Advances in Environmental Biology, 8(7) May 2014, Pages: 2822-2829

AENSI Journals
Advances in Environmental Biology
ISSN:1995-0756 EISSN: 1998-1066

Journal home page: http://www.aensiweb.com/aeb.html

The Comparison of Evapotranspiration Different Methods (Case Study: Qazvin Province in Iran)

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ARTICLE INFO

Article history:
Received 25 April 2014
Received in revised form 20 May 2014
Accepted 26 May 2014
Available online 22 June 2014

Key words:
Evapotranspiration, Qazvin, Romanenko, Blaeny-Criddle.

ABSTRACT

To calculate the water balance, there are many different ways most of which make use of calculating potential evapotranspiration. Evapotranspiration is an important determinant of the hydrological cycle the estimation of which has many uses such as runoff prediction, irrigation canal design etc. To obtain evapotranspiration of the reference crop there are many methods that can be divided to two main categories; combinatory and experimental. In this study, using data from Qazvin meteorological organization, evapotranspiration rates have been calculated by 14 experimental methods and by comparing the results of these methods with the data measured by pan evaporation, which is one of the common direct methods in measuring is considered as the most appropriate way for measuring potential evapotranspiration in Qazvin region. The results of this study show that Romanenko and Blaeny-Criddle equations With 1.94 and 3.31 percent error relative to the measured values are the most appropriate method for estimating evaporation - transpiration in Qazvin are annual.

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To Cite This Article: Saeed Kazemi Mohsenabadi, Mohammad Reza Biglari, Mahdi Moharrampour., The Comparison of Evapotranspiration Different Methods (Case Study: Qazvin Province in Iran). ***Adv. Environ. Biol., 8(7),*** *2822-2829, 2014*

INTRODUCTION

Evaporation procedure occurs through heat energy absorbance by the water molecules and their escape from the surface, In addition to evaporation from soil and water there's also evaporation from plant surfaces, which is called evapotranspiration altogether. It is very difficult to separate these two parameters and they are measured in combination. This study is important because it indicates that 99% of water absorbed by plant is used for evaporation - transpiration and only 1 % is used for building plant tissues [7]. Worldwide, 57% of the water that falls on the land surface would be unavailable through evaporation - transpiration, And in Iran, by evaporation - transpiration 72% of the total precipitation is immediately dissipated into the atmosphere [2]. An important determinant of hydrological cycle is evapotranspiration, estimation of which has important applications in runoff prediction, crop performance and land use plans. In addition, evaporation - transpiration is an important parameter in the design of irrigation and drainage networks and water channels, and has a significant impact on the estimated crop water requirement. Factors affecting the rate of solar radiation evaporation are wind speed, air flow, relative humidity, ambient temperature, water purity and evaporation level. In addition to the above, factors such as day length, type of plant, physiological characteristics of plant affect the amount of evapotranspiration. Using empirical methods many researchers have been conducted in the field of evapotranspiration and in some of them upon FAO Journal's recommendation, FAO Penman-Monteith method is considered as the base with which other methods are compared. In southern California, Rao and Costaned introduced Turc method as the best method to calculate evapotranspiration of the reference, With the same method by comparison in Fukouka, Japan Osman et al (2006) concluded that the outputs of FAO Penman-Monteith method are very close to those of Thorenthwait. In another research conducted in Ghana, Daniel k. Asare et al by comparing experimental outputs with Penman-Monteith method introduced the method of Hargreaves - Samani as the best way for this area. In their study in the southeast of the United States, Jianbiao Lu et al [8] introduced Thorenthwait as the best method for calculating actual annual evapotranspiration in this area. In 1989 and 1990 Rahimzadgan conducted a research in Isfahan region introduced the method of Jensen - Hayes as the best method for this area. In addition, Alizadeh recommended Penman-Monteith for Mashhad area and Anasari did the same for Azerbaijan as the best method for calculating the evapotranspiration.

