Water Harvesting Research, 2017, 2(2): 54-70
DOI: 10.22077/JWHR.2018.830
www.jwhr.birjand.ac.ir
P-ISSN: 2476-6976, E-ISSN: 2476-7603

Evaluation of Base Flow Separation Methods for Determining Water Extraction (Case study: Gorganroud River Basin)

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Received: 12 April 2017/ Accepted: 1 July 2017

Abstract

The world's population is continuously growing, so the water demand is increased and the water crisis tends to intensify the use of groundwater. With regard to the reduction of groundwater resources, the use of surface water is a priority. Base flow is the minimum flow rate that flows in the river. Base flow is the maximum discharge which is extracted from the river regardless of the environmental flow. In this research, to estimate the main flow and its index at a daily time step for 8 representative gauging stations located at the Gorganroud river basin during a period of 34 years (1981 to 2014) the Hysopp methods (local minimum, fixed intervals and Sliding-interval), B-Flow method, one-parameter digital filter method, Chapman digital filter method, EWMA method and Eckhardt method used to estimate base flow index from the measured streamflow, and their results compared. Using two parameters of α and BFI_{max}, the base flow was separated by Eckhart's method and the base flow index was calculated. Finally, it can be observed that one-parameter digital filter method (with MAE, RMSE and r values of 0.28, 0.22, and 0.976, respectively), and the Chapman digital filter method (with the MAE, RMSE and r values of 0.29, 0.33 and 0.979, respectively) give the best results. In both methods, the base flow has the least standard deviation (SD≤0.66), which was selected as the best flow separation method in the study area.

Keywords: *Baseflow, Gorganroud, Recession curve, Water Extraction.*

1. Introduction

Determining water resources capacity and its demand are key indicators in decision making for the management and extraction of water resources and phenomena such as drought. In recent years, studies have shown that surface and groundwater resources have undergone changes in various regions of Iran.

Groundwater use can also increase in drought periods in response to the reduced availability of surface waters. Groundwater extraction can modify the catchment hydrology by reducing water available for groundwater-dependent ecosystems such as wetlands, and reduce base flow in surface streams.

Understanding the minimum river flow is an important and fundamental aspect for optimizing of water resources management and for the extraction of surface waters, which is called base flow in hydrology studies (Qin et al., 2017).

Increased water consumption and the need for further exploitation of water resources in recent years has led researchers to further consider the characteristics of the base flow (Thomas et al., 2013). Miller et al. (2016) indicated that base flow is an important factor in supplying and extracting water for 50 million people living in the Chlorida River basin. Wild and Nimiroski (2004) calculated the base rate at 25, 50, and 75 percent probability, and showed that in August all of the basic water supply must be extracted.

Some researchers have shown that base flow can be used to estimate the average amount of groundwater (Longobardi and Villani, 2008; Miller et al., 2016; Tamaskani et al., 2013). Base flow is sometimes used as an approximation of recharge. According to Risser et al. (2005), the major assumptions in using base flow for estimating recharge are that base flow equals groundwater discharge and that groundwater discharge is approximately equal to recharge. Meyer (2005) also estimates the long-term flow rate as an indicator of the extent of groundwater recharge in large basins. The most accurate method for analyzing flow is chemical or isotopic detectors, and mass balance method (Sloto and Crouse, 1996).

There is no direct way to measure base flow throughout a basin continuously. Consequently, since the early 1990s, many approaches have been developed to estimate or separate base flow from streamflow continuously in time (Rutledge and Daniel, 1994; Wittenberg 1999; Chapman 1999; Arnold and Allen 1999; Piggott et al. 2005; Eckhardt 2005). The digital filter method was proposed by Chapman and Maxwell (1996) for separating the base flow and a simple conceptual model called GROUND, which was also proposed by Kulhavy et al. (2001) to separate the direct runoff.

Eckhardt (2005) also developed an empirical model for the filtering algorithm that these one-parameter filters describing an exponential base flow recession whose equation is specified all special cases of a two-parameter filter. Smakhtin (2001) has been illustrated that technique for base flow separation is capable of reproducing the correct pattern of baseflow variability by comparison of the separated monthly base flow hydrographs with the results of more detailed “daily” base flow separation previously tested extensively in South African conditions. Hydrograph separations were performed using various methods on 3,936 streamflow-gaging stations in Ontario, Canada by Neff et al. (2005).

In a recent study, Arfaeniaand Samani (2005) applied three separation methods in Zayandehorud watershed and reported that the differences between long-term results were less than 7.2%. Lott and Stewart (2016) compared six analytical methods to a mass balance method to determine the base flow. They concluded that once calibrated, the analytical methods can closely reproduce the base flow values of a mass balance method. Mehaiguene et al. (2012) provided a regression relation based on physiographic and climatic data for BFI estimation.

Indarto et al. (2016) compared seven methods of digital filtering and two graphical methods to determine the base flow index and showed that the optimal parameters values of digital methods can be used to separate base flow in other watersheds. Ghanbarpour et al. (2008) and Teimouriet al. (2011) applied recession filtering methods in Karoun watershed and eight gauging stations located in the western Azerbayjan, respectively. Kazemi and Ghermez Cheshmeh (2016) used the base flow and BFI extracted using daily flows of 20 gauging stations located in the Khazar region. They reported that the average annual of BFI, fluctuate between 0.56 and 0.91.

He et al. (2016) introduced a base flow regression-based to estimate from climate characteristics of catchments and they concluded that the regression-based equation has better results than Eckhart's in shallow aquifer region. Seven different base flow separation methods were analyzed using statistical analysis and correlation method by Eckhardt (2008) and compared with the tracer method. The results showed that the proposed algorithm, Eckhardt digital recession filter in case of accurate determination of parameters is the most suitable method in different regions. Ferket et al. (2010) used a base flow estimation method based on a physically-based digital base flow filter to validate the internal model dynamics of two widely used rainfall-runoff models. The separation of the base flow was done in various methods by Gonzales et al. (2009) and Corzo and Solomatin (2007) in the Netherlands. They determined the base flow after determining the two parameters of the Eckhardt recession filter method. The comparison of four methods for determining the base flow in Australia showed that the results of base flow separation would be acceptable if the Eckhart parameters were determined with accuracy (Zhang et al., 2017). Taormina et al. (2015) concluded that the base flow produced by the modular models largely underestimates the actual base flow component expected for most of the considered gages.

