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Development of a multimetric index based on benthic macroinvertebrates for downstream Jajrud River in Tehran province, Iran

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Abstract

Jajrud River is the main source of drinking water in the East of Tehran. The river originates from heights of the Alborz Mountain in Northern Tehran. In this study, five stations were sampled for water quality assessment in downstream. Brgjhan and Afjeh stations were considered as reference stations. Benthic macroinvertebrate sampling was repeated 3 times at each station with a Surber sampler device and an area of 900 square cm and a mesh size of 250 microns, in four seasons. For the development of MMIDJ (Multimetric Macro-invertebrate Index Downstream Jajrud-MMIDJ) multimetric index based on benthic macro-invertebrate, 25 bio-indicators were compared in the reference stations with the data of two years, 2013 and 2014. The features of the bio-indicators included measurement of components tolerance, composition, richness, and trophic. MMIDJ multimetric index was developed from 6 indices including HFBI (Hilsenhoff Family Biotic Index), BMWP/ASPT (Biological Monitoring Working Party/Average Score per Taxon), NJIS (New Jersey Impairment Score), MMIF (Multimetric Macro-invertebrate Index Flanders), % Ephemeroptera, and BBI (Belgian Biotic Index). Indices selected were significantly correlated with at least one physicochemical parameter and low degree of changes like % Chironomidae, % non-insects, the ratio of EPT (Ephemeroptera, Plecoptera, and Trichoptera) individuals to Chironomidae, and high density. Water quality in MMIDJ multimetric index was classified into four. Index values were from 6 to 30. The water quality improved from 6 to 30. With regard to water quality assessment of Jajrud River using MMIDJ multimetric index, Jajrud River did not have a good quality. Appropriate management actions should be considered in Jajrud River for improvement of the water quality.

Keywords: Jajrud River, Water quality, Benthic macro-invertebrate, MMIDJ multimetric Index

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Introduction

The recognition and evaluation of the quality and quantity of water resource form major factors in resource management, which has its work base as recognition of aquatic ecosystem and ecological study (Robinson *et al.*, 2001). Different methods have been developed for the determination of water quality based on biological indicators. All these methods were developed and used as biological monitoring methods. Bio-monitoring or biological monitoring is generally defined as "the systematic use of living organisms or their responses to determine the condition or changes in the environment" (Li *et al.*, 2010). Benthic macro-invertebrates are one of the most important and most useful organisms in biological monitoring. At least one of the stages of its life is spent in the aquatic environment and is visible to the naked eye (Rosenberg *et al.*, 1997). Benthic macro-invertebrates are one of most important component of the aquatic ecosystem and have been used for so long to assess the quality of streams water. Among members of the aquatic ecosystem, they are probably the most suitable; because they are numerous in almost every stream, readily collected and identified, not very mobile and generally have life cycles of a year or more (Hilsenhoff, 1977), sensitivity in different chemical condition, easy sampling and requiring low numbers of the taxon and they are reliable purposes that can respond to stress and environmental changes (Abbaspour *et al.*, 2017). Also, benthic macro-invertebrates fauna's structure is affected by environmental factors such as temperature, pH, dissolved oxygen (DO) and pollution (Mehdipour *et al.*, 2018). According to multimetric indices, benthic macro-invertebrates are important tools for the assessment of biological resources quality. Multimetric indices consist of a number of biological and/or ecological indicators (often called metrics because they are measures of the system) which combine as a one-dimensional indicator of the biological or ecological condition of a system (Karr and Chu, 1997). In developing multimetric indices using benthic macro-invertebrates in various streams of environments worldwide, a great number of metrics have been examined accordingly and evaluated in streams (Whittier *et al.*, 2007; Macedo *et al.*, 2016; Liu *et al.*, 2017). It seems that use of biological indicators in a program monitoring the state of water in Iran has received less attention in only a few studies, most of which rely on a metrics of biological indicators, including indices Shannon–Wiener, EPT, HFBI, BMWP, and Taxa Richness, to mention a few. The purpose of this study is the development of a multimetric index (Multimetric Macro-invertebrate Index Downstream Jajrud-MMIDJ) based on benthic macro-invertebrate communities for the water quality assessment in Jajrud downstream.