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Problem Statement:
Characteristics of the study area:

Airport station is located in Qazvin Plain at longitude 50 degrees and 0.03 minutes east and latitude 36 degrees 15 minutes north and height from sea level to 1279.2 meters. The average annual rainfall (1992-2012) of the station is 323 mm and the amount of evapotranspiration potential in the first 8 months of the year (1992-2012) is 4.9 times the amount of rainfall annually. The average number of frost days during the study period has been recorded 83 days. The average maximum monthly temperature (1997-2012) of August is 35.48 ° C and the average minimum monthly temperature (1997-2012) of February is -3.06° C. The highest average monthly evaporation (1997-2012)recorded is in June with 312.09mm and average minimum monthly evaporation records (1997-2012) in the first eight months of the year is in November with 61.62 mm.

Research Methods:

Measurement of evapotranspiration with Lysimeter is very accurate but would be very costly and time consuming. For this reason, the experimental method is preferred. In this study, using data from airport meteorological stations in Qazvin plain, monthly values of evapotranspiration will be calculated by 14 experimental methods and then the outputs will be compared with the measured values in evaporation pan and the best methods for calculating monthly and yearly evapotranspiration for the study area will be presented. In addition, the parameters used in an average period of 16 years (1997-2012) used in these equations are presented in Table 1.

The experimental method used:
Penman-Fao equation:

In 1948, English scientist Penman proposed a formula combining the energy and aerodynamic equation in order to calculate evapotranspiration potential. Penman-Fao method is made by some reforms on Peman method and is a combinatory formula.

$$PET(mm/day) = \left[\frac{\Delta}{\Delta+\gamma}Rn + \frac{\frac{0}{27\gamma}}{\Delta+\gamma}(1+0/01U)(Es-Ea)\right] \quad (1)$$

$$\Delta = 2(0/00738Tmean + 0/8072)^7 - 0/00116 \quad (2)$$

$$\gamma = 1/6134\frac{P}{\lambda} \quad (3)$$

$$P = 1013 - 0/1055(E) \quad (4)$$

$$\lambda = 2500/78 - 1/3601\,Tmean \quad (5)$$

$$Es = 33/8639[(0/00738Tmean + 0/8072)^8 - 0/000019\,(1/8Tmean + 48) + 0/001316] \quad (6)$$

$$Ea = Es\left(\frac{RH}{100}\right) \quad (7)$$

$$Rn = 0/75R_S - R_b \quad (8)$$

$$Rs = \left(0/35 + 0/61\frac{n}{N}\right) \quad (9)$$

$$Rb = \left(1/2\frac{Rs}{Rso} - 0/2\right)Rbo \quad (10)$$

$$Rbo = \frac{\varepsilon\sigma}{2}[(Tmax+273)^4 + (Tmin+273)^4] \quad (11)$$

$$\varepsilon = -0/02 + 0/261\exp[-7/77 * 10^{-4}\,Tmean^2] \quad (12)$$

Where PET is the potential evapotranspiration (mm/day),Δ is the slop of the saturation vapour pressure temperature curve(mb/◦c),γ is the psychrometric constant(mb/◦c),P is the air pressure (mb),E is the elevation of the site(m),λ is the latent heat of evaporation(kj/kg), T_{mean} is the daily mean air temperature(◦c),E_s is the saturation vapour pressure(mb),E_a is the actual vapour pressure(mb),RH is the daily mean relative humidity(in percent), R_n is the net radiation(mm/day),R_s is the solar short wave radiation(mm/day),N is the possible sunshine hours(hour) ,n is the actual sunshine hours (hour), R_b is Outgoing radiation from the earth's surface with Long wavelength (KJ/m^2.day) ,R_{so} is the Short Wave Radiation on a Clear-Sky Day (cal/cm^2.day) ,R_{bo} is Output pure radiation (KJ/m^2.day) ,σ is the Stefan-Boltzmann constant (4/8995*10^{-3} J/m^2.day.K^4) ,ε is Radiation coefficient of the surface.