The specific objectives of the study were to evaluate and compare the commonly used four base flow separation methods for application in eight gauges river catchments in Gorganroud river basin and determine BFI_{max} parameter according to the geological formations and the filter parameter of α was determined by the Master Recession Curve (MRC).

2. Materials and Methods

Study area

Gorganroud Basin is located in the north of the country and in the south-east of Caspian sea with an area of 11380 km^2. This area is limited in the north to the Atrak basin, south to the Kavir Namak basins, in the west to the Caspian Sea, and in the southwest to the Nekaroud Basin. The southern and eastern parts of the basin are located in the Alborz mountain range. The geographical position of the Gorganroud watershed lies between the latitudes of 36˚ 33′ to 37˚ 45′ N and the geographic longitudes are from 54˚ 03′ to 56˚ 13′ E. The maximum altitude of this basin is about 600 meters and at least 26 meters above sea level. Due to the lack of base flow measurements, this study performed hydrograph separations from the observed streamflow in order to improve the understanding of river characteristics at the regional level. In this regard, we investigated eight gauged stations (Tammer, Lazoore, Jangaldeh, Nodeh, Arazkouse, Gorgan dam, Taghi Abad, and Vatana) to minimize the effects of flow routing, and limit the influence of reservoir releases, and the selected gauges were due to availability of continuous daily streamflow data from 1981 to 2014. The characteristics of these stations and their geographic location are presented in table (1) and Figure (1), respectively.

Table 1. Specifications of hydrometric stations in the Gorganroud Basin

River	Gauge Station	Station code	Metric coordinates		Height (m)	Average flow rate (m^3/s)	Flow Standard deviation	Hydrological ratio Q90/Q50
			X	Y				
Gorgonroud	Tammer	12-005	367584	4150504	132	1.56	4.18	0.22
Chelchai	Lazoore	12-013	358258	4120965	190	2.52	3.39	0.42
Normab	Jangaldeh	12-015	353505	4114636	180	1.54	5.06	0.25

Khormalo	Nodeh	12-017	346617	4102953	280	2.18	2.51	0.34
Gorgonroud	Arazkouseh	12-019	336132	4121414	35	5.48	9.39	0.27
Gorgonroud	Gorgan dam	12-025	299510	4119958	12	7.94	16.86	0.16
Jafarabad	Taghi Abad	12-033	288986	4083239	100	0.39	1.37	0.30
Gaz	Vatana	12-053	765022	4067560	100	0.16	0.59	0.23

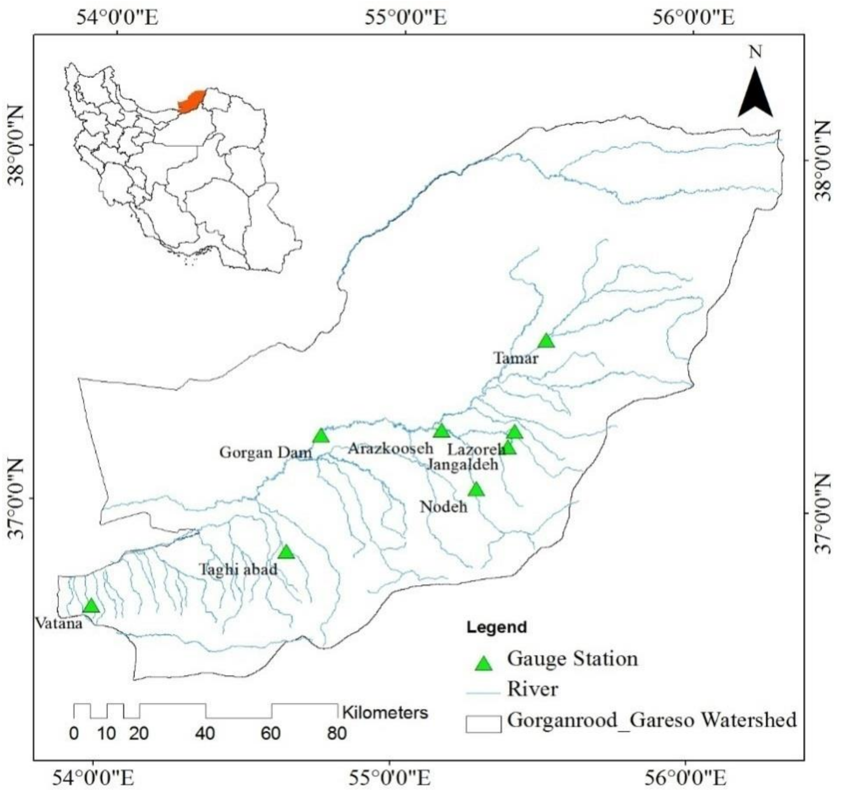

Fig. 1. Geographical location of the hydrometric stations studied in the Gorganroud Basin

Methodology

The base flow is related to groundwater storage and the general assumption is that the flow of outflow from the aquifer in a non-recharge course has a linear relationship with its storage (Eckhardt, 2008). For this purpose, there are many methods for accurately and precisely estimating of hydrograph decomposition. Stable isotopes are generally considered to be the most accurate chemical tracers for hydrograph separation (Kendall and Caldwell, 1998). However, the analytical costs associated with these constituents often limit their use in large studies. Therefore, various methods for hydrograph decomposition and base flow estimation are presented. Streamflow at any time ($q_{(i)}$) is composed of the sum of quick flow and baseflow (equation 1).

$$q_{(i)} = q_{b(i)} + q_{f(i)} \quad (1)$$

According to equation (1) $q_{(i)}$, the total flow at time i, $q_{b(i)}$ is the baseflow at time i and $q_{f(i)}$ is a direct runoff at the time step i. Quickflow or direct runoff results from rainfall events and often drops to 0 between events, while baseflow is continuous as long as the stream flows.

Base Flow Index (BFI)

Base flow index (BFI) is a non-dimensional ratio introduced by the Institute of Hydrology

(1980). BFI is calculated based on the division of the baseflow volume on the total volume of streamflow for each year or the entire period. The BFI index generally indicates what portion of a streamflow occurs from baseflow and what portion occurs from the overland flow (Risser et al., 2005). A large amount of this indicator means that the basin has a steady flow and is capable of sustaining river flow during the dry period. The baseflow index is mostly dependent on the hydrological characteristics of the soil, geology, and other storage properties (Gregor, 2010; Longobardi and Villani, 2008).

