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Development of multimetric index based on benthic macroinvertebrate for water quality assessment of Jajrood River in Iran

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ABSTRACT
Increased anthropogenic disturbances in river ecosystems has led to a reduction in the biodiversity of rivers. The purpose of this study was to develop a multimetric index based on benthic macroinvertebrate for water quality assessment of Jajrood River. Biological and physicochemical sampling from seven stations was performed in the upstream basin of the river, located in the northeast of Tehran. Therefore, for the development of the MMIJ (Multimetric Macroinvertebrate Index Jajrood upstream) index, as a complementary tool in analyzing the physicochemical parameters, the data and indices calculated in the first two years (2011 & 2012) were used and validated with the data of the third year (2013). So, 24 biological indices were selected. Range, stability, sensitivity, responsiveness (to the anthropogenic impact gradient), and redundancy were tested on indices. Finally, the five indices including FBI, MMIF, NJIS, Shannon-Wiener, and Margalef from four tests were performed for the development of the MMIJ multimetric index. Each index was given a values of 1, 3, and 5 about its score, and then this index was obtained with a sum of calculated scores. As a result, the calculated indices in the third year were valued according to the calibration of the five biological indices, and the water quality of the seven stations was determined. This study showed that MMIJ multimetric index had a high sensitivity to organic pollutants and was suitable for use in national monitoring and assessment programs in the Jajrood River basin.

Keywords: Sampling, Jajrood upstream, Biological indices, Anthropogenic impacts, Monitoring.
Article type: Research Article.

INTRODUCTION

The issue of water quality in the rivers has been investigated in order to provide food and water for living, agriculture, recreation, industry, shipping, and trade (Wei *et al.* 2009). Increasing anthropogenic disturbances in freshwater ecosystems, especially all the world's rivers, has led to a reduction in the biodiversity of freshwater (Fierro *et al.* 2018). Rivers are one of the most important aquatic ecosystems in terms of providing habitats for biodiversity and supplying drinking water in arid and semi-arid regions, especially Iran (Tavabe *et al.* 2008). The discharge of destructive pollutants into the rivers, the construction of a dam, the destruction of vegetation in coastal areas, etc. has led to a change in the water quality, ecological decline, degradation of rivers' biological communities, and eutrophication (Wei *et al.* 2009). Therefore, reconstruction, restoration, and maintenance of river ecosystem integrity have become the essential objectives of water quality management. Ecological integration is a general concept that depends on the state of the whole system, including the presence of species, the occurrence of environmental processes, and all factors that support the ecosystem's environmental conditions (Cabecinha *et al.* 2004). Biological assessment is in fact use of regular and systematic from biological responses; In order to investigate environmental changes with the aim of using this information in the water quality control

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program. In this regard, biological responses are measured using biological indices (Cabecinha *et al.* 2004; Verdonschot & Moog 2006; Kebede *et al.* 2020). Biological indices are divided into two major groups of metric and multimetric indices. The metric index can only reflect the overall picture of the stressed aquatic ecosystem. But multimetric indices include additional information from a wide range of stressors (Nguyen *et al.* 2014; Alemneh *et al.* 2019). Meanwhile, the most common indices used throughout the world are the diversity indices of Simpson, Shannon, Hilsenhoff Family Biotic Index (FBI), Margalef, combination indices of %Ephemeroptera, %Trichoptera, %Plecoptera, %EPT (Ephemeroptera, Trichoptera, and Plecoptera) taxa, tolerance indices of BMWP (Biological monitoring working party) and ASPT (American Society of Plant Taxonomists) and abundance indices of the number of taxa, the number of Ephemeroptera and the number of EPT (Klemm *et al.* 2003; Hering *et al.* 2006; Baptista *et al.* 2007; Couceiro *et al.* 2012; Nguyen *et al.* 2014; Elizabeth Graham *et al.* 2017; Kumari & Maiti 2020).

