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Assessment of the environmental condition of mountainous streams in macrohabitat scale (Case Study: Delichai Stream in Tehran, Iran)

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Key words: mountainous stream, hydrological and hydraulic approaches, riffle habitat, pool habitat.

Abstract

In the present research environmental condition of a mountainous stream in macro habitat scale is investigated, and Delichai mountainous stream is selected as the pattern stream for investigation. At first hydrological and hydraulic approaches in the study stream were investigated. In the next step, physical habitat in macro scale was evaluated. Based on the results in normal conditions 10% of mean annual flow (MAF) according to the Tennant criterion and also 25% of MAF determined in the region of Atlantic in Canada are not suitable for this type of stream. Theoretically, calculation of maximum curvature in wetted perimeter method will produce the best answer for environmental flow assessment considering the physical macro habitat. But scientifically this flow cannot be applicable in these streams. In the range of 80% to 100% of MAF, minimum habitat suitability condition will be created, if the restoration and rehabilitation habitat condition techniques in moderate level are used. If the stream has sensitive biologically condition (sensitive and endangered species), considering the 25% of MAF and extensive restoration projects with this flow is recommended.

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Introduction

River systems as one of the main sources of water supply in human life are very effective, and directly or indirectly affect on various human activities in industrial and agricultural parts. Human activities has led to negative effects on environmental condition of many rivers, so in many countries governments are aware of this environmental risk and have regulated principles and policies in order to assess environmental conditions of streams since many years ago. The importance of rivers life is so high that such evaluations are completely necessary in small streams too. In fact the river system is a dynamic system and negative effects in each part of this system will cause risk for the whole set. In order to maintain favorable ecological conditions of the rivers, concept of environmental flow requirement (EFR) is defined and different approaches are used for its assessment. Some types of approaches determine environmental flow without focusing on river ecological condition. Hydrological approach is almost the most straight-forward approach in rivers. These types of methods are also known as desktop methods that rely on annual, monthly or daily flow discharge data of the river. There are two main limitations for hydrological approach. First, in this type of approach ecological values are not considered directly. Secondly, this type of approach has little defense capability in interactions of water allocation, but because of having some advantages it is used in many countries. The main advantage of this method that caused to apply it worldwide is its simplicity and also it is inexpensive. The Tennant method (Tennant, 1976) is the most widely known of these methods and is based on field data of 11 streams in Montana, Nebraska and Wyoming. According to this method in different management conditions a percentage of annual flow is determined as EFR. The threshold of flow announced by Tennant has been used with other judgments, for instance in the region of Atlantic in Canada 25% of the mean annual flow is determined as minimum environmental flow. The Accuracy of the Tennant method is evaluated in 7 western U.S. states. According to the results of this research the Tennant recommendations can be applied in regions where the stream slope is less than 1%, and is not suitable for streams having more than 1% slope in western regions of U.S. (Mann,2006). According to the Tennant method the range of 60% to 100% of MAF is defined as the optimum amount of environmental flow.

Using the single flow indices is another popular hydrological method for determining the ERF threshold. The 7Q10 flow index is one of the most widely used flow indices that its concept is the 7-day low flow with a 10-year return period (using daily discharge data). Along with the 7Q10 flow there are a variety of other 7Q flows that have been used or are currently in use, including the annual 7-day low flow (7Q1), the 7Q2, 7Q5, 7Q20, and 7Q25 flows. One of the other widely used methods for EFR assessment from hydrological method is using the flow duration curve. Smakhtin (2001) indicated that the discharge range with exceedance percentile of 70-99% is the minimum threshold in EFR assessment. The most important index determined with this method is Q_{95} index.

Another major approach in determining environmental flow is hydraulic approach. Two methods of R2Cross and wetted perimeter are examples of this approach. Colorado adapted the R2Cross methodology from a cross-section model used by Region 2 of the Forest Service; hence the name (Region2 cross-section model). Selecting the critical riffles is necessary in this method. This method assumes that the evaluated discharge for maintaining the ecosystem in riffle habitat is suitable in other habitats for different life stages of fish. Three hydraulic parameters of average depth, wetted perimeter in floodplain and flow average velocity are criteria of this method. Table 1 shows the acceptable range of these three parameters. If every three parameters are satisfied in a cross section, suitable environmental condition will exist. In fact adjustment of these three parameters in a stream indicates the maximum maintenance of habitat in this method.