Recession-Curve (RC)

This method gives an acceptable result, but its problems are hard to work, time-consuming, performance problems and a large number of flood events per year (Kulhavy et al., 2001). Also, there are several methods for averaging or combining separate recession curve in order to find the baseflow recession in the basin, which can be referred to Master Recession Curve (MRC) (Teimouri, 2014). In this research master, recession curve was used to determine the recession coefficient in Eckhardt's equation. The recession coefficient expressed by the equations (2) and (3).

$$Q_t = Q_0 e^{-kt} \quad (2)$$

$$a = \exp(-k) \quad (3)$$

Where Q_t is the flow at time t, Q_0 is the initial flow, k is the recession constant and a is recession coefficient.

HYSEP

The basis of this computer program was tested by Sloto and Crouse (1996) and was developed by Pettyjohnand Henning (1979). The basis of this program is based on the graphical methods in which $2N^*$ time interval is used to plot the recession curve. To obtain this parameter, using the empirical formula (equation 4) the base time N and then twice the base time 2N is assumed, and in the next step, the closest integer is determined as the value. In Equation 4, A is the upstream area of the station in square kilometers. This method consists of three methods of the fixed interval, Sliding Interval, and a local minimum method. These methods have been widely used in various watersheds (Hasani et al., 2012).

$$N = 0.827A^{0/2} \quad (4)$$

Fixed Interval method

The fixed-interval method assigns the lowest discharge in each interval (2N*) to all days in that interval starting with the first day of the period of record. The discharge at that point is assigned to all days in the interval (Arfaenia and Samani, 2005).

Sliding Interval

The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The discharge at that point is assigned to the media day in the interval. The assigned daily values are then connected to define the base-flow hydrograph (Arfaenia and Samani, 2005).

Local Minimum

The local-minimum method checks each day of a period of record to determine if it has the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered. If this criterion is satisfied, the discharge value for that day is considered a “local minimum” value and is connected to other local minimum values (Sloto and Crouse, 1996).

Recession digital filter (Lyne and Hollick)

The program BFLOW proposed algorithm is represented by Equation (5) which was apparently first suggested by Lyne and Hollick. (1979). In the frequency spectrum of a hydrograph, long waves will be more likely to be associated with baseflow while the high-frequency variability of the streamflow will primarily be caused by direct runoff. It should, therefore, be possible to identify the baseflow by lowpass filtering the hydrograph. Nathan and McMahan (1990) found that the most acceptable results occurred in this method when the filter parameter was within the range of 0.90-0.95 with an average value of 0.925. Smakhtinand Watkins (1997) found that the values of the optimal filter parameter normally fluctuated between 0.985 and 0.995 and a value of 0.995 were recommended for the separation of the daily baseflow.

$$q_{f(i)} = aq_{f(i-1)} + (q_{(i)} - q_{(i-1)})\frac{1+a}{2}$$
(5)

Subject to $q_{f(i)}$≥0 ‘$q_{f(i)}$direct runoff filtered at time stepi ‘$q_{f(i-1)}$direct runoff filter at time i-1, α filtering parameter, $q_{(i)}$ Total flow in time i,$q_{(i-1)}$total flow at time step i-1 and qb = q-qf is the baseflow.

Chapman's Recursive Digital Filter

Chapman (1991), pointed out that the Lyne–Hollick algorithm incorrectly provides a constant streamflow or baseflow, respectively when direct runoff has ceased and therefore developed the new algorithm (6). Which is developed according to the reservoir linear model

$$q_{f(i)} = \frac{3a-1}{3-a}q_{f(i-1)} + \frac{2}{3-a}\left(q_{(i)} - aq_{(i-1)}\right) \quad (6)$$

Where, $q_{f(i)}$ directly filtered runoff at time i, $q_{(i)}$ total flow at time i, $q_{f(i-1)}$ direct runoff filtration at time i-1, $q_{(i-1)}$ the total flow at the i-1 time point and α is the field-related filter parameter.

One-parameter digital Recursive filter (One-parameter)

One-parameter digital Recursive filter developed by Chapman and Maxwell (1996) is based on the Lyne and Hollick (1979) and Chapman one parameter algorithm (Chapman and Maxwell, 1996). A one-parameter recursive digital filter is proposed for analyzing, processing and filtering surface runoff (high-frequency signals) from baseflow (low-frequency signals). The equation is as follows (Chapman and Maxwell, 1996):

$$q_{b(i)} = \frac{K}{2-K}q_{b(i-1)} + \frac{1-K}{2-K}q_{(i)}$$
(7)

Subject to qb (i) ≤ qi, where, K is the filter parameter defined in the basin, qbi-1 is the filtered baseflow for the time before i, qi, mainstream flow for time i and qbi is filtered baseflow for time i.

Exponential weighted moving average filter (EWMA)

The exponential weighted moving average filter is a simple model calculated baseflow for time period i, $q_{b(i)}$, is baseflow on time series with equation (8).

$$q_{b(i)} = aq_{(i)} + (1-a)q_{b(i-1)} \quad (8)$$

Where $q_{b(i-1)}$ is the baseflow for the time before i, q_i main total for time i and α is the constant filter related to the watershed.

Eckhardt Two-parameter digital Recursive filter (Two-parameter)

This method was first proposed by Eckhardt (2005). To decompose the hydrograph into the baseflow, it is necessary to determine the recession coefficient (α) and the maximum baseflow index (BFI_{max}) (equation 9).

$$q_{b(i)} = \frac{(1-aBFI_{max})ab_{(i-1)} + (1-a)BFI_{max}q_{(i)}}{1-aBFI_{max}} \quad (9)$$

Subject to $q_{b\,(i)} \leq q_i$, where α filter parameter associated with the basin can be determined by recession curve, $q_{b(i-1)}$ baseflow filtering for a time before i, qi river mainstream. For time i and q_{bi} filtered baseflow for i-th time and BFI_{max} is the maximum base-flow indicator.