The multimetric indices, made up of numerous features of biological assemblage, are very useful for assessing anthropological pressures (Macedo *et al.* 2016). The multimetric process typically is used for the analysis of benthic macroinvertebrates data (Melo *et al.* 2015; Liu *et al.* 2017). Benthic macroinvertebrates due to relative immobility, river health indicators, in close contact with subsurface sediments and water columns, can respond to a variety of anthropological effects and show the cumulative effects of many stressors (Huang *et al.* 2015; Aazami *et al.* 2015). Indeed, the multimetric index based on benthic macroinvertebrates is an attempt to provide an integrated analysis of the biological community in a region. In these indices, each metric index shows reactions about to the specific stress caused by environmental changes. Therefore, they consider multiple effects by combining metric indices (species richness, variation in measurement based on susceptible and resistant species, nutritional structures, etc.). Therefore, multimetric indices are a more reliable tool for assessing environmental conditions than single indices. According to the background of this research in Iran, using a few limited indices such as Shannon-Wiener, Hilsenhoff, Margalef, BMWP, and ASPT for the assessment of the water quality. Some of these researches can be mentioned. Hatami *et al.* (2011) examined the effect of aquaculture on benthic macroinvertebrates communities and water quality of Isfahan's Zayandehrud River using the BMWP index. In another study, Alizadeh *et al.* (2019), evaluated the ecological and biological indicators of benthic macroinvertebrates communities in Sari-Su River of Golestan using the Hilsenhoff was examined. These studies evaluated the river water quality without calibrating the indicators for the environmental conditions of the region. These studies evaluated the river water quality without calibrating the biological indices for the environmental conditions of the region. The production of multimetric indices to express the exact result of the water quality in the region requires some years of research, analysis, repetition, and review for certainty in conclusion. Therefore, this study is defined in the Environmental Sciences Research Center of the Shahid Beheshti University of Tehran in the basin area of Jajrood River. In this study, considering the demographic characteristics and changes of the Latian Dam basin, which is one of the significant sources of Tehran's drinking water, providing 30-35% of the total resources, the determination of the qualitative status of this river was given special attention. The growing expansion of residential areas and urban contexts, along with the development of industrial and agricultural, makes it possible to create considerable damages to the environment of the natural community of Jajrood's. Therefore, pollution from the entry of pollutant sources affects the quality of water. Therefore, physicochemical analysis, along with biological analysis, has been done in the bioassay monitoring program in 4 seasons and seven study stations. The purpose of this paper is to develop the MMIJ multimetric index for water quality assessment using benthic macroinvertebrate and biological indices on the upstream of the Jajrood River.

MATERIAL AND METHODS

Study area

Jajrood River in the Alborz Mountains is formed by joining two main branches of Zayygan and Migun. These two branches come together in the field of Fasham. Along the way, the branches of Abnik, Lalan, Ruteh, Shemshak, Darbandsar, Ahar, and Amaymah join it, and eventually, the river leads to Lake Latyan Dam. This river with 140 km long and 710 km^2 of drainage basin area has a 4% slope and a gravel bed, cut sand. In recent years, the increase of industries active in the Jajrood area and the non-systematic disposal of industrial and chemical wastewaters have contaminated surface and groundwater in the area.

In this study, seven stations were selected in the upstream of the Jajrood River for physicochemical and biological monitoring (Fig. 1).

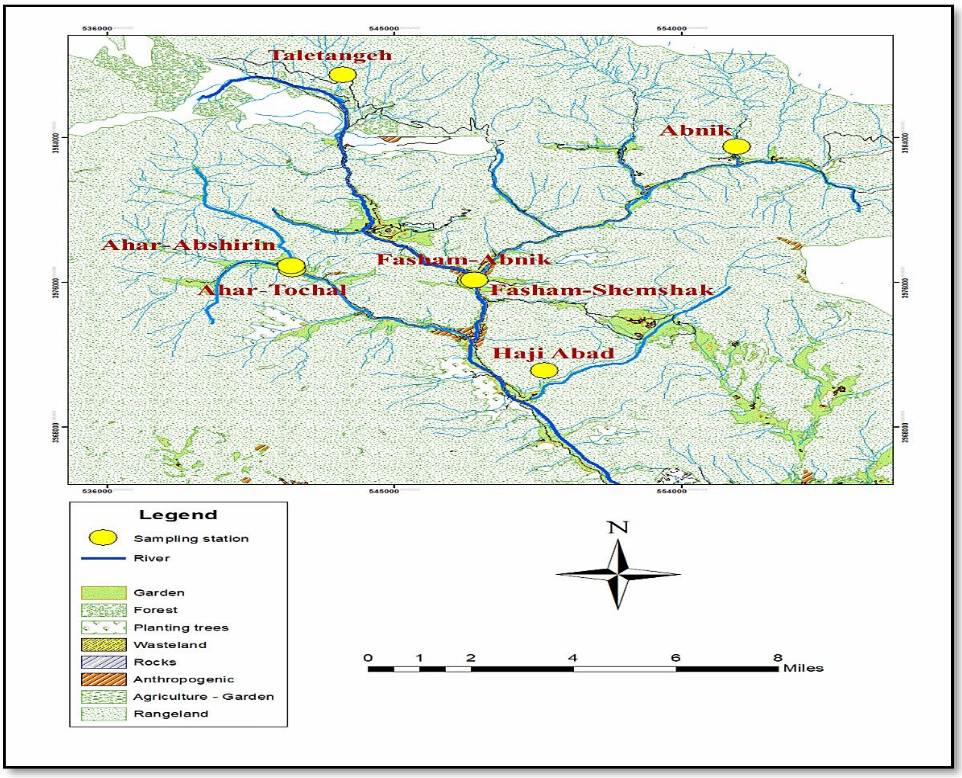

Fig. 1. Location of sampling stations in the upstream of the Jajrood River.

