

Study of the environmental flow of rivers, a case study, Kashkan River, Iran

Elnaz Shahriari Nia, Gholamreza Asadollahfardi and Nima Heidarzadeh

ABSTRACT

Environmental flow is an essential factor in the survival of river ecosystems. Growing populations cause increased demand for water and a decrease in water available for habitat. The objective of this study was to estimate the environmental flow of the Kashkan River in Iran, where a dam is going to be built. Due to a lack of ecological data in the area, and to allocate a reasonable value of flow to environmental needs in the Kashkan River Basin, we applied several hydrological methods. We used Tennant, aquatic base flow (ABF), ABF of Maine, Hoppe, Arkansas and flow duration curve methods. We compared the results, and considered the estimated flow reported by the Ministry of Energy of Iran. We estimated the best value of environmental flow was a minimum amount equal to or exceeding 70% of the time (Q70) and a flow equal to or exceeded 95% of the time (Q95). Results indicated that Tennant is a suitable method for estimating the lowest value of flow, and is higher than the minimum values that should be allocated to the environmental flow. The amount of environmental flow that needs to be allocated to the river in the mainstream and a tributary are 6–14.3 m³/s and 0.7–1.14 m³/s, respectively.

Key words | aquatic base flow, Arkansas, environmental flow, flow duration curve, Hoppe, Tennant

Elnaz Shahriari Nia (corresponding author)
Gholamreza Asadollahfardi
Nima Heidarzadeh
Kharazmi University,
Tehran,
Iran
E-mail: e.shahriari@yahoo.com

INTRODUCTION

One of the basic needs of all creatures, including humans, is water, which plays a significant role in survival and development. However, population growth, economic development, food production and environmental pollution have raised concerns about access to fresh water. The natural environment of a river is one of the most important ecosystems that need enough water to survive. The importance of allocating a secure proportion of water to the environment is recognized all over the world. Several methods are available for estimating the environmental flow worldwide. The process of developing environmental flow requirement (EFR) methodologies is more advanced in some parts of the world such as Australia, England, Japan and Portugal; however, other countries such as Eastern Europe, much of Latin America, Africa and Asia, appear to be poorly advanced in this field (Tharme 2003). The EFR methods range from rapid ones to more comprehensive approaches that present

the required flow monthly and annually. The sum of estimated environmental flows over a year represents a total annual water volume, which could be allocated for environmental purposes (Smakhtin & Anputhas 2006; Kashaigili *et al.* 2007). The EFR methodologies are divided into four main categories, namely hydrological, hydraulic rating, habitat simulation (or rating), and holistic. In this study, because of the lack of ecological data, we focused on estimating the environmental flow of the Khashkan River using several hydrological methods. These methods are simple, low-cost, and rapid, with acceptable low levels of required data. Due to these advantages as well as their acceptable accuracy, they have been recommended in situations with no or poor ecological data (Wallingford 2002).

The hydrological methods are often referred to as fixed-percentage or look-up table methodologies, in which the environmental flow is a proportion of the natural flow of

the river (Cavendish & Duncan 1986; Milhous *et al.* 1989). Tharme (1996) and Smakhtin (2001) reviewed many of the well-established hydrological methods to derive flow indices for gauged and un-gauged basins. Consequently, they found that hydrological methods are considered to be the most appropriate methodologies in cases of data scarcity, especially ecological ones. The Gilan Regional Water Authority in Iran applied the Tennant method and used 10% of mean annual flow to estimate the instream flow in the Sefidrud River's basin (The Gilan Regional Water Authority 2009). Mulvaney & Park (2010) used the lowest flow of a river for 7 consecutive days that would be expected to occur once in 10 years (7Q10), and used the Georgia, Arkansas and South Carolina methods to estimate the environmental flow of the Mississippi River, and found the 7Q10 to be inexpensive and easy to apply. These methods needed limited personnel hours and were inexpensive; however, they were less accurate and effective. Generally, 7Qy is the lowest flow of a river for 7 consecutive days that would be expected to occur once in 'y' years. Masih *et al.* (2009) studied the semi-arid Karkhe Basin by examining statistical parameters, flow duration characteristics and trend analysis to provide a comprehensive assessment of surface water resources. They obtained different aspects that affect water resources in the region, and while available water is enough to meet all demands, different factors will cause water scarcity in the region in the future (Masih *et al.* 2009). The Murray-Darling Basin Authority (MDBA) (2012) used a repetitive process to estimate instream water requirements in the Lower Goulburn River, and developed site-specific flow indicators (Murray-Darling Basin Authority (MDBA) 2012). In a comparison of two methods of flow duration curve index (FDCI) and Stream flow Drought Index in analyzing the flow of rivers by hydrological-environmental drought index, Eslami & Shokouhi (2013) selected the FDCI for Mediterranean and semi-arid regions. In an effort to estimate the instream flow of the Foe Big Creek in Canada, Maunder & Hindley (2005) used several methods including the Tennant, Range of variability approach, Tessman and 7Q10. The lowest flow of a river for 7 consecutive days that would be expected to occur once in 2 years (7Q2), and the lowest flow of a river for 7 consecutive days that would be expected to occur once in 5 years (7Q5) were also used to estimate its instream flow. Modeling the environmental flow of Sg.

(River) Pelus, Toriman (2010) applied a flow duration curve (FDC) and 7Q10 in two stations on the river and indicated that average daily flows for the stations are 5.080 m³/s and 11.391 m³/s, respectively. Morrison (2013) assessed minimum stream flow requirements in Southern New England rivers using aquatic base flow (ABF) and wetted perimeter (WP) methods, and obtained stream flows below the value estimated by ABF between 6–21% of the time and below the estimated value of WP flow between 37–72% of the time.

We studied the Kashkan River as one of the important rivers in Lorestan province, Iran, which covers one third of the province. The Lorastan Water Authority intends to construct a dam on the river to transfer water to other locations that encounter water scarcities. The Kashkan River has two main tributaries, the Horroud River and the Aleshtar River. The river and its tributaries are the vital source of water in the cities of Aleshtar, Khorramabad and Poldokhtar. The huge demand of water for human needs has caused damage to the ecological environment. We studied the Doab Veisian and Baraftab hydrometric stations on the river. Due to the shortage of ecological information on the Kashkan River, hydrological methods are more proper to use, as they are the simplest and involve the least data intensive methods (Wallingford 2002).

Because the selection of suitable methods to estimate an environmental stream flow in a river is sophisticated, researchers have applied several approaches. Chen & Chau (2006) applied a prototype knowledge-based system for model manipulation for the hydrological processes. In other research, Chau (2007) developed a prototype ontology-based knowledge management system. He integrated a knowledge management system into a numerical flow and water quality modeling using artificial intelligence (AI) technology. He stated that the KM system could assist the user in the selection of a model and its parameters (Chau 2007).

In this study, we applied some common hydrological methods such as the Tennant, ABF, ABF of Maine, 7Qy, Hoppe, Arkansas and FDC methods to estimate the environmental flow of the Kashkan River. To determine the best value, we compared different amounts of flow measured by different methods with the standards provided by the Iranian Ministry of Energy (the Tennant method in its fair condition) and the minimum amounts of Q70 and Q95.