In this method, it is necessary to determine two parameters BFI_{max} and α. According to Eckhart (2005), values of BFI_{max} is 0.8 for permanent rivers with permeable basin, for rivers with a permeable basin is equal to 0.5 and 0.25 for permanent rivers with rocky basin. Geological formation was prepared using 1: 250000 geological map in GIS and classify based on the Feyznia (2008). In terms of lithology characteristics, the existing lithological units with respect to this pyramid can be classified into five classes quaternary (A), limestone (B), limestone-dolomite-conglomerate-Neogene and shale (C), sandstone with silt (D), sandstone-silt-igneous and metamorphic rocks (E), which reduces the permeability and baseflow from class A to E, and increases direct runoff (Nader Sefat and Saidian, 2010). Then BFI_{max} was determined as Equation (10) for the basin. In the Eckhart digital filter, the BFI value of over 0.8 cannot be calculated, since, in this method, the BFI is at most 0.8.

$$BFI_{max} = \sum_{i=1}^{n} A_i * C_i \tag{10}$$

In equation (10) A_i, the area of the geological formation as a percentage of total area for the formation i, C_i, permeability coefficient related to the formation i and BFI_{max} is the parameter of Eckhardt's digital filter method.

Figure (2) shows an example geological unit of the Arazkouse station.

After determining the baseflow, the Eckhart digital filter method was selected as the best method in the studied area and as the basis of comparison with other methods.

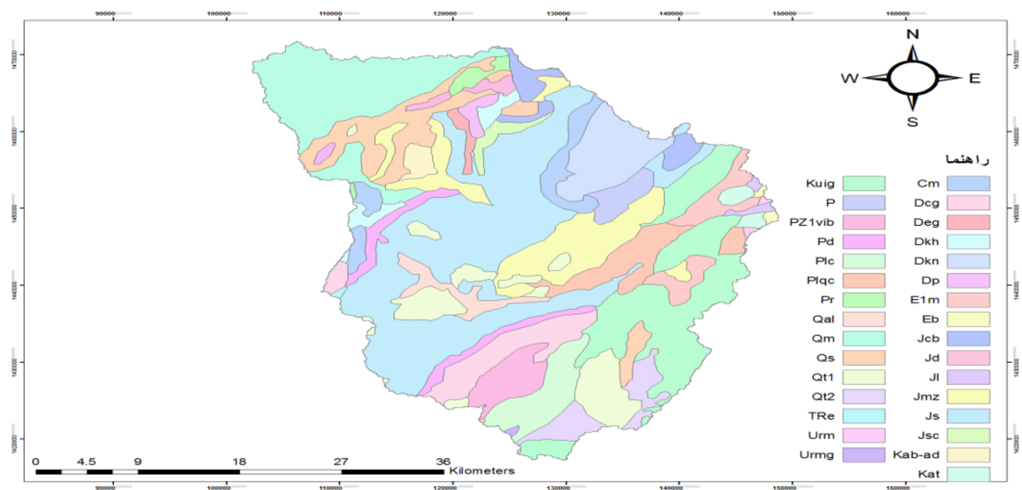

Fig. 2. Geological Formations related to Arazkouse Station

Evaluation criteria

Different objective functions can be adapted for different kinds of practical issues. In this study, three objective functions have been used for parameters calibration. Three objective functions namely MAE[1], RMSE, and R[2] were considered in this study (equation 11 to 13). Where Q_0^t is the observation discharge at time t, Q_m^t the

1- Mean absolute error
2- correlation coefficient

estimated discharge by the model at time t, Q is the mean observed observation (real), (Q_m), average discharge estimated by the model, and n the number of observations. According to these criteria, a method is suitable that the mean absolute error and the mean squared error is less, and as the correlation coefficient, which is a number between zero and one, is closer to one, the prediction of the model is more appropriate.

$$\mathrm{MAE} = \frac{1}{\mathrm{n}} \sum_{t=1}^{n} ({Q_0}^t - {Q_m}^t) \tag{11}$$

$$RMSE = \sqrt{\frac{1}{\mathrm{n}} \sum_{t=1}^{n} ({Q_0}^t - {Q_m}^t)^2} \tag{12}$$

$$r = \frac{\sum_{t=1}^{n} ({Q_0}^t - \overline{Q_0})({Q_m}^t - \overline{Q_m})}{\sqrt{\sum_{t=1}^{n} ({Q_0}^t - \overline{Q_0})^2 \sum_{t=1}^{n} ({Q_m}^t - \overline{Q_m})^2}} \tag{13}$$

3. Results and Discussion

In the current study, eight stream gage locations distributed across Gorganroud river basin were selected to estimate the baseflow index using different baseflow separation methods. Gages were selected with different drainage areas to minimize the effects of flow routing and limit the influence of reservoir releases, and each selected gage had 34 years of daily streamflow observations during 1981-2014.

First, Eckhardt method was used to estimate the baseflow index and then was compared with Hysep, B-Flow, one Parameter, Chapman, and EWMA procedures for evaluation. In Eckhardt's method, two parameters α (filter related to the catchment) and BFI_{max} (maximum baseflow index) are required in the baseflow separation (Equation 9). Firstly, the original recession curve for each of the watersheds was determined for the filter parameter associated with the watershed. Figure (3) shows an example of the main recession curve of the Arazkouse station. Given the equation (2) the value of the parameter α is determined by determining the coefficient k in equation (3). Table (2) shows the parameter α for each station, with the lowest value of α related to the Jangaldeh station with 0.72 and the highest value for the Nodeh station with 0.9.

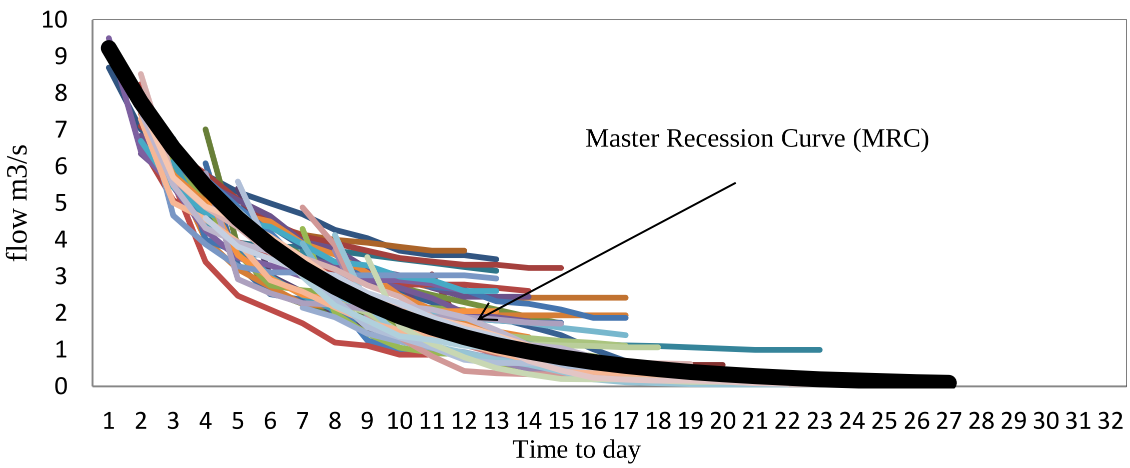

Fig. 3. Master Recession Curve (MRC) related to Arazkouse station

Table 2. Parameters related to the Master Recession Curve in the studied stations