The reasons for the selection of stations are as follows: 1. Contamination sources in the drainage basin of the Jajrood River, such as restaurants, residential areas, amusement places; 2. Abnormal anthropogenic parameters such as bridges, changes in the canal flow of the river; 3. Due to the geographic factors of the region; 4. Possibility of sampling of stations in different seasons. Two branches of the Abnik and Taletangeh from river branches and five branches of Fasham-Shemshak, Fasham-Abnik, Ahar-Abshirin, Ahar-Tochal, and Haji Abad as river sub-branches were selected. Land use of all branches except Taletangeh, which is pasture, is anthropogenic. The land use of the whole station in Fig. 1 is clearly specified. However, Abnik and Taletangeh are less polluted than other branches. All stations were divided into two groups, with the least-disturbed environmental conditions and disturbed environmental conditions. The Abnik station was selected with the least-disturbed condition, due to its environmental degradation less than other stations, such as vegetation, human activity, and agriculture. All other stations were selected as disturbed. The samples were taken in 4 seasons of spring, summer, winter, and autumn from 2011 to 2013. Data collected in 2011 and 2012 were used to develop the index, and the data collected in 2013 were used for validation.

Collection of physicochemical parameters

The physicochemical parameters were evaluated during sampling and measurement in the upstream of Jajrood River. These parameters included dissolved oxygen (DO), temperature (Te), nitrate (NO^-_3), nitrite (NO^-_2), percent of dissolved oxygen (%DO), turbidity (T), electrical conductivity (EC), ammonia (NH_3), and biological oxygen demand (BOD_5), chemical oxygen demand (COD), fecal coliform, total phosphorus (P) and phosphate (PO_4^{3-}), total suspended solids (TSS) and Iranian water quality index (IRWQI).

Benthic macroinvertebrate sampling and identification

To investigate aquatic insects for use in biological indices, sampling was carried out from seven stations with three replications using the Surber sampler device with dimensions of 30 × 30 cm and mesh size of 250 μm. At each station, three areas were randomly selected in the continuous river bed and the device placed, then the stones, soil, and plants were washed to a depth of 5 cm from the bed. The purpose of this work was to wash benthic macroinvertebrates living on the river bed and transduction them in the Surber fabric environment.

Table 1. Nominating biological indices for the development of the MMIJ multimeter index based on range, stability, and sensitivity tests.

index Number	index category	Range			Stability Mann–) (Whitney test		Sensitivity	
		%25	%75	Valid	P-Value	Valid	Box-and-whisker plot	U-test confirm ((p-value
	Tolerance							
1	FBI	5.35	7.87	+	0.230	+	+	+
2	TBI	2.62	10.25	-	-	-	-	-
3	BMWP/ASPT	2.55	4.51	+	0.225	+	+	+
4	Signal	3.02	4.75	+	0.463	+	-	-
5	BBI	5.00	7.00	+	0.201	+	+	+
6	MMIF	0.33	0.48	+	0.142	+	+	+
7	IBI	1.66	2.47	+	0.206	+	+	+
8	NJIS	9.25	16.75	+	0.604	+	+	+
	Diversity							
9	Margalef	0.59	1.40	+	0.083	+	+	+
10	Shannon-Wiener	0.72	1.31	+	0.133	+	+	+
11	Simpson	0.40	0.62	+	0.117	+	-	-
12	Evenness	0.44	0.74	+	0.018	-	-	-
	Abundance							
13	Number of Ephemeroptera	6.00	43.25	+	0.503	+	-	+
14	Number of Plecoptera	0.00	0.67	_	-	-	-	-
15	Number of Trichoptera	0.33	13.12	+	0.611	+	-	-
16	Number of dipteral	14.00	61.58	+	0.631	+	+	+
17	EPT taxa	1.07	3.00	+	0.005	-	-	-
18	EPT/CHIR	0.16	2.55	+	0.695	+	-	-
19	Taxa Richness	4.10	8.52	+	0.033	-	-	-
	Composition							
20	Ephemeroptera (%)	9.69	42.83	+	0.950	+	-	-
21	Plecoptera (%)	0.00	0.87	-	-	-	-	-
22	Trichoptera (%)	0.25	3.94	-	-	-	-	-
23	Diptera (%)	31.69	75.15	+	0.604	+	-	-
24	CDF (%)	51.75	68.79	+	0.404	+	+	+

The contents of the Surber were then placed into a large plastic container and passed through a sieve with a mesh size of 250 microns, followed by inserting them into a box of benthic macroinvertebrate and fixing in 4% formalin solution and identifying the samples. The date and location of sampling were recorded using the label on each sample and they were transferred to the lab for identification. The specimens were then placed on the tray for describing, and their family and genus were identified by light microscopy and identification key (Serra *et al.* 2009).