Table 1. R2Cross method.

Bankfull width (m)	Average depth (m)	Wetted perimeter in floodplain area (m)	Average velocity (m/s)
0.3-6.6	0.066	16.5	0.33
6.6-13.2	0.066-0.132	16.5	0.33
13.2-19.8	0.132-0.198	16.5-19.8	0.33
19.8-33	0.198-0.33	≥ 23.1	0.33

Wetted perimeter method is one of the other important hydraulic methods. This method assumes that there is a direct relationship between wetted perimeter and habitat conditions of the river at riffle habitats. By plotting of wetted perimeter and discharge relationship and deriving the point that has the most curvature in the curve as the index point, the minimum environmental flow can be determined. Determining this point by eye is not correct and there are two methods to determine this breakpoint (Christopher *et al.*, 1988). In the first method the first derivative of discharge-wetted perimeter equation equals to 1, but according to the management conditions other values can also be applied instead of 1. In the second method according to the relationship of maximum curvature of the discharge-wetted perimeter, the discharge equivalent to the maximum curvature of the function is computed and is used as the minimum environmental flow.

Generally, riffle, run and pool habitats are known as the main river habitats by ecologists. Identification of these three habitat types has long been a problem. Many researchers identify these habitats in rivers without stating the criteria. Specific criteria or descriptions have been proposed. These include bed material size (Leopold *et al.*, 1964; Mosley 1982), water surface slope (Yang, 1971), range of water depth and velocities (Allen, 1951), bed topography (Richards, 1976), and Froude number (Wolman, 1955). Morphologists suggest that a definition based on bed topography is better because it changes less with discharge than hydraulic characteristics. A definition based on physical characteristics of flow is useful to biologists, because it describes an aspect of river physical conditions. Pridmore and Roper (1985) studied the run habitat in three streams, in one stream the flow velocity in this type of habitat ranged from 0.06-0.085 m/s and in two other streams ranged from 0.16-0.2 m/s. Henderson (1966) described Froude number as an acceptable indicator of the state of affairs in free-surface flow. The classification of habitat types in river has been carried out based on Froude number in some studies. Velocity/depth ratio is also a criterion in distinguishing habitat types. Based on the researches there is not considerable difference between the hydraulic characteristics of riffle and run habitats, while there is significant difference between hydraulic characteristics of pool and run and also between pool and riffle. Water surface slope is one of the important determinants of habitat types in a river. Pools occur only where the local stream gradient is low and riffles in areas where the gradient is high.

According to Mosley's studies (1982) the average velocity/depth ratio and Froude number in pools is 0.4 and 0.07, in runs 2.15 and 0.22, and in riffles 5.34 and 0.43, respectively. Allen's classification gave pools a Froude number of less than 0.15 and a velocity/depth ratio of less than about 0.8, and riffles a Froude number greater than 0.25 and a velocity/depth ratio greater than about 1.8.

Jowett's visual assessment (1993) of habitat types based on Froude number, water surface slope and velocity/depth ratio in the Ashburton River in New Zealand is shown in Table 2. Generally the three discussed habitats are expressed as macrohabitat.

Table 2. Results of Jowett's studies.

Model	Pool	Run	Riffle
Fr discriminant	<0.18	0.18-0.41	>0.41
Sl discriminant	<0.0039	0.0039-0.0099	>0.0099
V/D discriminant	<1.24	1.24-3.20	>3.20
Fr & Sl rule	Fr<0.18	Fr>0.18 & Sl≤0.0099	Fr≥0.18 & Sl>0.0099
V/D & Sl rule	V/D<1.24	V/D≥1.24 & Sl≤0.0099	V/D≥1.24 & Sl>0.0099

Approaches such as the River Habitat Survey (RHS) which is developed by the UK Environmental Agency assesses the habitat condition in macro scale and mathematical models such as PHABSIM assesses the habitat condition in micro scale and these models focus on a species. Investigating the habitat areas is one method of physical habitat assessment in macro scale. The aim of the present research is to investigate the environmental condition of a mountainous stream in macro scale. In fact the aim is to investigate the simple methods of EFR evaluation and assessment of physical habitat condition in macro scale, and expressing the future research needs about environmental condition of mountainous streams.