We had some limitations, such as the lack of ecological data, and time and budget constraints for the performance of sampling and collection of data. However, our case study was necessary because the construction of a dam on the Kashkan River may change the ecological situation of the river. Therefore, we decided to estimate the environmental flow of the river by using hydrological methods. In this regard, we used several common hydrological methods from different parts of the world to research our case study, and used the studies of other researchers which estimated the range of environmental flow, to achieve the most accurate results that were possible with the available data.

Study area: the Kashkan River

The study area is the Kashkan River, one of the most important subbasins of the Karkhe Basin in Lorestan province in Iran. The Horroud river and the Aleshtar river are two tributaries of the Kashkan River that stem from the Takhte Kouh, the Babahor and the Varkhash mountains. The drainage area of the river is approximately 9,498 km², and most of the watershed consists of mountains and uplands with poor vegetation (Allahyari Pour 2011). The flow varies from less than 0.5 m³/s to more than 190 m³/s, with an average of 30 m³/s. The mean annual precipitation ranges from 217 to 740 mm/y in the mountainous parts and the average value of temperature varies from -3 to 21 °C across the Kashkan Basin (Negaresh *et al.* 2011; Tizro *et al.* 2014). The estimated water demand for irrigation, drinking and industrial needs in the study area are 1,325, 5.75 and 0.03 million cubic meters per year, respectively (Iran Water and Power Resources Development Co. 2008). Design and implementation of a dam on the river are planned. The Kashkan formation is in the Zagros fold-thrust belt, with a 2,000 km extension from southeastern Turkey to southwestern Iran, which is intercalated between two marine limestone formations consisting of conglomerates,

sandstones and siltstones. The accumulated sediments are low-sinuosity and low-gradient braided-river. The region consists of twelve lithofacies, three ichnosubfacies and seven architectural elements, with meandering characteristics represented by overbank deposits and large bars (Yeganeh *et al.* 2012). The mean annual flow in the Baraftab station (a gauging station located in a tributary), which has a drainage area of 1,108 km², is about 1.71 m³/s. The Doab Veisian station (a gauging station located in the mainstream) has a drainage area of about 3,670 km² with a mean annual flow of 30.42 m³/s. Table 1 and Figure 1 indicate the characteristics of the two stations in the rivers.

METHODOLOGY

Different hydrometric stations were installed on the tributaries of the river, each having different lengths of data. We collected the required data from the Energy Ministry of Islamic Republic of Iran and the Lorestan Regional Water Authority. The series of observed data, which were the mean daily flow of the Kashkan River, covered 27 years (1978–2004) in the Baraftab station and 31 years (1967–2005 with a gap between 1991–1998) in the Doab Veisian station used in this study. These periods all have high-flow (wet), low-flow (dry), and normal river flow conditions as shown in Figure 2. The data are a little old; however, fresh daily flow data were not accessible to the authors. The variability of the river flow is also negligible during the historical records. Therefore, using the available data to estimate the environmental flow of the river is acceptable. The minimum flow in a river can also be predicted by different methods such as neural network river forecasting, interactive time series modeling and support vector regression (Cheng *et al.* 2005; Wu *et al.* 2008; Shahriari Nia 2011; Taormina & Chau 2015). Table 2 indicates the

Table 1 | Characteristics of the two hydrometric stations (Lorestan Regional Water Authority 2012; Ministry of Energy 2014)

River	Station name	Longitude	Latitude	Elevation, masl ^a	Recorded length	Basin area (km ²)
Madian Roud	Baraftab	47° 74'	33° 42'	780	1978–2005	1,108
Kashkan	Doab Veisian	47° 97'	33° 59'	960	1973–2004	3,670

^aMeters above sea level.

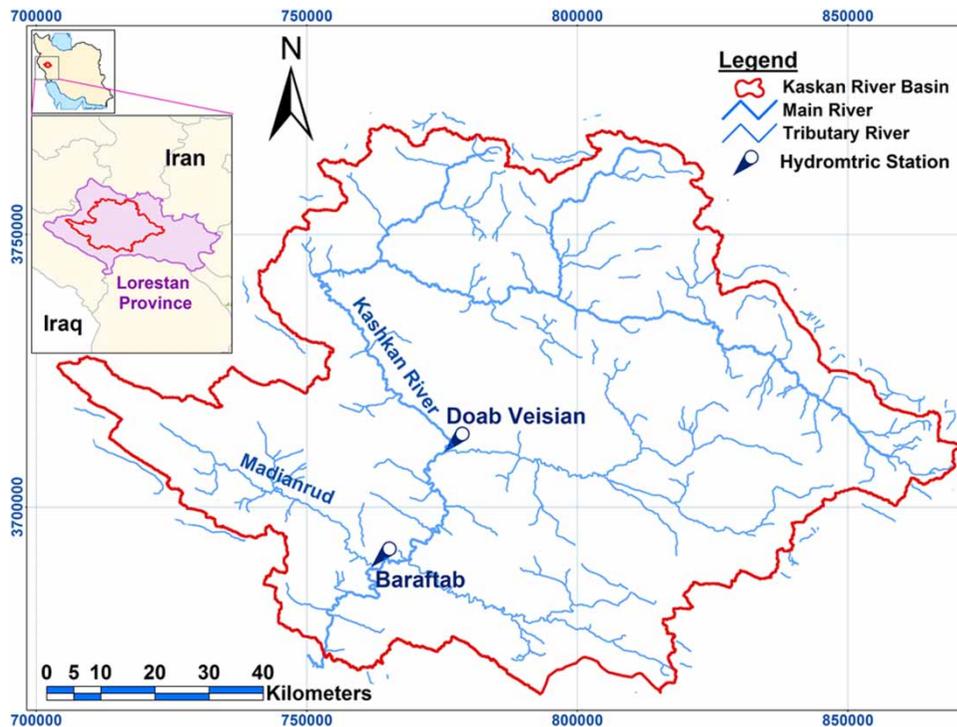


Figure 1 | Geographical location of the Kashkan Basin in Lorestan Province, Iran.

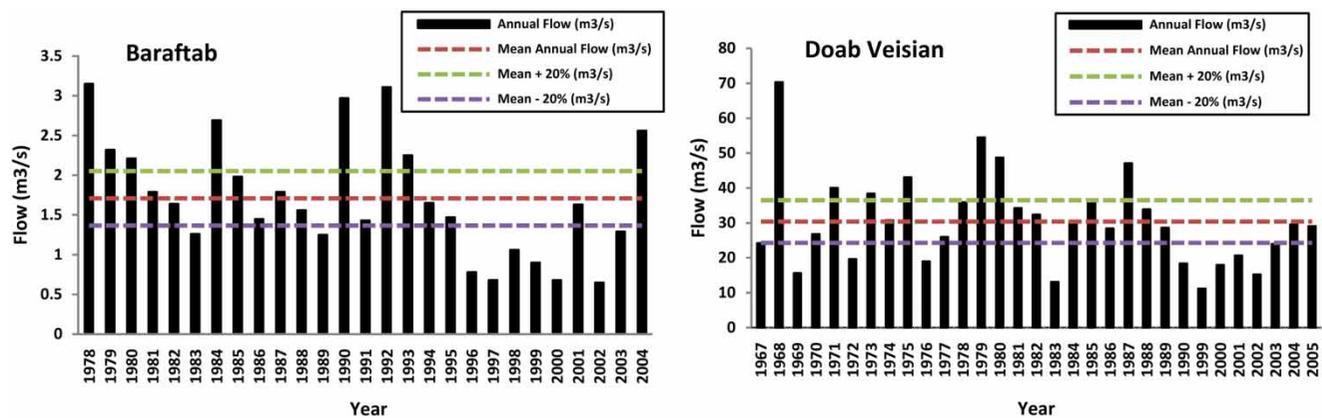


Figure 2 | Annual flow variations of the Kashkan River and its tributaries in selected EFR estimation periods.

statistical summary of annual flows in the Doab Veisian and the Baraftab hydrometric stations.