RESULTS

Multimetric index development

During seasonal sampling from seven stations in the upstream basin of Jajrood River (2011-2013), six orders of benthic macroinvertebrate were identified, including Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, and Oligochaeta. 23 families and 25 genera in 2011, 27 families and 32 genera in 2012, as well as 28 families and 30 genera in 2013 were identified. Biological indices were then calculated for the assessment of the river water quality. Twenty-four biological indices were selected as representing four characteristics of ecosystem quality, including tolerance, diversity, abundance, and composition of the benthic macroinvertebrate assemblages. On candidate indices, four parameters including range, stability, sensitivity and response to human impacts were tested. The range test was first conducted to formulate the MMIJ multimetric index. So that, all the indices were box-and-whisker plotted, and it was validated based on dispersion and flood data. This method has been schematically shown in Fig. 2 (Hering *et al.* 2006). Another method of this test is to determine the first and third quartiles. To validate the indices, the range was first calculated by subtracting the quartiles, then in the case of each unit, less index was rejected if the scope of each index was less than 5% of its qualitative classes, while in the case of indices with group in percentage, if this value was less than 10% (Klemm *et al.* 2003; Couceiro *et al.* 2012; Nguyen *et al.* 2014; Shiyun *et al.* 2017). To determine the reliability of the validated indices in the first part, SPSS-22 software was used for the U-test. Here, the indices measured in the dry and wet season were compared together. Since sampling was made in this study in four seasons, therefore, summer and autumn, except dry season and winter and spring except wet season, were considered. If p-value > 0.05, then the index is valid (Nguyen *et al.* 2014; de Bikuna *et al.* 2015). At the third step, the indices selected in the second part were a box-and-whisker plotted for the sensitivity test, and U-test was taken from those which did not exhibit good sensitivity with a box-and-whisker plot. If the p-value > 0.05, the index was rejected. Here is a comparison between the indices of two least-disturbed and disturbed stations (Baptista *et al.* 2007; Nguyen *et al.* 2014; Lakew & Moog 2015). The sensitivity test by the box-and-whisker plot method is that the median of the least-disturbed station index box is compared with the disturbed one. Then, a score is assigned to each of the four cases in Fig. 3. In this test, only the indices with score 3 were accepted (Pond *et al.* 2003). At the fourth step, among the indices selected with the physicochemical parameters, the Spearman test was conducted using SPSS-22 software.

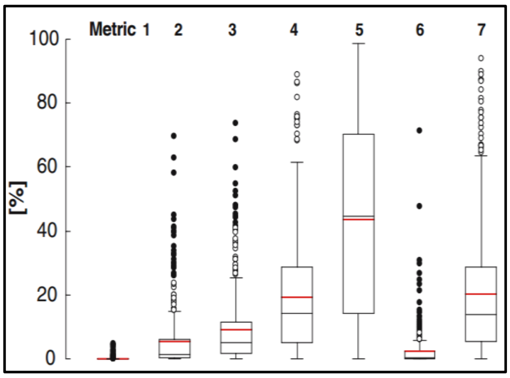

Fig. 2. Validation of using the dispersion of biological indices, in this example, indices 1, 2, 3, and 6, were rejected.

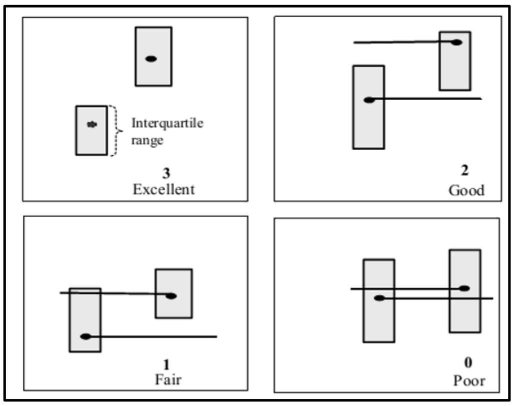

Fig. 3. Sensitivity test with a box-and-whisker plot.

An index is selected that correlates at least with one of the parameter. Then, the Spearman test was conducted on the selected indices. The index with the highest correlation to R > 0.70 was selected for the development of the multimetric index (Baptista *et al.* 2007; Nguyen *et al.* 2014). Finally, for each selected index relative to scores measured in the least-disturbed station, the highest, 75%, 50%, 25%, and the lowest was calculated. The scores of 1, 3, and 5 for each of the indices were determined as follows. For indices whose score decreases with the increasing pollution, the score 5 is assigned to the calculated low quartile (Q_1). To determine the score 1, the lowest calculated score (Q_0) is the criterion. Finally, the score 2 is the distance between these two scores. For indices whose scores elevate by increasing contamination, the calculated high quartile (Q_3) gets a score 5. To determine the score 1, the highest calculated score (Q_4) is considered as the criterion. Finally, the score 2 is the intervals between these two scores (Fig. 4; Baptista *et al.* 2007).

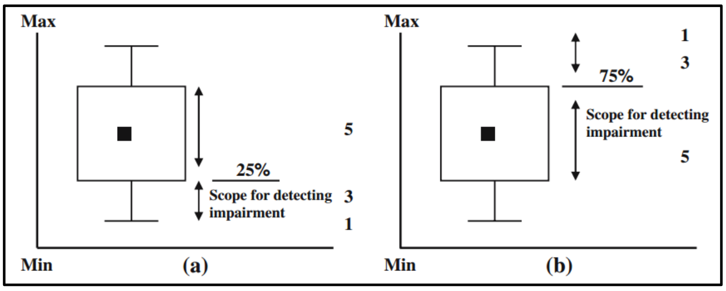

Fig. 4. Scoring based on quartiles of the least-disturbed station: (**a**) metrics expected to have decreasing numbers in response to impairment; (**b**) metrics expected to have increasing amounts in response to impairment.

Relationship between biological indices and physicochemical parameters

Correlation between biological indices and physicochemical parameters has been shown in Table 2.

Table 2. Correlation between biological indices and physicochemical parameters.