Materials and methods

Study stream and study reach characteristics

Delichai stream is one of the important tributaries of Hablerood, source of this stream is the drain of Tar and Havir lakes and joins to Hablerood in Simindasht plane. Hablerood continues its way to south direction and finally enters to Garmsar region. The stream has a watershed area of approximately 340 km^2. Mean altitude of region of this stream is 2182.23 m. The average slope of the stream is 2% and is a mountainous stream. The researches have been carried out on this stream showed that currently qualitative parameters of the stream are not in a critical condition. Due to the morphological and hydraulic conditions self purification of the river is possible. Because of the special topographic condition of the region, the stream is morphologically undisturbed and maintains its natural condition (Sedighkia *et al.*, 2014). Schematic view of the stream is shown in Fig. 1. Because of the special topographic condition of the region, the stream is morphologically undisturbed and maintains its natural condition. Considering that the scope of this research was investigating the environmental condition of a mountainous stream under natural condition so this stream was an appropriate option. The twenty-year review of statistical data from Simindasht gauging station located at the end part of the stream shows that the long-term mean annual flow (MAF) is approximately 1.11 cms and the long-term maximum mean monthly flow (MMF) is 2.813 cms. And also the stream has experienced severe low flow periods in warm month of the year and long-term mean monthly flow in August is about 182 lit/sec, and due to having variant hydrological condition this stream is a suitable representative for assessing environmental condition in other similar mountainous streams. The study reach (for hydraulic simulation) was about 1-km-long near the Simindasht gauging station.

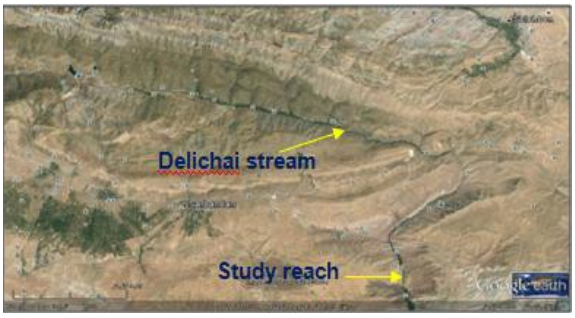

Fig. 1. Schematic view of the Delichai stream and study reach of interest.

Methods of this research

In order to carry out this study, at first hydrological and hydraulic methods in the study stream were investigated. In this regard the Tennant method in its minimum condition (10% of MAF), the average optimal condition (80% of MAF) and maximum (200% of MAF) were investigated. The 25% of annual flow recommended for Atlantic region was investigated too. In hydraulic approach at first the water surface within the study reach was simulated using HEC-RAS model. This model is one-dimensional hydraulic model. The stream schematic and cross section data were created in ArcGIS software and then imported to HEC-RAS for hydraulic simulation. Due to the size and hydraulic condition of the stream one-dimensional model provides appropriate responses, then riffle cross sections having more critical condition were selected (8 cross sections) and discharge-wetted perimeter curve was plotted for these cross sections and finally with curve fitting the discharge-wetted perimeter function was extracted and according to the methods described in previous section minimum of EFR was determined. In the next step, assessment of physical habitat in macro scale was carried out. In this regard the simulation was carried out in a wide range of possible discharges in the stream. The minimum and maximum discharges in this range considered for this step were 10% of MAF and 20 times of MAF in long-term. Then velocity/depth ratio of the macro habitat condition was investigated based on the model results. Based on the researchers' consensus, velocity/depth ratio has been an acceptable criterion in various studies for assessing habitat condition. The ranges of velocity/depth ratio presented by different researchers, discussed in previous parts, were assessed for investigating habitat types. Photos taken from the stream were assessed in this part in order to have a qualitative investigation of habitats, too. Finally the habitat distribution along the study reach was plotted and results were analyzed carefully.

Results and discussion

Estimation of EFR using the hydrological approach is shown in Table 3.