Materials and methods

Study area

Jajrud River with an approximate length of 140 km originates from Alborz mountain range in the north of

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Tehran, Iran. It's most important function is as a source of drinking water for surrounding villages and the East of Tehran. Because of the mountainous area and problem of waste disposal, the surrounding villages dump their wastes into Jajrud River. The river is located in the recreational area annually visited by many people from this area and has its highest portion in the water supply of Latyan dam (About 60%). Latyan dam in turn provides about 30% of Tehran's water. In this study, five stations were studied in downstream for assessment of the river water quality. The stations were divided into groups of reference and impaired stations. Reference stations included areas the with minimum pollution, least need for development and land use, less than 30% agriculture, and less than 20% urban areas. Impaired stations also included areas with maximum pollution and high turbidity. The 3 stations before Lake Latyan dam, Najarkola, and Saeadabad were referred to as the impaired stations and Bargejahan and Afjeh were the reference stations. Location of sampling stations and the land use around them can be seen in Fig. 1. Land use around stations included residential, commercial, garden, and pasture.

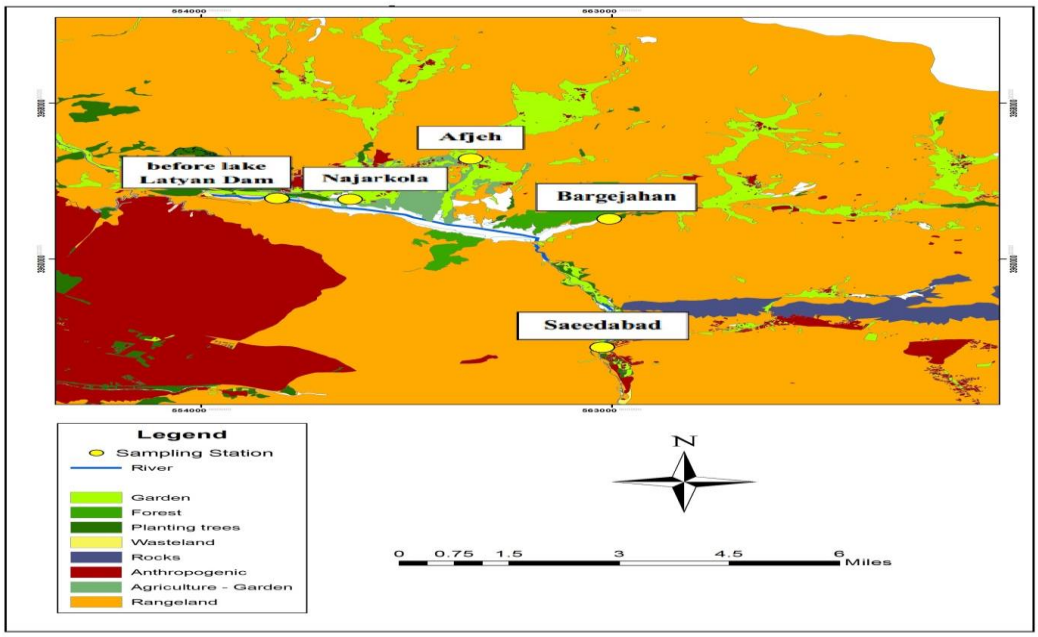

Figure 1: Location of sampling stations in downstream Jajrud River.

Measurement of physicochemical parameters

The physicochemical parameters were evaluated during sampling and measurement in Jajrud River. These parameters included dissolved oxygen (DO), temperature, percent of dissolved oxygen (% DO), electrical conductivity (EC), total ammonia (NH_4^+), turbidity, biological oxygen demand (BOD), fecal coliform, and phosphate (PO_4^{3-}).

Benthic macroinvertebrate sampling

Benthic macro-invertebrate organisms in Jajrud River were sampled using Surber sampler device, with an area of

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900 square centimeters and mesh size of 250 microns. Sampling was done in 3 repetitions in each station. For this purpose, Surber floor framework was made from materials including stone, rubble, gravel, and sand and was positioned and in opposite direction of the flow of the river bed, thus preventing the bed from washing. Then, benthic macro-invertebrate organisms were guided by flowing water into a Surber net. The contents of the Surber net were washed up into the pan and the benthic macro-invertebrate organisms were removed from the river bed. Then by pence and sieve of 250 micron, the benthic macro-invertebrate organisms obtained from the river bed were thrown into benthic storage containers. The samples were fixed with 4% formalin and transported to the laboratory for isolation and identification. To separate benthic macro-invertebrate organisms, samples were passed through a sieve of 250 microns and through flowing water and were finally washed up with formalin. The contents of the sieve containing benthic macro-invertebrate and river bed were poured into trays and benthic organisms were placed under a microscope for identification and counting. Using identifier key, benthic macro-invertebrate organisms (Tachet *et al.*, 2000) were identified in the level of orders, families, and genera.