	Vatana	Taghi Abad	Gorgan dam	Arazkouse	Nodeh	Jangaldeh	Lazoore	Tammer

k	0.27	0.29	0.16	0.14	0.16	0.33	0.15	0.13
α	0.76	0.75	0.85	0.87	0.90	0.72	0.86	0.88

In order to determine the maximum baseflow index (BFI_{max}) of the Eckhardt method, the geological formation permeability and river type (permanent, non-permanent) were determined. Considering the continuity of the rivers in the study area as well as determining the permeability coefficient of each formation and the area of the formation, and based on equation 10, the BFI I_{max} value of the Eckhardt method for the basins for each station is calculated (Figure 4). The highest BFI_{max} value is 0.65, indicating the high porosity of the basic constituents and the high contribution of subsurface water in the river. The lowest BFI_{max} value for the Vatana station is 0.32, which indicates that due to the difficulty of the formation of the basin, groundwater has a small contribution to surface flow.

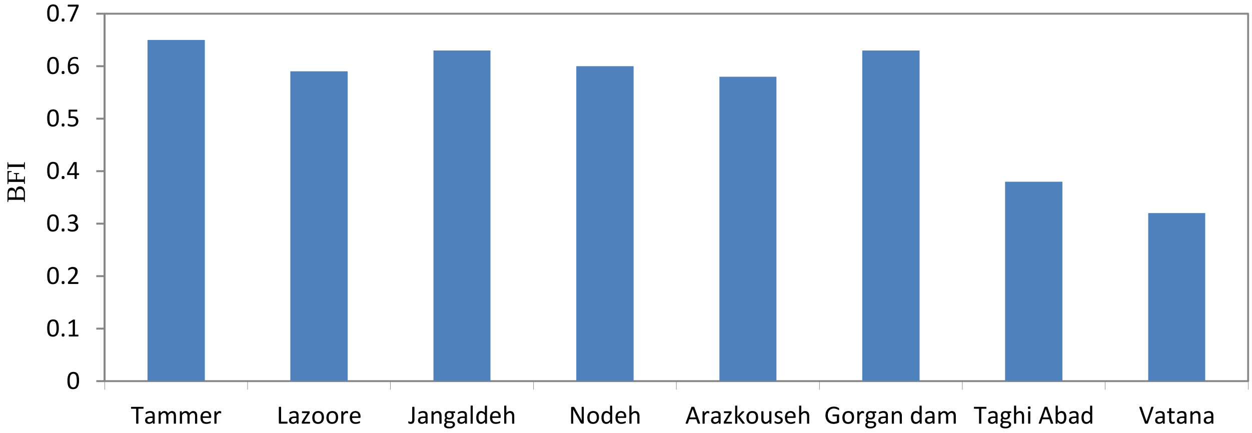

Fig 4. Maximum baseflow index in Eckhardt method

A review of references shows that various researchers have used the Eckhardt method as an appropriate method which presents satisfactory results (Gonzales et al., 2009; Taormina et al. 2015 and Eckhardt, 2008). Therefore, the Eckhardt method was used as the basis for making a comparison with other methods. In this study, determining the α parameter and maximum baseflow index (BFI_{max}) in basins was separated by Eckhardt recession filter method. Table (3) presents the annual statistical properties (baseflow extraction and baseflow index) obtained by the Eckhardt recession filter method in the studied stations. The low standard deviations observed in all the stations indicate that the results are acceptable (Hasani et al., 2012; Longobardi a nd Villani, 2008). Based on the results shown in Table (3), the lowest mean rate of extractable flow was 0.05 cubic meter per second that was observed in Vatna station and the highest mean rate of extractable flow was 4.77 cubic meter per second that was observed in Gorgan dam station. Moreover, the lowest and the highest baseflow index were observed in Vatana (0.27) and Tamar (0.66) stations, which indicated the effect of sub-surface water on the level of the flow.

Table 3. Annual Characteristics of the baseflow extraction and Baseflow Index of the Eckhardt Method

	baseflow index				baseflow extraction			
stations	**Min**	**Max**	**Average**	**Standard deviation**	**Min (m3/s)**	**Max (m3/s)**	**Average (m3/s)**	**Standard deviation**
Tammer	0.47	0.66	0.60	0.06	0.40	2.09	0.95	0.40
Lazoore	0.54	0.60	0.58	0.01	0.53	2.53	1.19	0.46
Jangaldeh	0.50	0.65	0.60	0.04	0.30	1.50	0.92	0.35
Nodeh	0.53	0.61	0.58	0.02	0.74	2.29	1.26	0.41
Arazkouse	0.52	0.59	0.57	0.02	1.26	6.15	3.06	1.21
Gorgan dam	0.54	0.64	0.60	0.03	0.19	13.83	4.77	3.49
Taghi Abad	0.30	0.40	0.36	0.02	0.04	0.27	0.14	0.07
Vatana	0.27	0.32	0.31	0.01	0.01	0.15	0.05	0.03

Hyssop methods, which include the three methods of local minimum, sliding interval, and fixed interval, are compared to Eckhardt recession filter method in terms of graphical features and the evaluation criteria. Figure (5) shows an example of the baseflow separation via Hysep methods and the Eckhardt recession filter method during a water year (2010-2011) at the Arazkouse station. The graphical assessment of Hysep methods via the Eckhardt recession filter method shows that Hyslop methods overestimate the baseflow. The local minimum method provides a good estimation of the rising limb of the hydrograph, but it has some fault when estimating the ending part of surface runoffs. The fixed interval method does not show a proper flow at the peak of the hydrograph. In addition, the sliding interval method overestimates the baseflow. In these three methods, depending on the size of the field, one can change the time steps in the model to achieve more accurate results. In general, considering the graphical aspects, Hyslop methods do not seem to be appropriate, because they overestimate the baseflow when there are multiple peak fluctuations in the flow and when estimating the flow between the two events that are affected by each other. Furthermore, in some cases, they estimate the baseflow to be higher than the flow rate, which indicates the weakness and the drawback of this method.