Jensen – Hais equation:

After studying 3000 observed statistics which were collected over 35 years, Jensen and Hais proposed the following radiative equation to calculate the evapotranspiration potential.

$$PET(mm/day) = C_c(Tmean - T_c)Ra \quad (13)$$

$$C_c = \frac{1}{(C_1 + 7/6C_H)} \quad (14)$$

$$C_H = \frac{50}{e_2 - e_1} \quad (15)$$

$$C_1 = 38 - \left[\frac{2E}{305}\right] \quad (16)$$

$$T_c = -2/5 - 0/14\,(e_2 - e_1) - \left(\frac{E}{550}\right) \quad (17)$$

$$E_t = 33/8639[(0/00738Tmean + 0/8072)^8 - 0/000019\,(1/8Tmean + 48) + 0/001316] \quad (18)$$

Where PET is the potential evapotranspiration (mm/day), T_{mean} is the daily mean air temperature (◦c), Ra is the Extraterrestrial Radiation for Daily Periods (mm/day), E_t is the saturation vapour pressure (mb), e_1 is vapor pressure related to the mean minimum temperature in Hottest month of the year (mb), e_2 is vapor pressure related to the mean maximum temperature in Hottest month of the year (mb), E is the elevation of the site (m).

Table 1: Parameters used in an average period of 16 years (1997-2012)

Pan (mm)	Maximum Incoming Solar Radiation (mm Day)	Extraterrestrial Radiation (mm.day)	Wind Speed At 2m Height (m.S)	Percent Relative Humidity	Actual Sunshine Hours	Maximum Possible Sunshine	The Mean Of Minimum Temperature (° C)	The Mean Of Maximum Temperature (° C)	Parameter Month
82.4	18.87	14.34	2.58	53.93	7.30	13.15	5.24	18.59	April
167	12.68	15.46	2.62	54.87	8.59	14.10	9.34	24.28	May
265.8	13.68	16.77	2.56	44.20	11.16	14.63	13.63	31.22	June
312.1	12.98	16.38	2.58	42.99	11.47	14.40	17.30	35.20	July
303.3	11.82	15.06	2.40	41.00	11.54	13.53	17.88	35.48	August
244	10.15	13.00	2.39	42.13	10.71	12.40	14.66	32.26	September
157.7	7.89	10.17	2.24	45.33	9.03	11.28	10.31	26.73	October
61.6	6.25	7.68	2.25	58.08	6.54	10.23	4.88	17.46	November
-	5.07	6.45	2.25	63.80	5.37	9.68	-0.19	10.29	December
-	5.64	7.00	2.26	66.73	5.20	9.96	-3.05	5.45	January
-	8.21	9.21	2.54	65.93	5.61	10.93	-3.06	7.78	February
-	9.45	11.75	2.81	54.17	6.63	11.9	0.6	13.64	March

Thorenthwait equation:

In 1948 Thorenthwait offered the following equation for calculating evapotranspiration potential. This method is based on the average monthly temperature and is of the temperature equations. in this method It has been assumed that Every month is 30 days and there is 12 hours of light each day and in order to remedy the default, a factor of N_m and have to be multiplied by equation.

$$PET(mm/month) = 16Nm\left(\frac{10\,T_m}{I}\right)^a \quad (19)$$

$$i_m = \left(\frac{T_m}{5}\right)^{1/51} \quad (20)$$

$$I = \sum_1^{12} i_m \quad (21)$$

$$a = (6/75 * 10^{-7})I^3 - (7/71 * 10^{-5})I^2 + (1/792 * 10^{-2})I + 0/492 \quad (22)$$

Where PET is the potential evapotranspiration(mm/day),N_m is adjustment factor related to number of daylight and latitude, i_m is the thermal profile of every month (if the average temperature for the month is zero or negative, the value of i_m is considered zero), I indexed in the heat, T_m is the month average air temperature (° c).

Linecar equation:

In 1977 Linecar presented the following equation which is a thermal equation to calculate the evapotranspiration potential:

$$PET(mm/day) = \frac{\left[\left(\frac{700T_m}{100-L}\right) + 15(T - T_d)\right]}{80 - T} \quad (23)$$

$$T_m = T + 0/006E \quad (24)$$

$$T_d = (112 + 0/9\,T)(RH)^{0/125} + (0/1\,T - 112) \quad (25)$$

Where PET is the potential evapotranspiration(mm/day), T is the monthly mean air temperature (◦c), E is the elevation of the site(m), L is the latitude of the site(◦), T_d is the dew point temperature(◦c), RH is the daily mean relative humidity (in percent)

Romanenko equation:

In 1961 Romanenko presented a simple equation based on relative humidity and average monthly temperature to calculate the evapotranspiration potential:

$$PET(mm/month) = 0/0018(25+T)^2 * (100-RH) \quad (26)$$

Where PET is the potential evapotranspiration (mm/month), T is the monthly mean air temperature (◦c), RH is the monthly mean relative humidity (in percent).