HYDROLOGICAL METHODS

Hydrological methods rely on historical flow data recorded at a hydrometric station on a river (Allain & El-Jabi 2002). If

historical data are not available, regional equations can be developed, or a correlation can be established between the basin in question and the surrounding basins. Little or no fieldwork is required for this method, its cost is considerably lower, and it is considered the simplest and quickest assessment technique. One of the downsides of using hydrological methods, also referred to as ‘office’ methods, is the fact that aquatic biota is not taken into account when calculating

Table 2 | The statistical summary of annual flows in the Doab Veisian and the Baraftab Hydrometric stations

Annual runoff	Mean		Minimum		Maximum	
	Doab Veisian station	Baraftab station	Doab Veisian station	Baraftab station	Doab Veisian station	Baraftab station
Average (m ³ /s)	30.42	1.71	6.02 September	0.71 July	84.11 March	2.95 April
Maximum (m ³ /s)	70.35	3.15	9.47 September	1.43 July	196.39 April	18.23 November
Minimum (m ³ /s)	11.21	0.65	1.57 August	0.09 July	27.36 April	0.91 February
Standard deviation	13.01	0.74	2.42 September	0.42 September	52.18 April	3.57 November
Coefficient of variation	0.43	0.26	0.4 September	0.04 September	0.69 May	1.56 November

instream flow values. We introduced some hydrological methods which are detailed in the following sections.

Tennant method

The Tennant method (Tennant 1976), also referred to as the ‘Montana’ method, is the most commonly applied hydrological technique worldwide (Tharme 2003). In developing the method, Tennant (1976) measured variables from hundreds of gauged flow regimens in 21 states. Tennant (1976) proposed that certain flows could achieve the maintenance of particular amounts of habitat (Table 3). Arthington & Zalucki (1998) observed that a flow range of 0–10% of the

mean annual flow would cause the greatest changes in habitat. The method is designed for application in streams of all sizes, for cold and warm water fish species, as well as for recreation, wildlife and other environmental resources (Australian Department of the Environment & Chinese Ministry of Water Resources 2008).

FDC

An FDC is one of the most informative means of displaying the complete range of river discharges, from low flows to flood events (Smakhtin 2001). Using an average daily discharge data, FDCs are cumulative frequency distributions that indicate the percentage of time that a specified discharge is equaled or exceeded during a period of interest (daily, monthly, annually, or the entire recorded period) (Pyrcce 2004). An FDC can be calculated by ranking the river flow data. The first use of this curve was attributed to Clemens Herschel in about 1880 (Foster 1934). A duration curve can be calculated based on multiple years of data, preferably using records for more than 20 years (Caissie et al. 2007). Smakhtin (2001) indicated that the ‘design’ low flow range of an FDC is in the 70–99% range, or the Q70 (the amount of flow that occurs in less than 70% of cases) to Q99 (the amount of flow that occurs in less than 99% of cases) range. The Q95 and Q90 flows are often used as low flow indices in government literature and academic sources (Pyrcce 2004; Özdemir et al. 2007). The 90% flow duration method (Q90) recommends the flow for each month to be

Table 3 | Critical minimum flows required for fish, wildlife, and recreation in streams identified by Tennant (Australian Department of the Environment & Chinese Ministry of Water Resources 2008)

Description of flows	% of mean annual flow	
	Dry season	Wet season
Flushing or maximum	200% of the mean annual flow	
Optimum range	60–100% of the mean annual flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	0–10% of the mean annual flow	

a minimum of the flow that is equalled or exceeded 90% of the time.

ABF method

The US Fish and Wildlife Service (USFWS) developed the ABF method as a temporary policy for minimum stream flows in New England (Özdemir *et al.* 2007). The USFWS ABF method assumes that August is the month when the metabolic stress to aquatic organisms is at its highest and flow maintenance is vital. Considering existing adequate records, the USFWS recommends that the median of the monthly mean August flows will be adequate throughout the year unless additional flow releases are necessary for fish spawning and incubation. If spawning and incubation are issues, the USFWS recommends flow releases equivalent to the historical median monthly mean stream flow throughout the applicable spawning and incubation period. Where inadequate records exist, or for rivers regulated by dams or upstream diversions, the USFWS recommends using 0.5 cfs (cubic feet per second per square mile). If spawning and incubation is concerned, the USFWS recommendations are 1.0 cfs in the fall/winter and 4.0 cfs in the spring (Table 4) (Richardson & Ridem 2005; Özdemir *et al.* 2007; Behrouzi Rad 2013).

Currently, the New England ABF method is used on a more seasonal basis than the previous August Q50 (discharge equal to or exceeded 50% of the time). For example, in the state of Maine, the ‘Seasonal ABF’ is determined as the median flow for six different time periods or ‘seasons’:

1. Winter (January 1–March 15): a flow equal to the February Q50.
2. Spring (March 16–May 15): a flow equal to the April Q50.
3. Early summer (May 16–June 30): a flow equal to the June Q50.

Table 4 | Allocation of river’s environmental flow in the ABF method

Season	Period	Standard mean flow	Assumed amount ^a (cfs)
Fall/Winter	11 Oct–30 March	February	1
Spring	1 April–30 May	April/May	4
Summer	1 Jun–30 Sep	August	0.5

^aThis is used when adequate data are not in hand.

4. Summer (July 1–September 15): a flow equal to the August Q50.
5. Fall (September 16–November 15): a flow equal to the October Q50.
6. Early winter (November 16–December 31): a flow equal to the December Q50.

The above ABF flow do not describe the environmental flow that needs to be maintained in different rivers in Maine, but indicate the level of flow when no further abstraction of water is allowed (called ‘hands-off flow’) (Linnansaari *et al.* 2012).

The Hoppe method

This method was developed from studies on the Frying Pan River, Colorado and estimates flow requirements as percentiles on an annual FDC for salmonid species. Through studies, researchers found that a flow that is equal to or exceeds 17% of the time is set for a 48-hour period to maintain flushing flows. A flow that is equal to or exceeds 40% of the time to protect spawning flows is recommended. A flow that is equal to or exceeds 80% of the time to maintain flows for food production and aquatic cover is recommended (Institute for Natural Systems Engineering, Utah Water Research Laboratory, Utah State University 1999).