Index	IRWQI	Factor Analysis	Entropy	T	TSS	EC	Te	FC	PO_4	NO_3^-	NO_2^-	DO	pH	BOD_5	COD	NH_3
FBI	0.275	-0.41	0.225	-0.093	0.142	0.189	0.099	-0.282	0.025	-0.052	-0.104	-0.156	-*0.369	0.3**96	0.250	0.188
BMWP/ASPT	-0.208	0.052	-0.309	0.124	0.043	0.093	-0.166	0.318	0.028	0.084	-0.029	0.207	0.271	0.247	-0.195	-0.160
BBI	0.105	0.135	-0.064	0.3*30	0.022	0.102	-0.089	0.031	-**0.462	-0.216	0.204	0.106	0.054	-0.222	0.3*71	0.3*89
MMIF	0.024	-0.105	0.326*	0.196	0.082	0.194	-0.045	0.210	0.001	0.023	-0.078	0.059	0.251	0.119	-0.176	-0.069
IBI	0.158	0.36	-0.226	-0.129	-0.057	0.045	-0.158	-0.046	-0.293	-0.028	-0.264	0.102	0.108	-0.271	-*0.338	-0.095
NJIS	-0.181	0.220	-*0.340	0.193	0.063	0.177	-0.105	0.4*29	-0.009	0.193	0.018	0.227	0.235	0.270	-0.274	-0.131
Margalef	0.122	-0.150	0.315	-0.102	0.087	0.3*38	0.042	-0.20	0.078	0.021	0.148	0.036	-0.014	-0.151	0.293	-0.076
Shannon-Wiener	0.032	-0.137	0.354*	-0.058	0.163	-0.238	0.101	-0.110	0.135	0.078	0.141	-0.012	-0.128	-0.097	-*0.394	-0.092
Number of Dipteral	0.193	-**0.534	0.125	-0.071	0.196	0.046	0.3**96	0.082	-0.070	-**0.435	0.257	-0.283	0.3*67	-0.153	0.165	-0.014
Number of Ephemeroptera	0.122	0.360*	-0.33	0.119	0.058	0.080	-**0.433	0.107	0.104	0.083	-0.080	0.4**74	0.089	0.049	-0.282	-0.274
% CDF	0.127	-0.275	0.274	-0.064	-0.119	-0.102	0.080	-0.247	0.038	-0.148	-0.076	-0.262	-0.146	-0.193	0.297	0.164

P* < 0.05 and P** < 0.01.

Environmental conditions of the upstream of Jajrood River

According to physicochemical data of 2011 and 2012, significant changes in water quality are observed. However the reason for the constant pH in the area is that despite the fact that the soil of the catchment basin should be calcareous due to limestone rocks but the lime content in the area is low on average. This topic indicates a large amount of leaching in these soils. Calcium carbonate also appears in the soil in a way that is mostly used to saturate soil complexes and neutralize mineral acids. Therefore, the range of pH changes in all stations during different seasons has been recorded from neutral conditions to alkalinity due to the presence of cationic material of the soil and its complex saturation by calcium ion. In addition, in this study, 35 taxa from benthic macroinvertebrates were identified at the levels of order, family, and genera from seven stations on the upstream of the Jajrood River basin. On average, the most diversity of benthic macroinvertebrate belonged to Abnik station, while the lowest to Ahar-Abshirin station, reflecting the habitat conditions of the region. The reason for the high diversity of Abnik station during the three years of sampling was the central stem nature of the river and low impressionability of human pollution sources. The variation in the aggregation of bed and upstream of Abnik River may be due to the presence of deciduous trees alongside the river led to a high diversity of the species and, the reason for the significant decrease in diversity at the Ahar-Abshirin station is the existence of a tomb in the area and drainage of wastewater from the morgue, which contains large amounts of camphor and cedar. Camphor is a toxic substance with a strong odor employing as insecticide. In addition, saponin, which contains a high percentage of acid-soluble ash, has a high cleansing power in cedar powder (Beketov 2004). There is also a great extent of oily spots on the surface of the water, and oil smell can be felt in the atmosphere. One of the reasons for this is the lack of a plumbing system in the village and the use of oil resources for the heating system of its places. Thus, resistant taxa such as Chironomidae and Oligochetae were classified under the conditions of the environment rich in organic matter with the redundancy of 46.37%, while 7.05% were classified as the highest and the least taxa at the station (Rosa *et al.* 2014). In total, the maximum abundance of orders is Diptera, with nine families, among which the Chironomidae family has the most abundance. Also, according to the sampling, the diversity of benthic macroinvertebrates is high in the winter due to the low oviposit of insects and hatching in late spring and early autumn.