Priestly and Taylor equation:

In 1972 after conducting researches in the field of evapotranspiration, Presley and Taylor presented a method for calculating evapotranspiration. The following equation is a simplified combinatory equation with empirical coefficients.

$$PET(mm/day) = \frac{1/26\Delta(Rn-G)}{\lambda(\Delta+\gamma)} \quad (27)$$

Where PET is the potential evapotranspiration (mm/day), Δ is the slop of the saturation vapour pressure temperature curve (kpa/◦c), R_n is the net radiation (Mj/m^2.day), G is the soil heat flux density (Mj/m^2.day) and assumed zero in this study because of the daily time step used for PET computation, λ is the latent heat of evaporation (Mj/kg), γ is the psychrometric constant (kpa/◦c).

Turc equation:

In 1961, Turc presented the following two-part equation which is a radiative equation to calculate evapotranspiration:

If: RH≤50

$$PET(mm/day) = \frac{0/013T(Rs+50)\left[\frac{120-RH}{70}\right]}{T+15} \quad (28)$$

If: RH≥50

$$PET(mm/day) = \frac{0/013T(Rs+50)}{T+15} \quad (29)$$

Where PET is the potential evapotranspiration (mm/day), RH is the daily mean relative humidity (in percent), R_s is the solar short wave radiation (cal/cm^2.day), and T is the daily mean air temperature (◦c).

Hargreaves and Samani equation:

In 1985 Hargreaves and Samani presented the following equation which is a thermal equation for calculating evapotranspiration. The only data required in this method is temperature and with latitude, extra-terrestrial irradiance will also be available.

$$PET(mm/day) = 0/0023Ra\,(T+17/8)\sqrt{TR} \quad (30)$$

$$TR = T_{max} + T_{min} \quad (31)$$

Where PET is the potential evapotranspiration (mm/day), R_a is the Extraterrestrial Radiation for Daily Periods (mm/day), T is the daily mean air temperature (◦c).

Irmak 1 equation:

Irmak and Associates in 2003 presented the following equation based on the amount of short-wavelength solar radiation and average air temperature for estimating evapotranspiration:

$$PET(mm/day) = -0/611 + 0/146Rs + 0/079T \quad (32)$$

Where PET is the potential evapotranspiration (mm/day), R_s is the solar short wave radiation (Mj/m^2.day), T is the daily mean air temperature (◦c).

Irmak 2 equation:

Irmak and colleagues in 2003 offered the following equation based on the average temperature and net solar radiation to estimate evapotranspiration in wet areas:

$$PET(mm/day) = 0/489 + 0/289Rn + 0/023T \quad (33)$$

Where PET is the potential evapotranspiration (mm/day), R_n is the net radiation (Mj/m^2.day), T is the daily mean air temperature (◦c).

Blaeny and Criddle equation:

In 1950, Blaeny and Criddle suggested one of the oldest temperature relationships for calculating evapotranspiration. Later, this method was revised and reviewed by experts. in 1991, Pruit presented a modified version of this equation:

$$PET(mm/day) = a + b[p(0/46T + 8/13)] \quad (34)$$

$$a = 0/0043(RH_{min}) - (\frac{n}{N}) - 1/41 \quad (35)$$

$$b = 0/82 - 0/0041(RH_{min}) + 1/07(\frac{n}{N}) + 0/066\,U - 0/006\,(RH_{min})\left(\frac{n}{N}\right) - 0/0006\,(RH_{min})U \quad (36)$$

Where PET is the potential evapotranspiration (mm/day), RH_{min} is the minimum daily relative humidity, (n/N) is the ratio of actual to possible sunshine hours, p is the ratio of actual daily daytime hours to annual men daily daytime hours, U is the daytime wind at 2 m height (m/s), and T is the daily mean air temperature (◦c).In the above equations, P is the coefficient corresponding to the day, a, b are climate coefficients, T is the mean air temperature (° c), N is maximum daily sunshine hours per month (hour), n the actual daily average sunshine hours per month (hour), U the average wind speed at a height of 2 meters (m / s), RH_{min} corresponds to minimum relative humidity (%).