According to the analysis, the relationship between discharge and wetted perimeter at riffle area is as follows:

$$P = 3.71 Ln(Q) + 13.64 \quad (1)$$

In above Equation P is wetted parameter (m) and Q is the discharge of stream (cms). Equation (2) and (3) show the minimum environmental flow using the maximum slope and curvature methods in wetted perimeter method, respectively.

$$\frac{dP}{dQ} = \frac{3.71}{Q} = 1 \Rightarrow Q = 3.71 \text{ cms} \quad (2)$$

$$\kappa = \frac{\left|\frac{-3.71}{Q^2}\right|}{\left[1+\left(\frac{3.71}{Q}\right)^2\right]^{1.5}} \Rightarrow \frac{d\kappa}{dQ} = 0 \Rightarrow Q = 2.63 \text{ cms} \quad (3)$$

As can be seen evaluated values for EFR are very different and accurate judgment between them is very difficult. Based on the results, the amount of minimum environmental flow recommended by Tennant's method is very low and two sub methods of wetted perimeter method recommended different values for minimum of EFR. Hydraulic simulation in the range of estimated flows by hydrological approach and also two estimated value by wetted perimeter method represented that three criteria of R2Cross method are not provided in any of the cross sections simultaneously, and this fact indicates that this method is not applicable for environmental flow assessment in the study stream and other similar streams. In order to investigate and analyze the subject and answer the question that between all these recommended values, without considering its providing in the river, one way is the best one for assessing the stream condition in macro scale, in the first step total available area of the habitat at discharges range from 10% of MAF to maximum recommended value by wetted perimeter method was evaluated without considering the qualitative aspect of the stream. Fig. 2 shows the relationship between total habitat area and discharge. According to the Fig. 2 it can be seen that the most suitable relationship between these two variables is logarithmic form. If the curvature value in this curve is investigated, it can be seen that according to the extracted function the maximum curvature will occur at discharge of 2.63. This fact represents an important point, and the point is that at discharge of equivalent to the maximum curvature in wetted perimeter method in the study stream and other similar streams the amount of available habitat will be in the breakpoint, and in fact in these types of streams determining the maximum curvature discharge by wetted perimeter method as the minimum environmental flow is the most suitable option. But another important point is the quality of available habitat which is investigated in the next parts.

Table 3. EFR estimation in hydrological approach.

Criteria	Estimation method	Estimated value(cms)
Tennant minimum flow	10% of MAF	0.11
Tennant average optimum flow	80% of MAF	0.88
Tennant maximum flow	200% of MAF	2.22
Minimum flow in Atlantic	25% of MAF	0.27

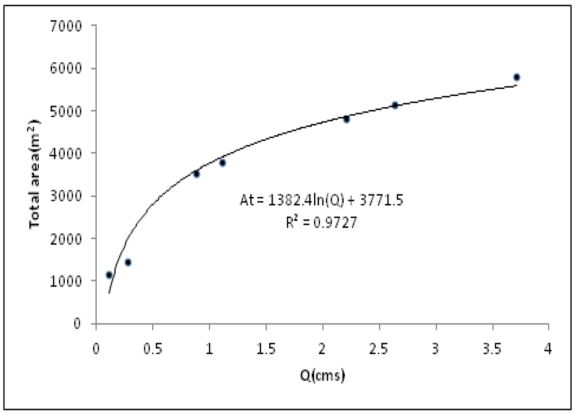

Fig. 2. Relationship between discharge and total habitat area.

Considering the velocity/depth ratio criterion and presented ranges by Allen (1951) and Jowett (1993) for distinguishing macrohabitat type in the stream the amount of available habitat for the full range of discharges to be considered in the study (range from 10% of MAF to 20 times of MAF) is shown in Table 3. As can be seen the Allen's standpoint is more conservative that Jowett's standpoint in determining the habitat type, and according to the photos of the stream Jowett's criterion is more acceptable. Ecological characteristics of habitat types must be considered in investigations. Riffles can be a supply of food and the rate of DO is more in these areas too, but this type of stream is not suitable due to the predator danger of species. Generally the Froude number in this type of habitat is high. Some larger aquatic organisms such as fresh water crabs come to this type of habitat periodically.

Water surface level in run habitat is flat enough for penetrating water and in fact breaking of water surface is less than riffle so the danger of predators is less for the organisms. Coldwater fish such as trout use this type of habitat as a suitable area for life and food. In pool habitat there is maximum conservation from predators due to having enough depth and equilibrium, but it is possible that this type of habitat has some food limitations. Thus, it can be said that in each stream the composition of the main described habitat types is necessary.