Table (4) shows the comparison of Hysep methods via Eckhardt method in the studied stations. The findings of our assessment show that the results are not uniform and constant at all the stations. At all the stations, the correlation coefficient of the local minimum method was less than that of the fixed interval and sliding interval methods. The sliding interval method has the highest correlation coefficient among all the Hysep methods. Based on the MAE and RMSE criteria, the minimum local method has the lowest rate of error at all stations, except for Jangaldeh and Gorgan dam stations. This finding is consistent with the results of Ghanbarpour et al. (2008) and Hasani et al. (2012). Using this method, the mean annual extractable flow rate in Tammar, Lazore, Nodeh, Arazkouse, Taghi Abad, and Vatana stations was 0.95, 1.36, 1.51, 3.03, 0.13, and 0.06 cubic meter per second, respectively. In addition, the fixed interval method had the lowest amount of error in Gorgan dam and Jangaldeh stations, since using this method, the mean annual extractable flow rate at the two mentioned stations was equal to 0.85 and 5.32 cubic meters per second, respectively. In general, the graphical evaluation and the use of assessment criteria for making comparisons between Hyslop methods did not provide us with a definite conclusion and it is not possible to determine the most appropriate method at the studied stations.

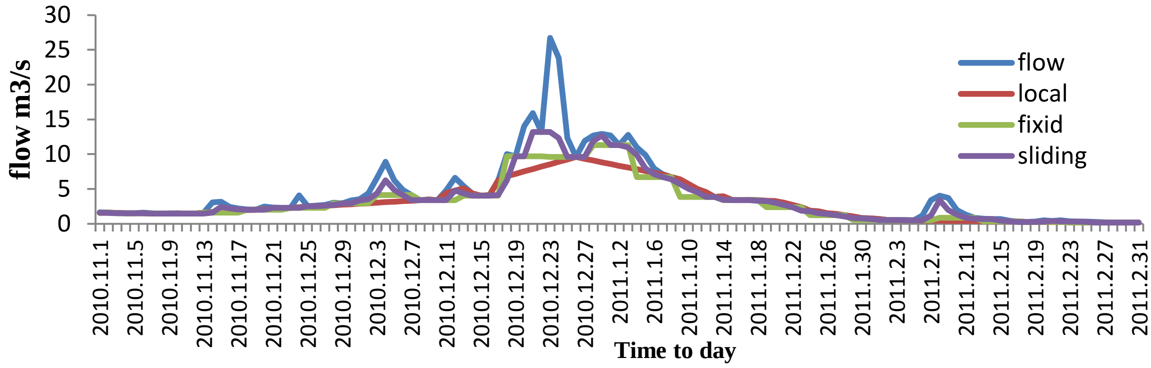

Fig 5. Separation of flow hydrograph with Hyslop and Eckhardt methods at Arazkouse Station in the part of water Year (2009-2010)

Table 4. Results of comparison of Hysep methods with three criteria of MAE, RMSE and correlation coefficient r at the studied stations

		Vatanah	Taghi Abad	Gorgan dam	Arazkouseh	Nodeh	Jangaldeh	Lazoore	Tammer
Local Minimum	Standard deviation	0.03	0.07	3.34	0.12	0.54	0.28	0.54	0.40
	Average (m^3/s)	0.06	0.13	3.64	3.03	1.51	0.65	1.36	0.95
	Max (m^3/s)	0.17	0.36	13.95	5.69	2.83	1.22	2.80	2.14
	Min (m^3/s)	0.01	0.03	0.06	0.99	0.77	0.25	0.67	0.28
	MAE	0.02	0.03	1.18	0.40	0.30	0.27	0.21	0.16
	RMSE	0.03	0.04	1.64	0.48	0.36	0.32	0.25	0.20
	r	0.42	0.51	0.68	0.65	0.65	0.69	0.48	0.90
Fixed Interval	Standard deviation	0.06	0.10	4.31	1.40	0.61	0.31	0.61	0.45
	Average (m^3/s)	0.10	0.19	5.32	3.66	1.72	0.85	1.58	1.05
	Max (m^3/s)	0.32	0.44	17.19	6.90	3.14	1.45	3.16	2.46
	Min (m^3/s)	0.03	0.05	0.18	1.48	0.85	0.29	0.75	0.42
	MAE	0.05	0.05	0.77	0.62	0.46	0.13	0.39	0.19
	RMSE	0.06	0.06	1.19	0.70	0.51	0.19	0.43	0.21
	r	0.51	0.72	0.81	0.77	0.80	0.86	0.61	0.95
Sliding Interval	Standard deviation	0.07	0.11	4.78	1.56	0.63	0.36	0.66	0.48
	Average (m^3/s)	0.12	0.23	6.25	4.09	1.86	0.98	1.71	1.14
	Max (m^3/s)	0.35	0.50	18.95	8.01	3.32	1.70	3.25	2.68
	Min (m^3/s)	0.03	0.07	0.23	1.71	0.94	0.32	0.77	0.48
	MAE	0.07	0.09	1.48	1.03	0.57	0.15	0.52	0.23
	RMSE	0.08	0.10	2.00	1.11	0.62	0.17	0.56	0.26
	r	0.57	0.84	0.79	0.78	0.86	0.91	0.61	0.97