Fao-Penman-Monteith equation:

It is a compound relationship in which the measurement of evapotranspiration is done with regard to the amount of energy and moisture between the atmosphere and the surface:

$$PET(mm/day) = \frac{0/408\Delta(R_{n-G}) + \gamma\left[\frac{900}{T+273}\right]U(Es - Ea)}{\Delta + \gamma(1 + 0/34U)} \quad (37)$$

Where PET is the potential evapotranspiration (mm/day), Δ is the slop of the saturation vapour pressure temperature curve(kpa/◦c), R_n is the net radiation (Mj/m^2.day), G is the soil heat flux density (Mj/m^2.day) and assumed zero in this study because of the daily time step used for PET computation, γ is the psychrometric constant (kpa/◦c), T is the daily mean air temperature(◦c),U is the wind speed at 2 m height(m/s), Es is the saturation vapour pressure (kpa), Ea is the actual vapour pressure (kpa).

Makkink equation:

In 1957 Makkink presented the following equation for estimating the evapotranspiration of the grass during the 10-day period:

$$PET(mm/day) = \frac{\frac{0}{61}\Delta\, Rs}{\frac{2}{45(\Delta + \gamma)}} - 0/12 \quad (38)$$

Where PET is the potential evapotranspiration(mm/day), Δ is the slop of the saturation vapour pressure temperature curve (kpa/◦c), R_s is the solar short wave radiation(Mj/m^2.day), γ is the psychrometric constant (kpa/◦c).

Penman-monteith equation:

It is a compound equation for which the Cropwat8 software is used.

Error calculation:

The error resulted from each method is measured using the following equation:

$$Error = \left(\frac{ET_M}{ET_{PAN}} - 1\right) \times 100 \quad (39)$$

In the above equation, Error is the error resulted from each method compared with the amount recorded on the basis of pan evaporation in percentage terms; ET_M corresponds to the amount of evapotranspiration calculations using empirical methods in millimeters per month, ET_{PAN} is evapotranspiration measured by evaporation pan in millimeters per month.

Analysis of results:

As described in this research 14 experimental methods have been used and the results of these methods are calculated using meteorological data presented in the table1. Table 2 indicates the results in millimeters per month.

Table 2: calculated evapotranspiration with various methods

Total Of Eight Months	November	October	September	August	July	June	May	April	Month. Method
1073.5	46	89.3	145.1	182	192.1	183.1	131	104.8	Penman-Fao
2976.9	146.5	254.9	390.9	493.7	530.9	489.6	378.1	292.4	Jensen-Hais
803.3	28.9	73.7	114.1	158.6	164.2	143.6	79.0	41.2	Thorenthwait
1989.1	142.6	229.0	299.6	344.4	332.4	281.5	199.5	160.2	Lincr
1563.1	98.7	186.4	244.0	283.6	269.5	225.8	142.0	113.0	Romanenko
1018.5	33.6	73.1	133.5	176.2	189.4	182.1	129.8	100.7	Priestly-Taylor
1095.8	53.4	100.5	156.1	190.0	193.2	183.7	124.7	94.2	Turc
1154.6	54.0	103.3	160.4	200.4	217.7	201.7	147.5	69.7	Hargreaves-Samani
983.3	58.1	97.9	134.2	156.7	162.0	155.8	120.6	98.1	Irmak 1
1025.4	53.9	86.6	131.9	160.8	170.7	169.6	135.4	116.6	Irmak 2
1646.8	90.9	158.8	263.8	282.9	295.2	259.5	187.0	135.7	Blaeny-Criddle
1188.3	56.9	107.0	166.5	204.4	213.2	195.7	135.2	109.4	Fao-penman-monteith
916.0	49.0	85.8	122.2	147.7	155.1	151.9	113.2	91.1	Makkink
1176.6	62.4	110.4	164.6	200.9	208.3	187.6	136.1	106.3	Penman-monteith
1594.0	61.6	157.7	244.0	303.3	312.1	265.8	167.0	82.4	Pan

Figure 1 also indicates the comparison of the total evapotranspiration calculated in eight-month period using experimental methods used in the present study with recorded values evaporation pan.