The biological rationale for this approach was adapted for the Klamath River by using the monthly 40% exceedance flows to protect spawning and incubation for the September through February period. A monthly 60% exceedance flow during the March through May period is needed to protect incubating eggs. A monthly 80% exceedance flow for the June through August period is necessary for food production and the protection of fish rearing habitats. Actual monthly exceedance values are utilized to preserve the characteristics of the natural stream patterns within a normal water year (Evans & England 1995; Institute for Natural Systems Engineering 1999; Serban 2004).

The Arkansas method

From all of the methods that can be used to estimate practical and defendable EFRs all over the world, hydrologists have found that technique varies from region to region

and state to state (Linnansaari *et al.* 2012). Consequently, a request was made for fish and wildlife instream flow guidelines for 56 streams in Arkansas. The Arkansas method is based on the premise that the average flow of a stream is a composite of the size of the drainage basin, geomorphology of the stream channel, climate, vegetation type and abundance, and related land uses (Filipek *et al.* 1987). This method divides the water year into three physical/biological units or seasons. These units are categorized by the physical processes that occur in the stream and critical life cycle stages of fish and other aquatic organisms inhabiting the stream (Reiser *et al.* 1989; Davis 2013).

RESULTS AND DISCUSSION

We applied the five hydrological methods mentioned to the sets of data. The specific instream flow was calculated for each of the five hydrological methods for each basin. Table 5 indicates the results of estimating the environmental flow using different methods in the Doab Veisian station.

Estimating the environmental flow can be classified according to the following methods.

The Tennant method

Comparing the flow with the mean annual flow of the stream, the year was divided into two wet and dry seasons.

The results showed that to keep the stream in its ‘excellent’ condition, we needed to allocate 30–50% of the average flow of the river to the environmental flow. In this situation, the ecosystem would be kept in a good condition.

FDC

By ranking the river flow data, we obtained the curves for the Doab Veisian and the Baraftab stations (Figure 3). As indicated by Figure 3, the curves are almost uniform and about 95% of the flows in the Doab Veisian and the Baraftab stations were less than 150 and 5 cubic meters per second, respectively.

The Arkansas method

As indicated in Figures 4 and 5, a very high percentage of the average flow of the river should be allocated to environmental flow. This flow would make an ideal condition of the stream ecosystem; however, because the Kashkan River is one of the main water resources for the region, this huge amount of flow is not suggested because the life of the people depends on this resource.

The Hoppe method

In this method, we divided the year into three seasons and allocated 80, 60 and 40% of the monthly mean flow for

Table 5 | The environmental flow of the Kashkan River (mean monthly flow) – the Doab Veisian station

		Jan	Feb	Mar ^a	Apr	May ^a	Jun	Jul	Aug	Sept	Oct	Nov ^a	Dec
Tennant (m ³ /s)	Fair	3.0	9.1	9.1	9.1	9.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Good	6.1	12.2	12.2	12.2	12.2	6.1	6.1	6.1	6.1	6.1	6.1	6.1
	Excellent	9.1	15.2	15.2	15.2	15.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Arkansas (m ³ /s)		18.2	27.8	50.5	57.4	27.8	9.0	4.2	3.2	3.0	4.2	8.6	15.7
Hoppe (m ³ /s)		12.1	18.5	50.5	49.2	23.9	10.3	6.7	5.1	2.4	3.4	5.7	10.4
FDC	Q90 (m ³ /s)	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
	Q70 (m ³ /s)	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
	Q50 (m ³ /s)	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
ABF (Maine) (m ³ /s)		33.8	33.8	33.8	67.5	67.5	10.6	6.3	6.3	6.3	6.3	6.3	17.7
ABF (m ³ /s)		33.8	33.8	33.8	48.0	48.0	48.0	6.3	6.3	6.3	33.8	33.8	33.8
Monthly mean flow (m ³ /s)		30.3	46.3	84.1	82	39.8	12.9	8.4	6.4	6	8.5	14.3	26.1

^aThe estimated value of flow by ABF (Maine) method in the middle of the months of March, May and November varied from 33.8 to 67.5, 67.5 to 10.6 and 6.3 to 14.3, respectively in the Doab Veisian station.

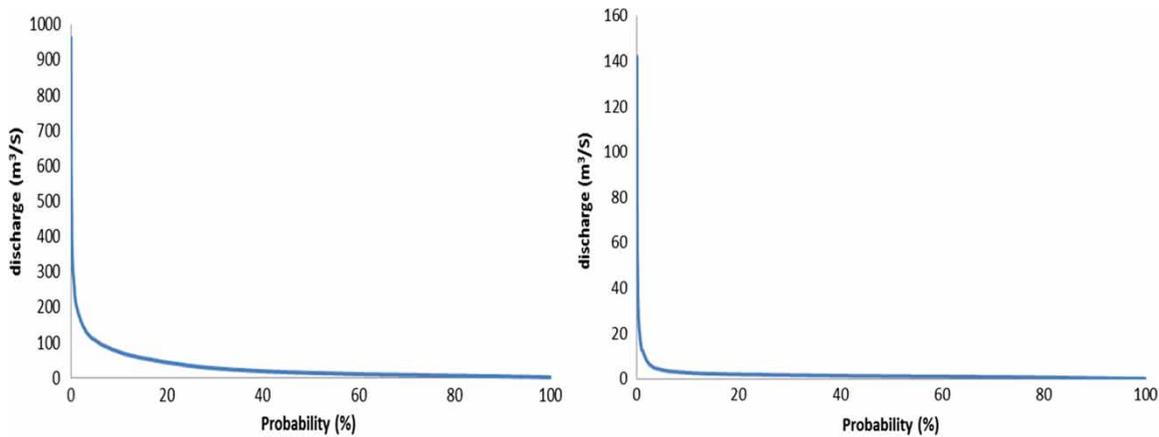


Figure 3 | FDCs in the Doab Veisian (a) and Baraftab (b) stations.

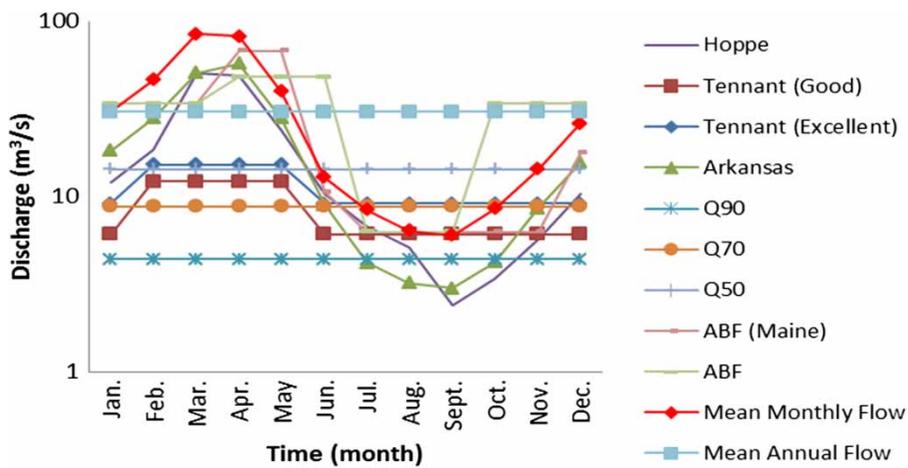


Figure 4 | The environmental flow of the Kashkan River – the Doab Veisian station.