Biological indices for index development

For developing multimetric index based on benthic macro-invertebrate, 25 biological indices were compared in the reference stations with two years data, 2013 (in 4 seasons) and 2014 (in 4 seasons). Biological indices feature included measurement of components like tolerance, composition, richness, and trophic (Wiseman, 2003; Jun *et al.*, 2012) (Table 1). Some of the metrics and indicators increased in value with increasing pollution and vice versa. The increasing or decreasing values of these biological indices were used to determine their response to pollution (Table 1) (Royer *et al.*, 2001; Jun *et al.*, 2012). Comparison of indices values between reference and impaired stations was done using box-and-whisker plot.

Table 1: Introduction of candidate indices in development of index and their response to pollution.

Measurement component	Index	Definition	Expected Response
Composition	%CDF	Percent Contribution of dominant family	Increase
	Shannon-Wiener	Shannon's diversity index	Decrease
	EPT/C	Ratio of EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa to Chironomidae	Decrease
	% Ephemeroptera	Percent of individuals in mayfly nymphs	Decrease
	% Oligochaeta	Percent of individuals in aquatic worms	Increase
	% non-insect	Percent of individuals in non-insects	Increase
	% Trichoptera	Percent of individuals in caddisfly larvae	Decrease
	% Chironomidae	Percent of individuals in Chironomidae larvae	Increase
Richness	Taxa Richness	Total number of taxa collected in the sample	Decrease
	EPT	Number of taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera	Decrease
Tolerance	HFBI	Hilsenhoff Family Biotic Index	Increase
	BMWP/ASPT	Biological Monitoring Working Party/Average Score Per Taxon	Decrease

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Table 1 continued:

	NJIS	New Jersey Impairment Score	Decrease
	MMIF	Multimetric Macro-invertebrate Index Flanders	Decrease
	SIGNAL	Stream Invertebrate Grade Number Average Level	Decrease
	IBI	Index of Biotic Integrity	Decrease
	BBI	Belgian Biotic Index	Decrease
	TBI	Trent Biotic Index	Decrease
	MBI	Macro-invertebrate Biotic Index	Increase
Trophic	% Shredders	Percent of individuals in the shredder functional feeding group	Decrease
	% Scrapers	Percent of individuals in the scraper functional feeding group	Decrease
	% Predators	Percent of individuals in the predator functional feeding group	Variable
	% Collector	Percent of individuals in the collector functional feeding group	Variable
	% Collector/Scrapers	Percent of individuals in the collector/scrapers functional feeding group	Increase
	%Collector/ Filterers	Percent of individuals in the collector/ filterers functional feeding group	Decrease

Results

Index evaluation

Index variability

Among the 25 biological indices studied, eventually, 6 indices were selected for the development of multimetric index (Table 2). The reasons for selecting these 6 indices for the development of multimetric index include the following:

1-The indices are suitable for water quality assessment, they do not vary and they are able to detect the degradation in the quality of habitat.

2-The indices have high abundance levels of pollution-sensitive order, % Oligochaeta, % Plecoptera, % non-insects, % Shredders and % Predators.

3-The indices have low degree of changes in % Chironomidae, % non-insects, the ratio of EPT (Ephemeroptera, Plecoptera and Trichoptera) individuals to Chironomidae and high density.

4-The high value of median indices in the reference stations compared to impaired stations improves their better water quality and lower value of median indices in reference stations compared to the impaired stations improved the quality of bad water.

5-The selected indices were significantly correlated with at least one of physicochemical parameters (Table 3).