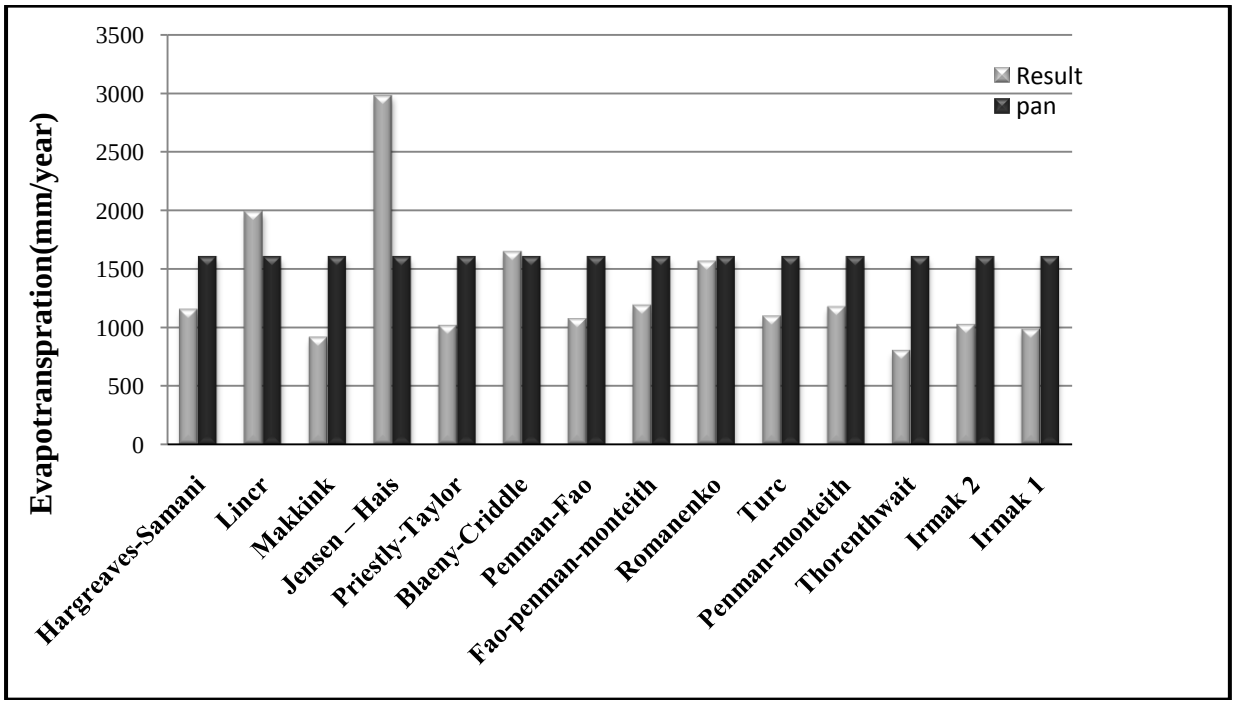

Fig. 1: Comparison of the total evapotranspiration calculated

Using equation 39 and with regard to the total evaporation obtained using pan evaporation during eight months, is measured about 1594 mm, Error of the measured and calculated values can be seen in the table below.

Table 3: Percentage Error

Percentage Error	Total Evapotranspiration Calculated	Methods
-27.57	1154.6	Hargreaves-Samani
24.79	1989.1	Linecar
-42.54	916	Makkink
86.76	2979.9	Jensen-Hais
-36.1	1018.5	Priestly-Taylor
3.31	1646.8	Blaeny-Criddle
-32.65	1073.5	Penman-Fao
-25.45	1188.3	Fao-Penman-Monteith
-1.94	1563.1	Romanenko
-31.26	1095.8	Turc
-26.19	1176.6	Penman-Monteith
-49.61	803.3	Thorenthwait
-35.67	1025.4	Irmak 2
-38.31	983.3	Irmak 1

Using the following chart, the changes of calculation errors can easily be analyzed.