The baseflow at the studied stations was evaluated by Lyne and Holick digital filter (B-Flow) method. The obtained results show that the accuracy of the B-Flow method is much higher than that of Hysep methods. It collects data on a flow rate that passes the filter three times (forward, backward, and forward again), thus, the filter can present the baseflow as a constant curve, which is consistent with the results of Nathan and McMahon (1992), Arnold et al. (1995), Smakhtin (2001), Ghanbarpour et al. (2008), Teimouri(2014), and Tamaskani et al. (2013). Selecting an appropriate filter coefficient for the utilization of the B-Flow method at the studied stations, we made a graphical comparison on the basis of the selected evaluation criteria. Figure (6) presents an example of a baseflow separation at the Arazkouse station during the water year of 2010-2011 using the B-Flow method and the Eckhardt recession filter method. The comparison of Figures (5) and (6) shows that the B-Flow method provides more logical and uniform results than Hysep methods. Comparison of the results of the B-Flow method at the studied stations is presented in Table (5). As shown in Table (5), the lowest rates of error of the B-Flow method were observed in Tamar, Jangaldeh, and Gorgan dam stations, while the highest rate of error was observed at Vatna station. Tamar station and Vatna station, respectively, had the highest (97%) and the lowest (65%) correlation coefficients, which is consistent with the results of Tamaskani et al. (2013). Based on the results of the assessments conducted in the studied area, the B-Flow method does not accurately calculate the baseflow, however, it is more accurate than the Hysep methods in the separation of the base flow.

The one-parameter digital filter method, the Chapman digital filter method, and the exponentially weighted moving average (EWMA) filter were graphically and statistically evaluated by Eckhardt recession filter method. Figure (5) presents the separated baseflow during the water year of 2010-2011 at Arazkouse Station. The results of evaluation of the one-parameter digital filter method and the Chapman digital filter method, assessed by Eckhardt method, are very similar to each other; they underestimate the baseflow only at the peak. The EWMA method estimates the baseflow much higher than the actual value (almost equal to the flow rate) and cannot be a suitable method for separating the baseflow in the studied area. Table 5 presents the statistical comparison of the baseflow index between the one-parameter digital filter method, the Chapman digital filter method, and the EWMA method, as assessed by the Eckhardt recession filter method. The results obtained from the one-parameter and Chapman methods at the studied stations are very similar.

Considering the aim of the study, which was to separate the base flow using different methods and select the most appropriate method, the results obtained from each method were evaluated. Table (6) presents a summary of the results of statistical analysis of different baseflow separation methods used in Gorganroud basin. Table (6) shows that a significant portion of the river flow in Gorganroud basin is originated by the base flow. The mean annual baseflow ranges from 1.27 to 2.59; the lowest flow was reported by the Chapman digital filter method, while the highest flow was reported by the EWMA method, which estimated almost the entire river flow as the baseflow. In fact, the baseflow value shows the permeability of the geological structures forming the region (Delinom, 2009; McGuire et al., 2005; Nathan and McMahon, 1992). The comparison of (mean, maximum, and minimum) annual baseflows via different methods shows that the results of the local minimum method, the one-parameter digital filter, and the Chapman digital filter had the highest level of approximation and proximity with the Eckhardt method.

Based on the results of the statistical analysis (Table 6), the lowest mean absolute error (MAE) and the root mean squared error (RMSE) were observed in the one-parameter digital filter method (0.28 and 0.29, respectively) and the Chapman digital filter method (0.32 and 0.33, respectively). The observed values are very similar to each other, indicating the appropriateness of the two methods for the separation of flow in the studied area. This is in line with the results of a study conducted by Kazemi and Ghermez chessmen. (2016). As presented in Table (5), the mean annual extractable flow at the Tammar, Lazoreh, Jangaldeh Nodeh, Arazkouseh, Gorgan dam, Taghi Abad, and Vatna, respectively, was 0.73, 1.01, 0.73, 1.10, 2.65, 3.80, 0.18, and 0.08 cubic meters per second as calculated by one-parameter digital filter method, and 0.72, 1.01, 0.71, 1.05, 2.64, 3.76, 0.17, and 0.08 cubic meter per second as calculated by Chapman digital filter method. The results indicate the proximity of these two methods in the separation of the baseflow from the main flow. Moreover, the maximum mean absolute error (MAE) and root mean squared error (RMSE) calculated by the exponentially weighted moving average filter (EWMA) method were 1.04 and 1.17, respectively; the large values indicate the weakness and inadequacy of this method in the separation of the flow.

The assessment of the correlation coefficients between all methods and Eckhardt method in terms of the annual baseflows in the studied area shows that the highest correlation coefficient was observed between the Eckhardt method and Chapman digital filter method (0.997) and the one-parameter digital filter method (0.976). The lowest correlation coefficient was observed in the local minimum method (0.620).

The low value of standard deviation indicates a better performance of the method in the separation of the baseflow (Hasani et al., 2012; Longobardi and Villani, 2008). The local minimum method, the Eckhardt method, the one-parameter digital filter method, and the Chapman digital filter method have a lower standard deviation than other methods (SD≤0.80). On the contrary, the highest standard deviation was observed in the EWMA method (SD≤1.32).

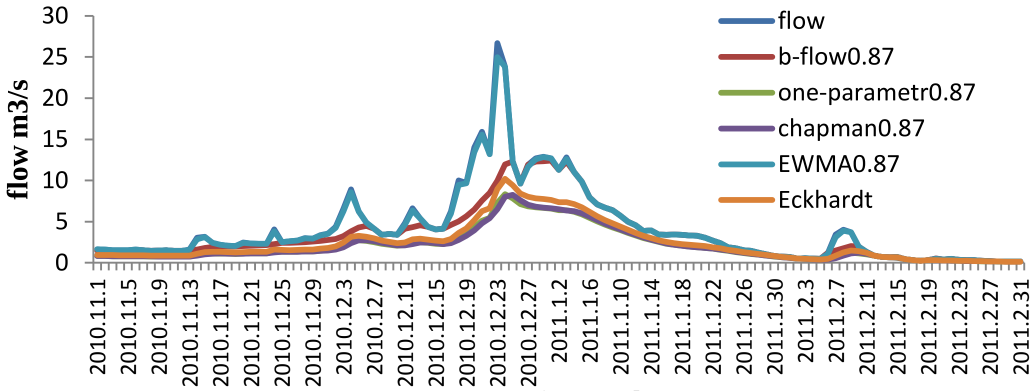

Fig 6. Separation of flow hydrograph with B-Flow, One-parameter, Chapman, EWMA, and Eckhardt methods at Arazkouse Station in the part of water Year (2009-2010)

Table 5. Results of comparison of B-Flow, One-parameter, Chapman, EWMA methods with three criteria of MAE, RMSE and correlation coefficient r at the studied stations