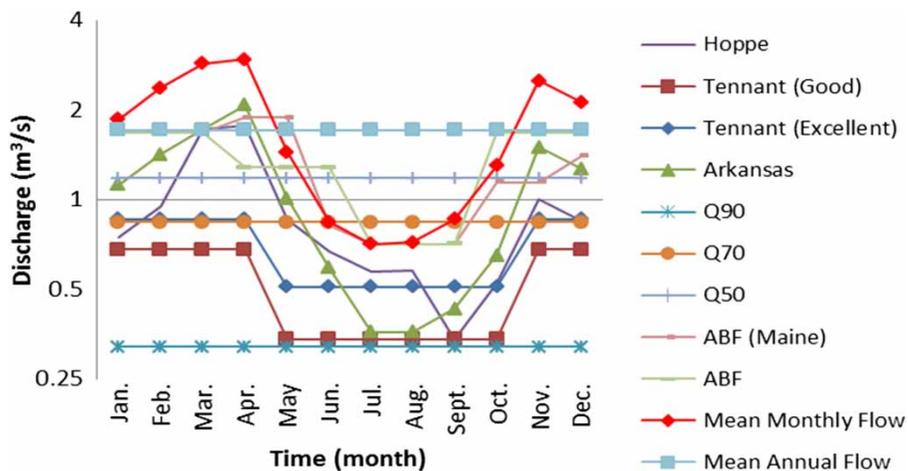


Figure 5 | The environmental flow of the Kashkan River – the Baraftab station.

each. Comparing the result of the Hoppe method to what we achieved by other methods, we describe the estimated value of each in the following paragraphs.

The ABF and the ABF (Maine)

As indicated in Figures 4 and 5, the estimated value of these methods in more than 6 months of a year was more than the monthly mean flow of the Kashkan River. The result is logically unsuitable, because the ecosystem of a river is adapted to the natural flow of the river. As mentioned previously, we used several methods from all over the world. Iran is located in an arid and semi-arid region, and these methods were developed in humid regions of the USA where most of the rivers are perennial and have a high value of flow from melting ice and snow. According to the Fattahpour *et al.* (2014) study of the Sefidroud River, Iran, which achieved the same result as this study, it was found that the ABF method is not suitable to use for rivers in arid and semi-arid regions as it overestimates the amount of environmental flow, which can explain the excessive flow estimates by these methods for the Kashkan River (Morrison 2013; Fattahpour *et al.* 2014).

Table 5 and Figure 4 indicate how the estimated environmental flow of the river varies from one method to another.

As the table describes, the river has its highest flow value in March and April and its lowest flow value in August and September.

Regarding Table 5 and Figure 4, the results indicate that the estimated instream flow using several methods is highly variable in the first 6 months of the year, but in the second half of the year the flow varies between 3 and 9 m³/s. During the first half of the year, the Hoppe method, ABF, ABF (Maine) and the Arkansas method describe the highest amount of flow, and this flow is an ideal flow for the river's ecosystem. However, allocating this amount of water is irrational as the human population in this region is highly dependent on the flow of the Kashkan River for their drinking and agricultural needs, and allocating that amount of water to the ecosystem does not leave an appropriate volume of water for human use.

Table 6 indicates the environmental flow in the Baraftab station. Figure 5 presents how the flow varies from one month to another. As described in Figure 5, the river has its highest value of flow in March and April and its lowest value in August and September.

Considering Tables 5 and 6 and Figures 4 and 5, Q90 estimated the least amount of flow, and the ABF and the ABF (Maine) assessed the most amount of environmental flow of the river. Similar to what we indicated in the estimated instream flow in the Doab Veisian station, the amount is highly estimated by the ABF, the ABF (Maine)

Table 6 | The environmental flow of the Kashkan River (mean monthly flow) – the Baraftab station

		Jan	Feb	Mar ^a	Apr	May ^a	Jun	Jul	Aug	Sept	Oct	Nov ^a	Dec
Tennant (m ³ /s)	Fair	0.51	0.51	0.51	0.51	0.17	0.17	0.17	0.17	0.17	0.17	0.51	0.51
	Good	0.68	0.68	0.68	0.68	0.34	0.34	0.34	0.34	0.34	0.34	0.68	0.68
	Excellent	0.86	0.86	0.86	0.86	0.51	0.51	0.51	0.51	0.51	0.51	0.86	0.86
Arkansas (m ³ /s)		1.12	1.42	1.72	2.07	1.01	0.59	0.36	0.36	0.43	0.65	1.5	1.27
Hoppe (m ³ /s)		0.75	0.95	1.72	1.77	0.86	0.67	0.57	0.58	0.34	0.52	1	0.85
FDC	Q90 (m ³ /s)	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
	Q70 (m ³ /s)	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	Q50 (m ³ /s)	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
ABF (Maine) (m ³ /s)		1.68	1.68	1.68	1.88	1.88	0.82	0.71	0.71	0.71	1.14	1.14	1.4
ABF (m ³ /s)		1.68	1.68	1.68	1.68	1.28	1.28	1.28	0.71	0.71	0.71	1.68	1.68
Monthly mean flow (m ³ /s)		1.86	2.37	2.86	2.95	1.44	0.84	0.71	0.72	0.86	1.3	2.5	2.12

^aThe estimated value of flow by ABF (Maine) method in the middle of the months of March, May, September and November varied from 1.68 to 1.88, 1.88 to 0.82, 0.71 to 1.14 and 1.14 to 1.4, respectively in the Baraftab station.

and the Arkansas methods in spring, fall and winter, and is overestimated by the Hoppe method in the spring.

This study is the first effort to estimate the instream flow for the Kashkan River. Therefore, we used the studies of other researchers in our study. In this regard, Q95 and Q90 are the amounts that cannot provide sufficient water for the ecosystem. The environmental flow should be higher than Q90, otherwise the ecosystem will be in danger and the quality of the river will deteriorate (Caissie & El-Jabi 1995; Babu & Kumara 2009). In addition, the growth rate of fish will significantly reduce, and the long-term effects on the fish population will be irreparable (Acreman & Ferguson 2010; Armstrong & Nislow 2012). Smakhtin (2001) stated that flows exceeding 70–99% of time are usually widely considered as design low flows. As a result, to protect the environment, we considered a flow of below Q70 as a threshold that disrupts ecosystems and the environment, and flows of more than Q70 to maintain ecosystems in a safe situation. We considered flows that were estimated by different approaches that reached environmental flows higher than Q70. Tables 7 and 8 present the estimated environmental flows for the Doab Veisian and the Baraftab stations, respectively.