As can be seen in Table 4, based on the Jowett's criterion from the discharge equal to the Tennant's optimum discharge the run habitat can be observed. At two initially discharges of simulation, riffle can only be seen in the total area of the habitat and indicates unsuitability of these values for this type of habitat and other similar habitats having the same hydrological and hydraulic conditions. Because indicator aquatics such as coldwater fish must consume much energy against the flow and predators and don't have refugee despite having suitable food condition, so totally there is not suitable habitat condition for them. In fact the Tennant's 10% and also 25% determined in the region of Atlantic in Canada are not suitable in this type of stream. If the relationship between percent of available riffle in the habitat and discharge is plotted, a logarithmic curve fitting like Equation 4 will be the most suitable relationship.

$$A_r = -12.82 Ln(Q) + 78.63 \qquad (4)$$

In above Equation Q is flow discharge (cms) and A_r is the riffle area (% of total area).

Table 4. Percent of habitat type in the study reach.

Discharge (cms)	Percent of available habitat related to the total habitat area					
	Allen's criterion			Jowett's criterion		
	Riffle	Run	Pool	Riffle	Run	Pool
0.11	100.00	0.00	0.00	100.00	0.00	0.00
0.27	100.00	0.00	0.00	100.00	0.00	0.00
0.88	100.00	0.00	0.00	84.40	15.60	0.00
1.11	100.00	0.00	0.00	83.80	16.20	0.00
2.20	100.00	0.00	0.00	67.28	32.72	0.00
2.63	100.00	0.00	0.00	64.11	35.89	0.00
3.71	100.00	0.00	0.00	56.92	43.08	0.00
7.42	100.00	0.00	0.00	20.87	79.13	0.00
9.27	100.00	0.00	0.00	15.56	84.44	0.00
11.13	100.00	0.00	0.00	7.68	92.32	0.00
12.98	100.00	0.00	0.00	3.57	96.43	0.00
14.84	100.00	0.00	0.00	4.05	95.95	0.00
18.85	100.00	0.00	0.00	0.28	99.72	0.00
22.26	98.85	1.15	0.00	0.00	100.00	0.00

Evaluating the curvature of this function shows that the maximum curvature will occur at discharge of 2.63 cms, and indicates that for qualitatively aspect of the stream there is also a suitable habitat condition at the maximum curvature of wetted perimeter in a mountainous stream similar to the study stream. Considering the lack of pool habitat in the stream, a logarithmic relationship similar to the Equation 4 will exist for run habitat too, and breakpoint of this function will also occur at discharge of 2.63 cms. A view of the stream is shown in Fig. 3 that riffle habitat is completely obvious in it.

Fig. 3. Schematic view of riffle habitat in the stream.

Finally it can be said that theoretically calculation of maximum curvature in wetted perimeter method will give the best answer for environmental flow assessment considering the physical habitat in macro scale, but this discharge cannot be applicable in this types of streams practically. According to the statistical monthly flow discharge of the study stream the mean monthly flow during 10 months of the year is less than 2 cms and only in maximum month is about 2.8 cms. Table 3 shows that in range of 80-100% of MAF that occurs practically in the stream, the amount of run habitat is about the average 16 % of the total habitat area. Monthly flow discharge data of the stream shows that the discharge is more than the mean annual flow in six month of the year, and minimum habitat suitability condition will be created, if the restoration and rehabilitation habitat condition techniques in moderate level are used. If the stream has sensitive biologically condition (sensitive and endangered species) considering the 25% of MAF and extensive restoration projects with this flow is recommended. The accuracy of developed relationships is recommended for other mountainous streams in future studies.

Conclusion

Concept of environmental flow requirement (EFR) is defined and different approaches are used for its assessment. In the present research environmental condition of a mountainous stream in macro habitat scale is investigated. Considering the velocity/depth ratio criterion and presented ranges by Allen (1951) and Jowett (1993) for distinguishing macrohabitat type in the stream the amount of available habitat for the full range of discharges to be considered in the study. Based on the results in normal conditions 10% of mean annual flow (MAF) according to the Tennant criterion is not suitable for this type of stream. calculation of maximum curvature in wetted perimeter method will produce the best answer for environmental flow assessment considering the physical macro habitat. But scientifically this flow cannot be applicable in these streams. In the range of 80% to 100% of MAF, minimum habitat suitability condition will be created, if the restoration and rehabilitation habitat condition techniques in moderate level are used. If the stream has sensitive biologically condition (sensitive and endangered species), considering the 25% of MAF and extensive restoration projects with this flow is recommended.

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