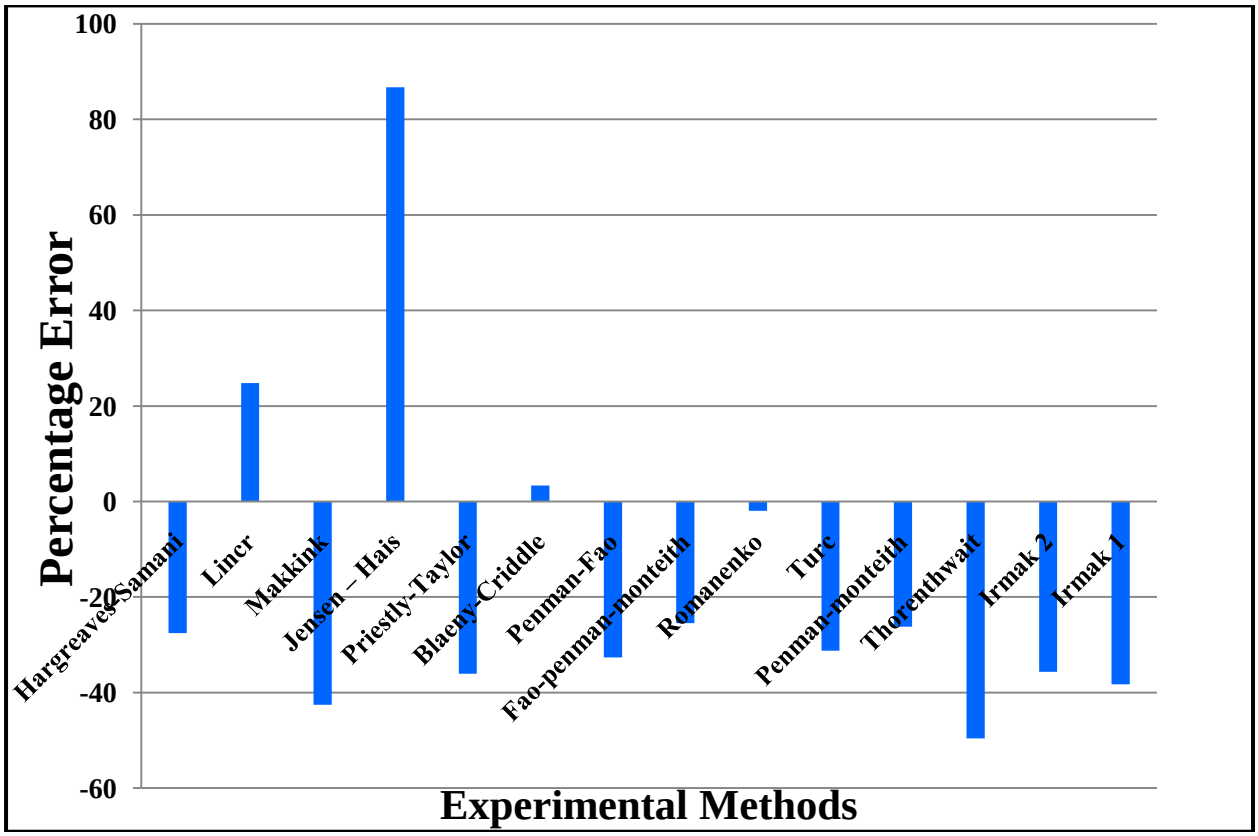

Fig. 2: Changes of calculation errors

Conclusions and recommendations:

Table (2) shows the evapotranspiration values calculated during different months using 14 methods. The total amount of evapotranspiration by each method is provided in this table. Chart 1 compares the measured values with the calculated values. According to these tables and graphs it can be seen that the total evapotranspiration using Romanenko method is 1563 mm and with regard to Blaeny and Criddle method it equals to 1646 mm and these results compared to the amount measured by evaporation pan which equals to 1569 mm have provided the best results .percentage error obtained according to table 3 in Romanenko method is 1/94 percent and in Blaeny and Criddle method is 3/31 percent which are really satisfactory. Methods of Jenson Haise and Thorenthwait show 86/76 and 49/61 percentage error respectively compared to calculated values which had the most error among the studied methods.

According to the obtained results, Romanenko method and Blaeny and Criddle method indicate the closest values to the obtained results from evaporation pan. Therefore the use of these two methods is proposed in the study area. With reference to the equations of these methods it can be seen that use of Romanenko equation is

much easier than Blaeny and Criddle equation and requires fewer parameters. Therefore, the method of Romanenko can be proposed as the best method in this area.

ACKNOWLEDGMENTS

We appreciate the cooperation of Qazvin meteorological research center and its staff, Mr. Kazemi and Mr. Nouruzi.

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