As mentioned previously, we estimated the amount of environmental flow of the Kashkan River in the two hydrometric stations. Our results indicate that the suitable method to estimate the environmental flow of the Kashkan River is the Tenant method, as this method determined the lowest amount of flow that exceeds the minimum flow of Q70. Using this method, we allocated approximately 9 and 0.86 cubic meters per second for the river's

mainstream and a tributary, respectively. As illustrated in Figures 4 and 5, the Q70 was higher than the mean monthly flow of the river in the months of June to September in the Baraftab station and July to October in the Doab Veisian station. The ecosystem of a river adapts to the river's condition and its monthly flow over a long period of time, and the best flow for an ecosystem is the river's monthly flow (McCartney *et al.* 2013). Hence, we considered the mean monthly flow as the environmental flow in the mentioned months (Figures 6 and 7).

We suggested that it would be a good idea to consider making regulatory structures to accumulate water to provide enough water for human needs in the rest of the year. We used several methods and achieved different amounts of flow, which were constant and variable in a year. We selected the Tennant method as the proper method to estimate the environmental river flow because of the situation of the river and its flow. We estimated an almost constant flow of the river, although we had an exception in the Baraftab station. While estimating the environmental flow for October, we found that the lowest value of flow that exceeded Q70 was calculated by the Hoppe method. Mohamoud (2004) also stated that the proper flow of a river should be between Q70 and Q40 to keep the environment in good condition and save water for human beings. We checked if the estimated flow was in the mentioned range or not. Our results indicated that, except for July to October in the Doab Veisian station and June to September in the Baraftab station, the Q70 was higher than the average flow. Our estimated flow was between Q62 to Q65 for the Doab Veisian station and Q53 to Q60 in the Baraftab station.

Table 7 | Environmental flow of the Kashkan River – the Doab Veisian station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Environmental flow (m ³ /s)	9.1	9.1	9.1	9.1	9.1	9.1	8.4	6.41	6.02	8.45	9.1	9.1
Mean monthly flow (m ³ /s)	30.34	46.3	84.11	81.98	39.78	12.87	8.4	6.41	6.02	8.45	14.29	26.1

Table 8 | Environmental flow of the Kashkan River – the Baraftab station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Environmental flow (m ³ /s)	0.86	0.86	0.86	0.86	0.86	0.84	0.71	0.72	0.86	1.14	0.86	0.85
Mean monthly flow (m ³ /s)	1.86	2.37	2.86	2.95	1.44	0.84	0.71	0.72	0.86	1.30	2.50	2.12

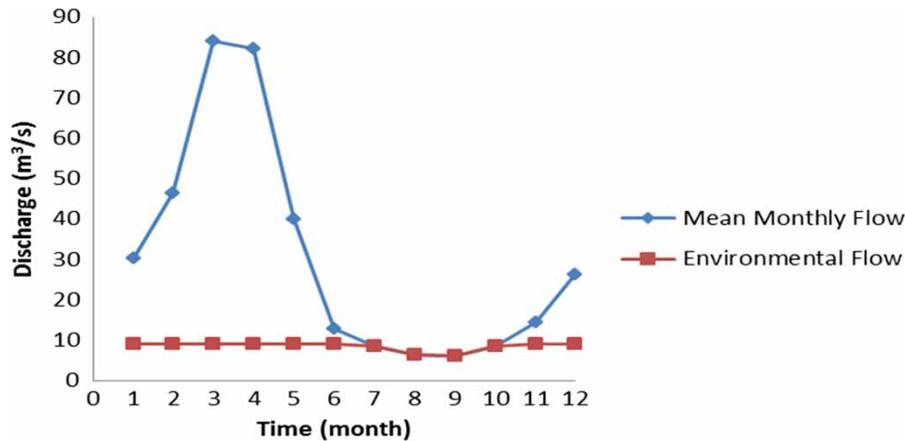


Figure 6 | Environmental flow of the Kashkan River – the Doab Veisian station.

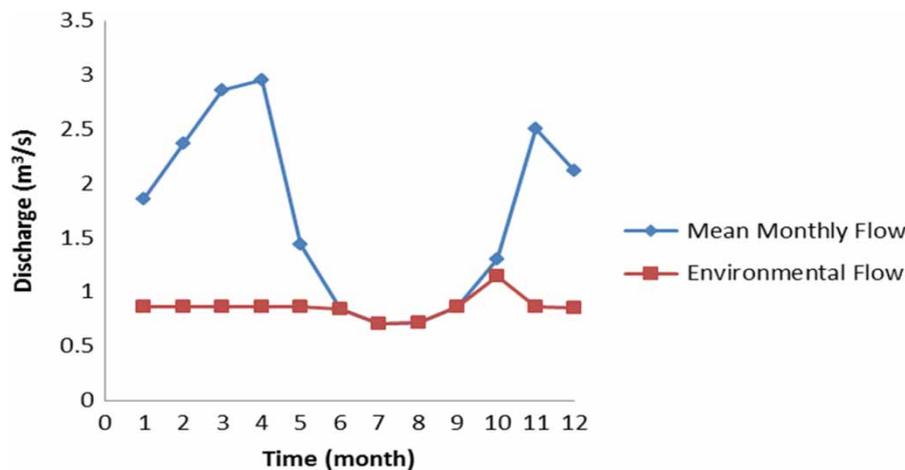


Figure 7 | Environmental flow of the Kashkan River – the Baraftab station.

Figure 8 indicates the approach that we used to estimate the environmental flow of the Kashkan River.

Fattahpour *et al.* (2014) estimated an amount of 12.7 m³/s environmental flow of the Sefidrud river. Dubey *et al.* (2013) found the Tennant method to be the acceptable method for estimating the instream flow of the Narmada River. They allocated amounts of 50.6–73.5 m³/s at the Sandia gauging site, 42.8–52.5 m³/s for the Barman site, 0.42–9.2 m³/s for the Manot site and 0.71–4.05 m³/s for the Dindori gauging site of the river. Assessing the instream flow of the Qezel Ozan basin, the Gilan Regional Water Authority used the Tennant method and estimated the amount of environmental flow at 0.02–1.3 m³/s for the Gerami Dam, 0.11–6.2 m³/s for the Sahand Dam, and

0.4–8 m³/s for the Taleqan Dam (Gilan Regional Water Authority 2009). In comparison with these allocated amounts of flow that took place in arid and semi-arid regions, reports of the Ministry of Energy of Iran for environmental flows indicate that the Tennant method is the suitable method for estimating environmental flows. Therefore, using the Tennant method to estimate the Kashkan River's flow is rational and acceptable. In addition, the advantage of our study in comparison with similar projects is that we used several methods of assessment from all over the world and compared them to estimate the suitable value of environmental flow. We did not carry out a sensitivity analysis, because only the amount of flow was a key parameter to compute environmental flow.