		Vatanah	**Taghi Abad**	**Gorgan dam**	**Arazkouseh**	**Nodeh**	**Jangaldeh**	**Lazoore**	**Tammer**
B-Flow	Standard deviation	0.07	0.13	4.64	1.63	0.61	0.41	0.66	0.50
	Average (m^3/s)	0.13	0.27	6.10	4.46	1.82	1.14	1.73	1.20
	Max (m3/s)	0.36	0.56	18.36	8.36	3.32	1.95	3.52	2.57
	Min (m^3/s)	0.03	0.08	0.24	1.74	0.98	0.38	0.80	0.55
	MAE	0.08	0.13	1.33	1.20	0.56	0.22	0.54	0.25
	RMSE	0.09	0.14	1.77	1.27	0.59	0.25	0.58	0.28
	r	0.65	0.92	0.89	0.89	0.90	0.96	0.78	0.97
r	Standard	0.05	0.09	2.77	1.05	0.34	0.28	0.39	0.31

	deviation								
	Average (m^3/s)	0.08	0.18	3.80	2.65	1.10	0.73	1.01	0.73
	Max (m3/s)	0.23	0.35	10.96	5.34	1.91	1.19	2.16	1.62
	Min (m^3/s)	0.01	0.05	0.15	1.10	0.62	0.23	0.45	0.31
	MAE	0.03	0.04	0.97	0.41	0.21	0.19	0.18	0.21
	RMSE	0.03	0.05	1.20	0.44	0.22	0.20	0.19	0.23
	r	0.90	0.99	0.99	0.98	0.99	0.99	0.67	0.99
Chapman	Standard deviation	0.05	0.08	2.76	1.04	0.34	0.27	0.39	0.31
	Average (m3/s)	0.08	0.17	3.76	2.64	1.05	0.71	1.01	0.72
	Max (m3/s)	0.23	0.35	10.94	5.29	1.91	1.19	2.15	1.62
	Min (m^3/s)	0.01	0.05	0.14	1.09	0.61	0.23	0.45	0.31
	MAE	0.03	0.04	1.01	0.42	0.21	0.21	0.18	0.22
	RMSE	0.03	0.04	1.23	0.46	0.22	0.22	0.20	0.24
	r	0.87	0.99	0.99	0.99	0.99	0.99	0.99	0.99
EWMA	Standard deviation	0.10	0.17	5.51	2.11	0.68	0.54	0.79	0.65
	Average (m3/s)	0.16	0.35	7.75	5.29	2.14	1.43	2.02	1.55
	Max (m3/s)	0.45	0.73	21.91	10.72	3.83	2.25	4.30	3.17
	Min (m^3/s)	0.03	0.10	0.33	2.12	1.28	0.42	0.90	0.61
	MAE	0.11	0.22	2.98	2.23	0.88	0.50	0.83	0.61
	RMSE	0.12	0.24	3.59	2.40	0.92	0.54	0.89	0.67
	r	0.63	0.85	0.83	0.78	0.89	0.95	0.64	0.97

Table 6. A summary of the statistical analysis of different methods of flow separation in Gorganroud Basin

	r	**RMSE**	**MAE**	**Min (m^3/s)**	**Max (m^3/s)**	**Average (m^3/s)**	**Standard deviation**
Local Minimum	0.620	0.42	0.32	0.38	3.64	1.42	0.79
Fixed Interval	0.754	0.42	0.33	0.51	4.38	1.81	0.98
Sliding Interval	0.791	0.61	0.52	0.57	4.88	2.04	1.08
B-Flow	0.871	0.62	0.54	0.60	4.90	2.08	1.08
One-parameter	0.976	0.32	0.28	0.36	2.97	1.28	0.66
Chapman	0.979	0.33	0.29	0.36	2.96	1.27	0.65
EWMA	0.818	1.17	1.04	0.72	5.92	2.59	1.32
Eckhardt	-	-	-	0.43	3.60	1.54	0.80

Conclusion

In this study, first, the baseflow separated by the Eckhardt method used as the basis for the comparison. The α parameter was determined via the analysis of the master recession curve (MRC) for each region. As they stated, selecting the correct filter in different regions can help to separate the baseflow with a high precision. The BFI_{max} parameter for the the the the each region was calculated through obtaining geological maps and determining the permeability coefficient for each formation. The lowest BFI_{max} values were observed in Nodeh and Taghi Abad stations, which indicates the low share of groundwater in the surface flows of the region. It is due to the type of formations in the studied areas, which is generally hard and rocky and impermeable. The maximum BFI_{max} was also observed in Tammar, Jangaldeh, and Gorgan dam stations, which is due to the permeability of the rocks in these areas which are formed by highly permeable alluvial rocks, fine permeable limestone, sandstone, shale, and moderately permeable dolomite. After determining these two parameters, using the

Eckhardt method as the best method the baseflow was determined and the baseflow index was calculated at the studied stations, and the results were used as a basis for comparison with other methods. The results showed that the one-parameter digital filter method and the Chapman digital filter method had the least mean absolute error and root mean squared error. They also had the highest correlation with the Eckhardt method and the least standard deviation in the studied area. Therefore, when the geological maps are not available in the area under the study to calculate BFI_{max}, these two methods can be used. The baseflow index can be a geo-hydrological characteristic of the basin. Using the Eckhardt method, the baseflow index was determined and it showed that the shared baseflow accounted for more than 50% of the total flow. The precise determination of this index shows the necessity and importance of the integrated management of surface water and groundwater as related resources.

It is recommended that further research is performed by use of different methods to determine the coefficient in Eckhardt relationship. Perform a sensitivity analysis on the two parameters of Eckhart equation to determine the most important parameter. Consequently, this should be the focus of future studies. Furthermore, comparison of Eckhart's relationship with mass balance equation and calibration Eckhart's digital filter parameters with mass balance and comparison of coefficients should be investigated in future studies. Also, it would be interesting to the determination of optimum Eckhardt BFI_{max} value and filter parameter values using Genetic Algorithm techniques. Although the empirical equations are effective tools for estimating the long-term contribution of annual baseflow and surface runoff to the annual total runoff instead of empirical equations, this relationship could probably be further improved through the application of artificial intelligence techniques due to capable of capturing both linear and complicated nonlinear relationships.

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