Table 2: Statistics summary of 25 candidate biological indices at the reference sites

Measurement component	Index	Interquartile values			Selection and reason for rejected indicators
		%25	Median	%75	
Composition	% Chironomidae	04/10	64/12	28/24	Variable
	Shannon-Wiener	59/0	8/0	89/0	Values low
	EPT/C	33/2	16/5	46/7	Values low
	% Ephemeroptera	39/63	2/71	93/75	Selected
	% Oligochaeta	39/0	67/0	36/2	Values low, variable
	% non-insect	39/0	67/0	36/2	Values low, variable

[DOR: 20.1001.1.15622916.2020.19.1.39.1]

Table 2 continued:

	% Trichoptera	0	0	15/0	Values low
	%CDF	25/61	58/72	29/80	Range very high Index
Richness	Taxa Richness	33/4	33/5	33/6	Values low
	EPT	5/1	66/2	83/2	Values low
Tolerance	HFBI	73/4	17/5	63/5	Selected
	BMWP/ASPT	31/3	72/3	92/3	Selected
	MBI	4/4	76/4	14/5	Lack correlation with physicochemical parameters
	SIGNAL	24/4	47/4	3/5	The higher median number in impaired stations than reference
	MMIF	3/0	4/0	58/0	Selected
	IBI	04/2	33/2	47/2	Lack correlation with physicochemical parameters
	BBI	16/5	6	5/6	Selected
	TBI	41/5	33/6	66/6	Values low
	NJIS	14	15	17	Selected
Trophic	% Shredders	0	55/0	84/0	Values low
	% Scrapers	0	25/0	74/0	Values low
	% Predators	0	0	25/0	Values low
	% Collector	62/10	1/16	58/31	Variable
	% Collector/Scrapers	71/60	43/71	16/80	Unnecessary and similar to % Ephemeroptera index
	% Collector/ Filterers	74/0	58/2	75/9	Values low, variable

Discriminatory Power of Index Sensitivity

The 6 indices remaining from the 25 indices of initial candidates clearly distinguished the reference and impaired stations (Fig. 2).

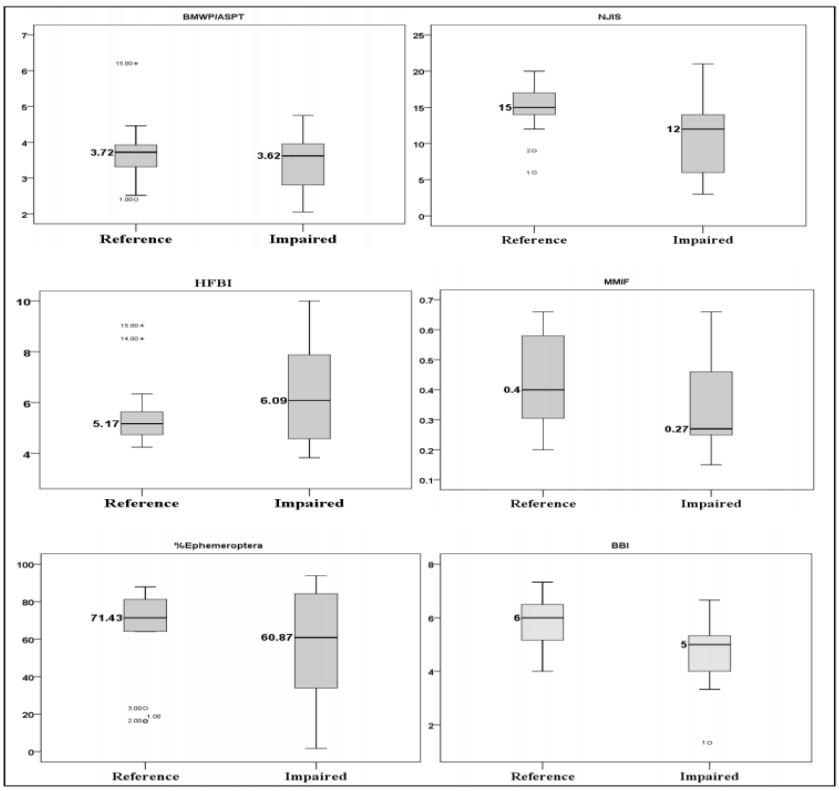

Figure 2: Comparison of indices values between reference and impaired stations.

[DOR: 20.1001.1.15622916.2020.19.1.39.1]

Relationship between Indices and Physicochemical Parameters

The 6 indices selected for the development of multimetric index were significantly correlated with at least one of the physicochemical parameters (Table 3).

Table 3: Spearman correlation coefficients between physicochemical parameters and biological indices.