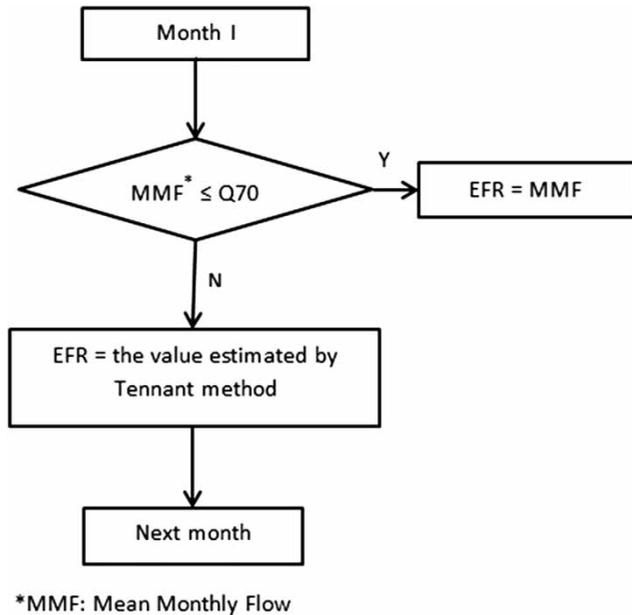


Figure 8 | The approach applied in this study to estimate the environmental flow of the Kashkan River.

CONCLUSIONS

We used several methods to assess the environmental flow of the Kashkan River, Iran in the Doab Veisian and the Baraftab hydrometric stations. Our study was the first research on the river.

The most important limitation we encountered was a lack of ecological data. Because of time and monetary constraints, we were not able to monitor ecological sampling. Therefore, we suggest studying the estimation of the environmental flow of habitats and holistic methods, and comparing the result of those methods to our study. Other studies would be the consideration of ecological factors such as the type of fish, their flow needs, their population and other hydrological and water quality factors, the effects of changes in water levels, quality of streams, and possible changes in the ecosystem.

Considering the results and discussion on the environmental flow for two stations in the Khashkan River, we summarized the following conclusions:

- Considering the lack of sufficient ecological data, the suitable hydrological method to evaluate the environmental flow of the Kashkan River may be the Tennant method.

Comparing the results of different methods, we obtained an instream flow for the Kashkan River of about 6–14.3 m³/s in the Doab Vesian station and 0.7–1.1 m³/s in the Baraftab station.

- We reached our estimated value of the environmental flow that was proper for the Khashkan River. The amount of flow in the two stations was between Q70 (the threshold below which the amount of flow disrupts ecosystems and the environment) and Q40 (the low end of medium flow conditions).
- The amount of environmental flow for the Baraftab station in the months of June to September and for the Doab Veisian station in the months of July to October was estimated to be equal to the river's monthly mean flow. Therefore, we suggest further studies to make a regulatory structure on the river to collect water in other months to fulfill human needs for drinking and agricultural water.
- Q95 and Q90 do not provide sufficient amounts of flow for the ecosystem of the Kashkan River and the minimum value of the flow of the river should exceed Q70, which is the amount of the low flow of the river.
- Application of the ABF and the ABF (Maine) methods is not recommended in this region as they overestimate the environmental flow for most of the year.
- It is recommended in situations that lack enough ecological data and feasibility studies of water dependent structures (such as weirs, dams, pump stations, etc.), the environmental flow of a river be estimated by hydrological methods. In addition, during this phase and based on available data, future supplementary studies and their related field surveys can be started. In this case study, we found that the Tennant method is suitable for the estimation of EFR.

ACKNOWLEDGEMENTS

The authors express their thanks to the Lorestan Regional Water Authority in Iran and the Environmental Engineering Group of Kharazmi University for providing the necessary help and research facility to conduct the current study as part of a Masters thesis (Shahriari Nia

2015). We wish to acknowledge Mr Ernest Rammel's assistance in editing the manuscript.

REFERENCES

- Acreman, M. C. & Ferguson, A. J. D. 2010 [Environmental flows and the European water framework directive](#). *Freshw. Biol.* **55**, 32–48.
- Allahyari Pour, F. 2011 Quality assessment of Karkheh River on the basis of Aq. Qa in Iran. *Adv. Environ. Biol.* **5** (8), 2377–2381.
- Allain, M. & El-Jabi, N. 2002 Hydrological approach to instream flow evaluation: a sensitivity analysis. In: *Annual Conference of the Canadian Society for Civil Engineering*. Montréal, Québec, Canada.
- Armstrong, J. D. & Nislow, K. H. 2012 [Modeling approaches for relating effects of change in river flow to populations of Atlantic salmon and brown trout](#). *Fish. Manage. Ecol.* **19**, 527–536.
- Arthington, A. H. & Zalucki, J. M. 1998 *Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Methods*. Land and Water Resources Research and Development Corporation, Canberra, Australian Capital Territory.
- Assessment of Environmental Effect Report of Tange Mashoore's Dam and Hydroelectric Power Plant* 2008 Iran Water and Power Resources Development Co., p. 33.
- Babu, K. L. & Kumara, H. B. K. 2009 Environmental flows in river basins: a case study of River Bhadra. *Curr. Sci.* **96** (4), 475–479.
- Behrouzi Rad, B. 2013 *Environmental Water of Rivers*, 1st edn. Jaam e Andishe Publication, Tehran, Iran.
- Caissie, D. & El-Jabi, N. 1995 [Comparison and regionalization of hydrologically based instream flow techniques in Atlantic Canada](#). *Can. J. Civil Eng.* **22**, 235–246.
- Caissie, D., El-Jabi, N. & Hebert, C. 2007 [Comparison of hydrologically based instream flow methods using a resampling technique](#). *Can. J. Civil Eng.* **34**, 66–74.
- Cavendish, M. G. & Duncan, M. I. 1986 Use of the instream flow incremental methodology: a tool for negotiation. *Environmental Impact Assessment Review* **6**, 347–363.
- Chau, K. W. 2007 [An ontology-based knowledge management system for flow and water quality modeling](#). *Adv. Eng. Softw.* **38** (3), 172–181.
- Chen, W. & Chau, K. W. 2006 [Intelligent manipulation and calibration of parameters for hydrological models](#). *Int. J. Environ. Pollut.* **28** (3–4), 432–447.
- Cheng, C.T., Chau, K. W., Sun, Y. G. & Lin, J. Y. 2005 Long-term prediction of discharges in Manwan Reservoir using artificial neural network models, ISNN 2005. *Lecture Notes in Computer Science* **3498**, 1040–1045.
- Davis, M. M. 2013 Environmental flow science: lessons learned from selected environmental flow programs. Arkansas Environmental Flow Science Advisory Board, Southeast Aquatic Resources Partnership (SARP) presentation, p. 244.
- Dubey, A., Kant, D., Singh, O. & Pandey, R. P. 2013 A comparative study of environmental flow requirement approaches using hydrological index methods. *J. Indian Water Resour. Soc.* **33** (3), 20–27.
- Eslami, A. & Shokouhi, A. 2013 Stream flows analysis using an environmental based hydrological drought index. *J. Watershed Eng. Manage.* **5** (2), 125–133.
- Evaluation of Interim Instream Flow Needs in the Klamath River, Phase 1, Final report. Prepared for Department of the Interior* 1999 Institute for Natural Systems Engineering (INSE), Utah Water Research Laboratory (UWRL), Utah State University (USU).
- Evans, J. W. & England, R. H. 1995 *A Recommended Method to Protect Instream Flows in Georgia*. Wildlife Resources Division, Virginia, USA.
- Fattahpour, F., Ebrahimi, K. & Liaghat, A. 2014 Assessment of the methods of estimating the instream flow (case study: Sefidrud). In: *8th World Environment Day Conference*. Tehran, Iran, p. 8.
- Filipek, S., Keith, W. E. & Giese, J. 1987 The status of the instream flow issue in Arkansas. *Proc. Arkansas Acad. Sci.* **41**, 43–48.
- Foster, H. A. 1934 Duration curves. *Trans. ASCE.* **99**, 1213–1267.
- Historical data of flow in Kashkan River 2012 Lorestan Regional Water Company.
- Kashaigili, J. J., McCartney, M. & Mahoo, H. F. 2007 [Estimation of environmental flows in the Great Ruaha River Catchment, Tanzania](#). *Phys. Chem. Earth* **32**, 1007–1014.
- Linnansaari, T., Monk, W. A., Baird, D. J. & Curry, R. A. 2012 *Review of Approaches and Methods to Assess Environmental Flows across Canada and Internationally*. DFO Can., Canadian Science Advisory Secretariat, National Capital Region, Canada. Research Document 2012/039.
- Mohamoud, Y. 2004 Comparison of Hydrologic Responses at Different Watershed Scales. EPA/600/R-04/103. National Exposure Research Laboratory Office of Research and Development US Environmental Protection Agency Research Triangle Park, NC 27711, p. 74.
- Masih, I., Ahmad, M., Uhlenbrooh, S., Turrall, H. & Karimi, P. 2009 [Analyzing streamflow variability and water allocation for sustainable management of water resources in the semi-arid Karkheh river basin, Iran](#). *Phys. Chem. Earth* **34**, 329–340.
- Maunder, D. & Hindley, B. 2005 *Establishing Environmental Flow Requirements, Synthesis Report*. The Ontario Ministry of the Environment (MOE), Ontario, Canada.
- McCartney, M., Cai, X & Smakhtin, V. 2013 *Evaluating the Flow Regulating Functions of Natural Ecosystems in the Zambezi River Basin*. Colombo, Sri Lanka: International Water Management Institute (IWMI). Research Report 148, p. 59.
- Milhous, R. T., Updike, M. A. & Schneider, D. M. 1989 *Physical habitat simulation system reference manual – Version 2*. Instream Flow Information Paper 26. USDI Fish and Wildlife Services, Biology Report 89(16).

