0.3913	0.3795	0.2973	-1.55E-15	0.4972	2.75E-13
Autumn	Makk-1957	0.5861	0.4481	0.3360	2.68E-15	0.7052	3.86E-13
Winter	FAO24-BC	0.2497	0.5003	0.3910	-4.07E-16	0.3188	4.78E-14
Half-Yearly (1)	Harg-1985	0.5370	0.4846	0.3727	-1.23E-15	0.6630	2.21E-13
Half-Yearly (2)	FAO24-Rd	0.5599	0.3807	0.2942	-2.23E-16	0.6830	5.51E-14
Yearly	FAO24-BC	0.6213	0.5137	0.3934	-5.02E-15	0.7384	1.25E-12

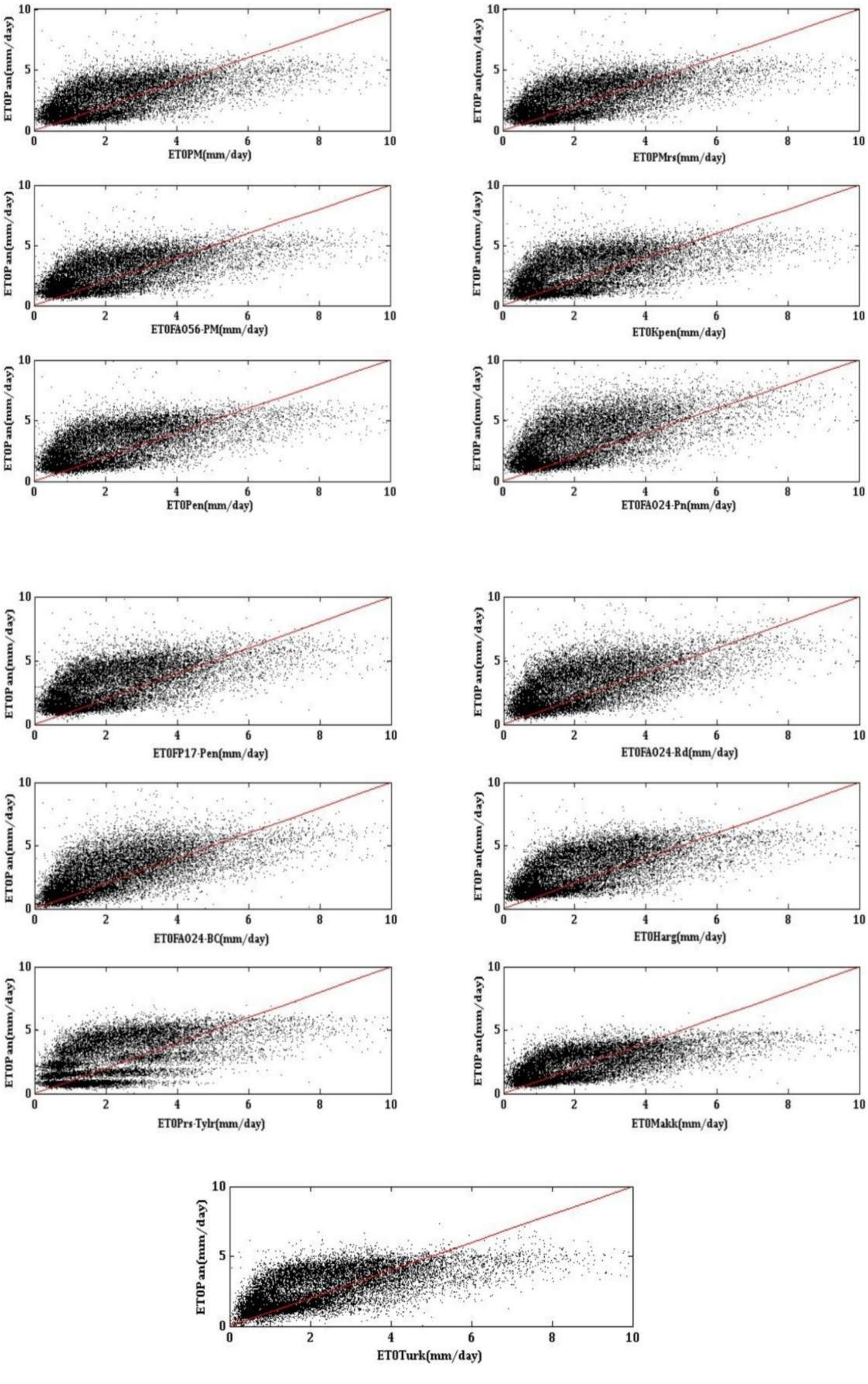


Figure 6: changes in different estimation methods of reference evapotranspiration (x) against estimation of reference evapotranspiration by method of FAO evaporation pan (y) - humid region

Noticeable point in tables 2 and 3 is lack of superiority of combined method of FAO-Penman in all basins. In other word combined method of Penman in comparison to radiation and temperature methods has more difference in estimating evapotranspiration from evaporation pan. While many researchers suggest Penman-Monteith as suitable method in most region of the world for its comprehensiveness that its outcome is published in studies of Rahimi-khoob[22]. But as Sabziparvar and colleagues [20] state suitable estimation method of ET_o in every region depends on the dominant climate on the region. That's why Iran is located in arid region of earth, according to studies of Kumar and colleagues [19] in region with dry climate, evapotranspiration with radiation and temperature methods are superior among other estimation methods.

CONCLUTION

In present essay outcomes from different relations of estimation methods of reference crop evapotranspiration are assessed by setting FAO evaporation pan as reference estimation method of reference evapotranspiration. In this study evapotranspiration of 264 climatology stations, pluviometers and evaporation gauges based in Caspian Sea basin in north of country is estimated by 9 methods defined in Ref-ET software. According to resulted outcomes, method of FAO-24 Blaney-Criddle in dry region in monthly, seasonal, and year's second six-month scales has less estimation error and temperature method of Blaney-Criddle in yearly time scale is superior than other methods in comparison to evapotranspiration resulted from pan evaporation. In both region maximum estimation error in dry and humid region occurs in January and winter season. Also research shows that in June and summer season the least estimation error in dry region, and in the June and spring season the least estimation error is seen in humid region. While both regions monthly scale has less error than seasonal scale. This result shows that reduction in estimation error of ET_0 is in little time scale.

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