Index	PO_4^{3-}	Fecal coliform	BOD_5	Turbidity	%DO	NH_4^+	EC	Temperature	DO
NJIS	-0/477	0/241	-0/647**	0/058	0/537*	-0/036	-0/624*	-0/364	**0/991****
BMWP/ASPT	-0/506	0/241	-0/65**	0/05	0/543*	-0/041	-0/593*	-0/379	**0/999****
MMIF	-0/519*	0/228	-0/618*	0/064	0/521*	-0/028	-0/590*	-0/380	**0/996****
BBI	-0/464	0/223	-0/652*	0/081	0/557*	0/018	-0/616*	-0/354	**0/991****
HFBI	0/506	-0/241	0/65**	-0/05	-0/543*	0/041	0/593*	0/379	**-0/999****
% Ephemeroptera	-0/506	0/241	-0/65**	0/05	0/543*	-0/041	-0/593*	-0/379	**0/999****

* And** respectively represent significance at %5 level (p<0/05) and %1 (p<0/01)

Development of multimetric index

The scoring criteria for each metric or index was effectively determined using threshold values from the reference stations (Table 4). The multimetric index was calculated by aggregating the scores of each of the 6 metrics. The possible index values ranged from 6 to 30; this was derived by summing the minimum and maximum scores for each metric. The range of the multimetric index has been shown for 4 classes of water quality (Table 5). Moving from 6 to 30, the water quality gets better.

Table 4: Descriptive statistics for 6 metrics core incorporated into MMIDJ multimetric index, and their scoring criteria.

Index	Descriptive statistics					Scoring criteria		
	Min	25%	Median	75%	Max	5	3	1
HFBI	24/4	73/4	17/5	63/5	03/9	65/5≥	9-66/5	01/9≤
BMWP/ASPT	4/2	31/3	72/3	92/3	2/6	3/3≤	29/3-01/2	2≥
MMIF	2/0	3/0	4/0	58/0	66/0	29/0≤	28/0-19/0	18/0≥
BBI	4	16/5	6	5/6	33/7	15/5≤	14/5-61/3	6/3≥
% Ephemeroptera	76/11	39/63	2/71	93/75	94/87	38/63≤	37/63-75/11	72/11≥
NJIS	6	14	15	17	20	9/13≤	8/13-61/5	6/5≥

Table 5: Water quality classes for MMIDJ multimetric index.

MMIDJ score	Water quality
12-6	Very poor
18-13	Poor
24-19	Moderate
30-25	Good

Water quality assessment in downstream Jajrud

Water quality assessment for 4 seasons in the studied stations, calculated using developed MMIDJ multimetric index, is presented in Table 6. In addition, a comparison of MMIDJ multimetric index values is shown in Fig. 3.

[DOR: 20.1001.1.15622916.2020.19.1.39.1]

Table 6: Water quality assessment for MMIDJ multimetric index in the studied stations.

Season	before lake Latyan Dam		Najarkola		Afjeh		Bargejahan		Saeedabad	
	score	water quality	score	water quality	score	water quality	score	water quality	score	water quality
spring	10	very poor	13	poor	17	poor	23	moderate	22	moderate
summer	20	moderate	20	moderate	30	good	-	-	24	moderate
autumn	28	good	24	moderate	26	good	24	moderate	24	moderate
winter	26	good	20	moderate	24	moderate	24	moderate	22	moderate