- Morrison, A. 2013 Sustaining Environmental Flows in Southern New England Rivers: Effects of Watershed Factors and Land Use. PhD thesis, University of Rhode Island, USA.
- Mulvaney, T. M. & Park, J. D. 2010 *Opportunities for Protecting Instream Flows in Mississippi*. A report prepared by the Mississippi-Alabama Sea Grant Legal Program under award number NA06OAR4170078 from the National Oceanic and Atmospheric Administration, US Department of Commerce, Washington, DC, USA.
- Murray-Darling Basin Authority (MDBA) 2012 *Assessment of environmental water requirements for the proposed Basin Plan: Lower Goulburn River (in-channel flows)*. MDBA Publication No. 30/12, Murray-Darling Basin Authority, Canberra.
- Negaresh, H., Tavousi, T. & Mehdi Nasab, M. 2011 Scrutiny of flooding severity of Kashkan river basin. *Journal of Physical Geography*, 4 (13), 49–58.
- Özdemir, A. D., Karaka, Ö. & Kemal Erkuş, M. 2007 *Low Flow Calculation to Maintain Ecological Balance in Streams Basin Water Management*. International Congress on River Basin Management, Antalya, pp. 402–412.
- Pyrce, R. S. 2004 *Hydrological Low Flow Indices and their Uses*. WSC Report No. 04-2004. Watershed Science Centre, Peterborough, Ontario, p. 33.
- Reiser, D. W., Wesche, T. A. & Estes, C. 1989 *Status of instream flow legislation and practices in North America*. *Fisheries* 14 (2), 22–29.
- Richardson, A. R. & RIDEM 2005 *Modified Aquatic Base Flow (RI-ABF) for Rhode Island*. RIDEM Office of Water Resources. States of Rhode Island, USA.
- Serban, A. 2004 Ecological discharges and demands for river ecosystems. In: *3rd European Conference on River Restoration*. Zagreb, Croatia, pp. 345–354.
- Shahriari Nia, E. 2011 Effects of Climate Change on Dam Operation. Bachelor thesis, Power and Water University of Technology.
- Shahriari Nia, E. 2015 Estimation of Environmental Flow Requirement of Rivers (Case Study: Kashkan River). Master thesis, Kharazmi University, p. 160.
- Smakhtin, V. U. 2001 *Low flow hydrology: a review*. *J. Hydrol.* 240, 147–186.
- Smakhtin, V. & Anputhas, M. 2006 An assessment of environmental flow requirements of Indian river basins. Colombo, Sri Lanka: International Water Management Institute (IWMI) Research Report 107, p. 42.
- Studies of integrated water resource planning Qezel Ozan-Sefidrud, revised environmental requirements. report number: 13523*. 2009 Gilan Regional Water Authority, p. 48.
- Taormina, R. & Chau, K. W. 2015 *Neural network river forecasting with multi-objective fully informed particle swarm optimization*. *J. Hydroinform.* 17 (1), 99–113.
- Tennant, D. L. 1976 Instream flow regimes for fish, wildlife, recreation and related environmental resources. *Fisheries*. 1 (4), 6–10.
- Tharme, R. E. 1996 Review of the international methodologies for the quantification of the instream flow requirements of rivers. Water Law Review Final Report for Policy Development for the Department of Water Affairs and Forestry, Pretoria. Freshwater Research Unit, University of Cape Town, Cape Town.
- Tharme, R. E. 2003 *A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers*. *River Res. Appl.* 19 (5–6), 397–441.
- Tizro, A. T., Ghashghaie, M., Georgiou, P. & Voudouris, K. 2014 Time series analysis of water quality parameters. *J. Appl. Res. Water Wastewater* 1, 43–52.
- Toriman, M. E. 2010 Assessing environmental flow modeling for water resources management: a case of Sg. (River) Pelus, Malaysi. *Nat. Sci.* 8 (2), 74–81.
- H. R. Wallingford 2002 *Principles of Integrated Water Resources Management, Chapter 9: Environmental water demand*. University of Dar es Salaam, Tanzania.
- Water Entitlements, Trading Project Phase 2 2008 Australian Department of the Environment and Chinese Ministry of Water Resources (MWR), China, p. 522.
- Wu, C. L., Chau, K. W. & Li, Y. S. 2008 *River stage prediction based on a distributed support vector regression*. *J. Hydrol.* 358 (1–2), 96–111.
- Yeganeh, Y. B., Feiznia, S. & van Loo, A. J. 2012 *Sedimentary environment and palaeogeography of the Palaeocene–Middle Eocene Kashkan Formation, Zagros fold-thrust belt, SW Iran*. *Geologos* 18 (1), 13–36.

First received 8 February 2015; accepted in revised form 4 September 2015. Available online 17 October 2015