Development of MMIJ multimetric index

In this study, the range test was performed on 24 biological indices. Indices of TBI, Number of Plecoptera, Plecoptera (%), and Trichoptera (%) were rejected, because their first and third quartile ranges were not sufficiently large for combining in the MMIJ multimetric index (Klemm *et al.* 2003; Couceiro *et al.* 2012; Nguyen *et al.* 2014). Then, U-test was performed on 20 other biological indices to determine the stability. In this test, the EPT, Taxa Evenness, and Taxa Richness indices were rejected. Signal, Simpson, Trichoptera family, EPT/CHIR, Ephemeroptera (%), and Dipteral (%) indices were also rejected in the sensitivity test, which took place between the indices of the least-disturbed and disturbed stations. The reason for their rejection due to the overlapping of Box-and-whisker plots of that index at two least-disturbed and disturbed stations (Fig. 5). To ensure the answer, U-test was performed with p = 0.05. This test confirmed the above results. Finally, after Spearman correlation analysis, nine biological indices associated with at least one of the parameters of physicochemical were selected (Table 2; Jun *et al.* 2012). The results of the correlation test between selected biological indices also eliminated the other four indices, and the indices of the FBI, MMIF, NJIS, Shannon-Wiener, and Margalef were selected to develop the MMIJ multimetric index (Table 3).

Table 3. Correlation between biological indices.

Biological Indices	FBI	BBI	IBI	MMIF	NJIS	Shannon-Wiener	Margalef	Number of Diptera	Number of Ephemeroptera
FBI	1								
BBI	0.145	1							
IBI	0.014	**0.526	1						
MMIF	**-0.0640	-0.262	0.080	1					
NJIS	**-0.780	-0.111	0.095	**0.718	1				
Shannon-Wiener	0.242	-0.004	-0.109	0.158	-0.127	1			
Margalef	0.220	0.050	-0.071	0.194	-0.145	**0.930	1		
Number of Diptera	0.039	-0.056	-0.145	0.088	-0.205	-0.031	0.025	1	
Number of Ephemeroptera	**-0.480	0.116	0.160	0.242	**0.445	-0.115	-0.152	*-0.313	1

P*< 0.05 and P**< 0.01.

Then, to determine the maximum score of the water quality class, the number of indices is multiplied by the highest score and to determine the minimum score, the number of indices is multiplied by the lowest score (Baptista *et al.* 2007). Finally, after giving the appropriate scores for each five selected indices commensurate with geographic area (Table 4), to calculate the MMIJ index, all the scores are summed and are described by the water quality classes. The water quality table was divided into four classes. As a result, the closer the MMIJ index is to 25, the better the water quality, and the closer it is to 5, the worse the water quality (Table 5).