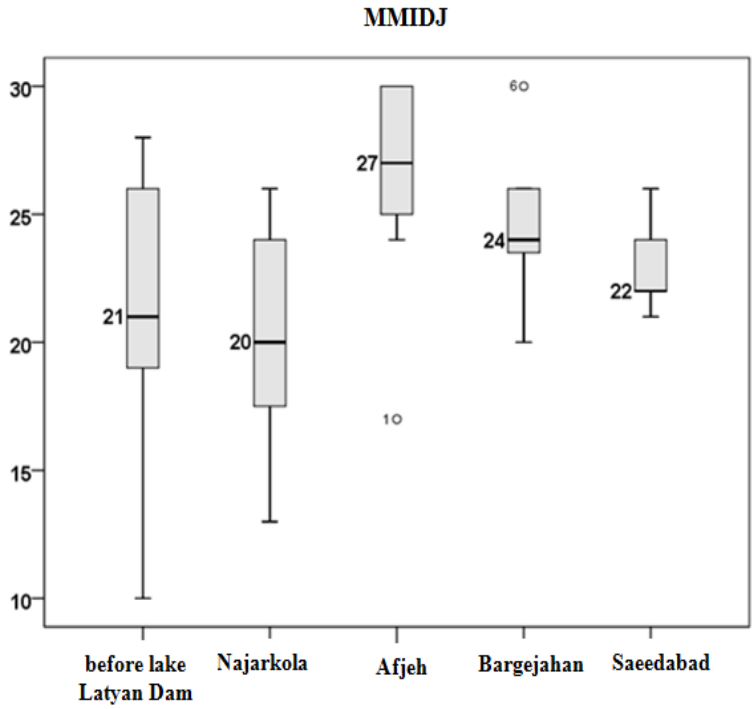

Figure 3: Comparison of MMIDJ multimetric index values in the studied stations.

Discussion

The larvae of the aquatic insect, the most dominant group of benthic macro-invertebrate was located downstream Jajrud, and many researchers had similar results (Lenat, 1988; Pipan, 2000). In all stations, families of Baetidae and Chironomidae were the high abundance benthic macro-invertebrate in bed of downstream Jajrud, which was similar to research results Wolmarans *et al.* (2017). The high abundance of benthic macro-invertebrate in autumn was because of its life-cycle and the low abundance of benthic macro-invertebrate in spring was due to an increase of water velocity and high flow rate of the river (Aguiar and Ferreira, 2002). Twenty-five indices were a candidate for the development of multimetric index. Finally, 6 indices were selected for the development of multimetric index. MMIDJ multimetric index was developed from 6 biological indices including HFBI, BMWP/ASPT, NJIS, MMIF, % Ephemeroptera, and BBI. Five indices were based on tolerance and one index was based on composition. In the 5 indices including BMWP/ASPT, NJIS, MMIF, % Ephemeroptera, and BBI water quality was better with increasing index. Therefore the median value in the reference stations was high compared to the impaired stations. Also in HFBI

[DOR: 20.1001.1.15622916.2020.19.1.39.1]

index water quality was bad with increasing index. Therefore, the median value in the reference stations was lower compared to the impaired stations. The selected indices showed significant correlation with at least one physicochemical parameter which correspond with the study by Jun *et al.* (2012). Among each of 6 indices overlapping, there was no significant correlation with the studies of Paul *et al.* (2005), Jun *et al.* (2012) and Mereta *et al.* (2013). The result of this study is consistent with the results of Jun *et al.* (2012) for the development of multimetric biological index KB-IBI for rivers in South Korea. KB-IBI multimetric index finally took shape with 10 metric and 4 classes of water quality, while MMIDJ multimetric index from 6 indices and 4 classes were developed for water quality assessment. Water quality assessment in MMIDJ multimetric index was classified into 4 classes of good, moderate, poor, and very poor. Index assessment for downstream Jajrud is shown in Table 6. In Afjeh station water quality was moderate to good due to the diversity of benthic macro-invertebrate. Except in spring, because of the natural cascade and tourists where the water quality is poor. In the station before Latyan dam lake, 3 qualities were assessed as very poor, moderate, and good. Very poor water quality in the river was due to the expansion of the construction of the villa. Najarkola station water quality was assessed as moderate and poor due to man-made effects. Water quality in Bargejahan station was assessed as moderate because it is located in the Forest Park. Water quality of Saeedabad station was also assessed as moderate.

The accurate assessment of biological monitoring of benthic macro-invertebrate is faster and done at lower cost than any other methods used for assessing water quality (Zimmerman, 1993). Multimetric indices provide a technically simple tool for summarizing the biological complexity of a system, where a gradient of disturbance can be effectively evaluated despite the limited sensitivity of individual metrics (Coucerio *et al.*, 2012). The purpose of this study was to assess the water quality of the river and find suitable biological indices that are consistent with the geographic, climatic and ecological conditions of Jajrud River and rivers of the Iran. With 2 years gathered data, MMIDJ multimetric index for downstream Jajrud was developed to better assess the water quality of Jajrud River and rivers of the Iran. Water quality of Jajrud River was assessed using MMIDJ multimetric index. According to the water quality of this river and the reasons given in the study stations downstream Jajrud, it can be said that it is not a desirable situation. And given the importance of Jajrud River as a source of drinking water in Tehran, appropriate managerial and executive action must be taken to improve the water quality in this river.

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