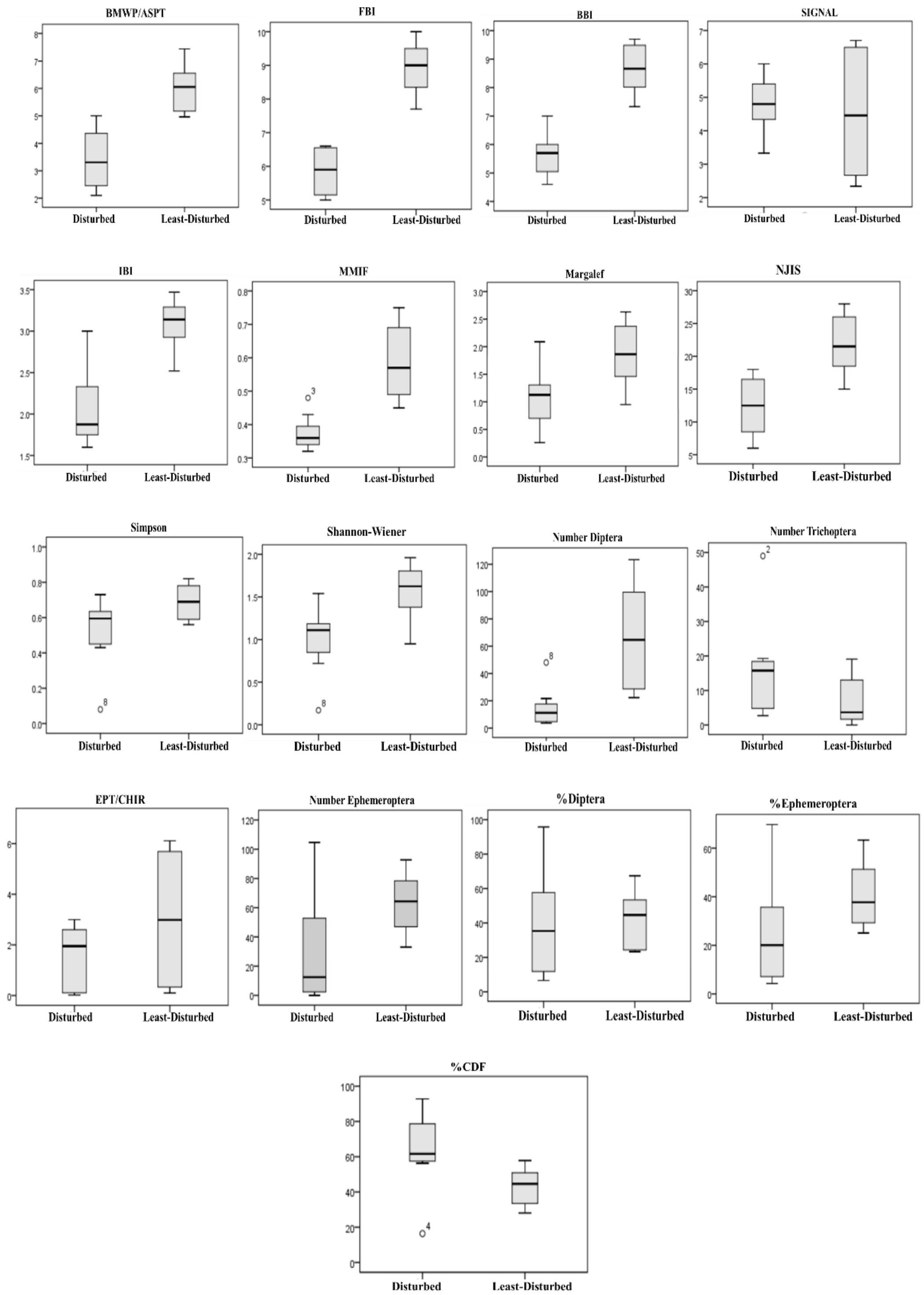

Fig. 5. Sensitivity test of biological indices using box-and-whisker plot.

Table 4. Scores of selected indices commensurate with area geographic.

Measurement indices in least-disturbed stations						Score		
Index	**Maximum**	**%75**	**%50**	**%25**	**Minimum**	**1**	**3**	**5**
FBI	5.79	5.27	5.02	4.15	2.7	>5.79	5.78 > 5.26≤	≤5.27
MMIF	0.75	0.68	0.57	0.49	0.45	<0.45	0.45-0.48	≥0.49
NJIS	28	25.5	21.5	19.75	15	<15	15-19. 74	≥19.75
Shannon-Wiener	1.96	1.75	1.62	1.39	0.95	<0.95	0.95-1.38	≥1.39
Margalef	2.63	2.34	1.86	1.54	0.95	<0.95	0.95-1.53	≥1.54

Table 5. Water quality classes for MMIJ multimetric index.

Water quality class	Color	MMIJ score
Poor	Red	5-10
Moderate	Yellow	11-15
Good	Green	16-20
Very Good	Blue	21-25

Water quality assessment based on MMIJ multimeter index

Assessment of water quality for four seasons in the studied stations, calculated using developed MMIJ multimetric index (Table 6). At Abnik station, water has good quality in all seasons of the year due to its branching nature. At Fasham-Abnik and Fasham-Shemshak stations, by increasing in the nitrate and ammonium salts in the autumn compared to other seasons for watering the sidewalk snows and its leakage to the river and also, the fossil form which is the permanent pollution of this area, causes a decrease in water quality of these two stations in high-precipitation season.

At Taletangeh station, due to the almost natural texture of the area and far from the complications of malicious human uses throughout the year, there is relatively good quality water. Also, the reason for the unfavorable qualitative results of Ahar-Abshirin station in most seasons of the year, except for spring, can be the vicinity to the tomb and the discharge of effluent. The high flow rate in autumn and rising self-effluent of rivers have a high impact on water quality. However, at Ahar-Abshirin station, there is no good quality water in these seasons. Although Ahar-Tochal station is located beside Ahar-Abshirin station in terms of geographic location, it has a better quality status than Ahar-Abshirin station.

Water quality at Haji Abad station has also been evaluated during the winter and spring seasons, which may be due to the elevations in nitrate, nitrate and ammonium ions, and even an upraised BOD_5 and also the overall shape of the water in the region. In addition, the rise of ions during the spring and summer seasons may be due to the fertilization rate on the gardens in the vicinity of Jajrood River. As shown in Table 7, the MMIJ multimetric index with most of the physicochemical parameters such as pH (p-value < 0.05, -0.450), turbidity (p-value < 0.05, -0.445), nitrate (p-value < 0.05, -0.404), ammonia (p-value < 0.01, -0.574), temperature (p-value < 0.01, -0.679), electrical conductivity (p-value < 0.01, 0.516) and fecal coliform (p-value < 0.05, -0.396) showed a significant and inverse relationship, while a direct and significant relationship with the dissolved oxygen parameter (p-value < 0.05, 0.412). This correlation confirms the above statement.

Table 6. Water quality assessment using MMIJ multimetric index.

Station	Category	MMIJ score							
		Winter	Quality	Autumn	Quality	Summer	Quality	Spring	Quality
Abnik	Least-Disturbed	21	Very good	25	Very good	25	Very good	23	Very good
Fasham-Abnik	Disturbed	7	Poor	13	Moderate	7	Poor	5	Poor
Fasham-Shemshak	Disturbed	5	Poor	11	Moderate	13	Moderate	5	Poor
Taletangeh	Least-disturbed	15	Moderate	-	-	25	Very good	19	Good
Ahar-Abshirin	Disturbed	5	Poor	11	Moderate	11	Moderate	9	Poor
Ahar-Tochal	Disturbed	9	Poor	15	Moderate	11	Moderate	9	Poor
Haji Abad	Disturbed	11	Moderate	15	Moderate	13	Moderate	5	Poor

Table 7. Correlation between MMJI index and physicochemical parameters.

Parameter	IRWQI	Fecal Coliform	EC	%DO	DO	T	pH
MMIJ	0.180	-0.396*	-0.516**	-0.365	0.412*	-0.679**	-0.408*
Parameter	NH_3	BOD_5	PO_4^{2-}	NO_3^-	NO_2^-	Turbidity	-
MMIJ	**-0.574	-0.134	-0.048	*-0.404	-0.258	-0.445*	-

P* < 0.05 and P* *< 0.01.

DISCUSSION

From a long time ago, biological indices of benthic macroinvertebrate have played a significant role to determine the water quality. One of their best benefits is consistency in the results of water quality. In Iran, so far, no biological indices have been developed based on benthic macroinvertebrate, and only a few limited indices such as Shannon-Weiner, FBI, Margalef, BMWP, and ASPT have been used for calculation of water quality without calibration with area conditions. The calibration of the indices, according to the natural geography of the environment has a significant impact on the water quality of the region. The multimetric index has a value-added in comparison with the single indices and the assessment of water quality based on the physicochemical parameters. In the years 2011 and 2012, Shahid Beheshti University has used MMIF, EPT, TR, FBI, SIGNAL, IBI, and NJIS indices that have a significant relationship with physicochemical parameters. In these two years, only the correlation between physicochemical parameters or biological indices has been taken. While an effective way for accurate evaluation and interpretation of an index, its comparison is based on two least-disturbed and disturbed ecosystems. Therefore, the selection of the least-disturbed station can be obtained using data from previous years or experts' views. In this study, physicochemical supervision and monitoring at all stations were carried out during different seasons of 2011-2013. However, qualitative monitoring of water-based on more physicochemical parameters is able to accurately respond to conditions with low human disturbance. This suggests the need for an easy tool to assist in the evaluation of physicochemical monitoring. For this reason, the MMIJ multimetric index has been developed using data from 2011-2012. In this study, the range test was used to determine the broad dispersion and stability test for considering similar results of indices in two dry and wet season and sensitivity tests to show the susceptibility of the indices of stressed stations relative to least-disturbed stations. In this test, due to low human degradation activities and high diversity of taxa at Abnik station, Abnik was considered to be the least-disturbed station. The output of this index is a more prominent image of the water quality status, which reflects the physicochemical parameters of water. The program of water quality assessment is a useful program based on the health status of sampling stations (Nguyen *et al.* 2014). In the meantime, some factors, such as the inappropriate level of classification of indices, also lead to incorrect interpretations. Therefore, special attention should be paid to statistical work. According to the data in this study, the qualitative table of this index is divided into four classes. The output of this classification is from very good to poor based on the water quality in the Jajrood River Basin. These classes reflect the correct slope of human effects from the upstream to downstream of the river, which is, in fact, equal to the least-disturbed station and the stations under stress and pollution. The five final biological indices were considered for integration with the MMIJ multimetric index. Each of them provides different responses to organic matter contamination to provide a complete picture of the status of river water quality. Except for the FBI index, all other indices have an inverse relationship with increasing pollution. Among the diversity indices, Shannon-Wiener is very sensitive to contamination, which was used to develop this index (Metcalfe 1989). Finally, the correlation was taken between the MMIJ multimetric index, the physicochemical parameters, and the IRWQI, which showed a strong correlation between most of the parameters and, at the same time, showed no correlation with the physicochemical index. However, the desired multimetric index cannot be ignored, because the biological indices give us more sustainable results than the physicochemical indices of water quality (Dama sio *et al.* 2007). Chemical indices indicate water quality at the same time. It is also possible that an error has been made in measuring the BOD_5 test outside the Iranian Environmental Research Institute standards, because the obtained values are higher than the standards of the Iranian rivers. Also, direct discharge of sewage can occur during sampling, which is due to high BOD_5 content. Therefore, physical and chemical indices require biological indices as a complement to sustainability in the results. However, to have sufficient stability in the development of multimetric indices, the repeatability of sampling over many years by taking into account the extensive biological indices is needed (Baptista *et al*. 2007). Statistical analysis plays an essential role in the development of multimetric indices (Hering *et al.* 2006; Edegbene *et al.* 2019; Arman *et al.* 2019). In this study, the use of simple graphical tests and also descriptive statistics showed that this method is an appropriate biological tool for detecting disturbed stations with least-disturbed stations.

CONCLUSION

In this study, the MMIJ multimetric Index for assessment of water quality was well developed using biological indices based on benthic macroinvertebrate for the Jajrood River upstream. The developed MMIJ multimetric index showed high sensitivity to physicochemical parameters, because this index shows a substantial and inverse connection with physicochemical parameters and, it has a direct and significant relationship with the dissolved oxygen content. This index is more reliable than metric indices because it considered various stressors through the integration of NJIS, MMIF multimetric indices, Shannon-Weiner, Margalef, and FBI metric indices. Although MMIJ multimetric index is the two years result of statistical analysis, however, research needs to be done over a more extended period to examine the range of data and the sustainability of the indices. The assessment of water quality using the MMIJ multimeter index showed that Jajrood River has not good condition. Due to the importance of Jajrood River as one of the important sources of drinking water supply in Tehran, capital of Iran, appropriate management measures should be taken to improve water quality and pollution control in this area.

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