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Assessment the effects of physiochemical parameters on water ecological quality using indices based on macro-invertebrates communities in the Karaj and Jajrood rivers

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Abstract

This is the first study with the greatest number of multimetric indices calculated in Iran to assess water quality at Jajrood and Karaj protected rivers. Given the point that these rivers supply a large portion of Tehran's drinking water, the present study aims at determining ecological quality of these rivers based on a suitable biotic index among these indices. Physicochemical and macro-invertebrate samples were collected with three replications during three consecutive years from 19 stations with a Surber sampler. In the Jajrood River, macroinvertebrates with 6667 abundance belong to 22 families and in the Karaj River, macro-invertebrates with 13,246 abundance belong to 24 families have been identified. The most appropriate time for sampling is in summer because of the existence maximum abundance and diversity of macroinvertebrates. The results of CCA have been shown physicochemical parameters TSS, EC, pH, and BOD have the most effect on the distribution of macroinvertebrates. Among the 16 biotic indices, the FBI index in Karaj River and the BMWP/ASPT index in the Jajrood River are the most reliable indices for assessing the water quality. The results showed that point pollution sources (orchards, restaurants and villages) and nonpoint sources (tourism activities and recreational area) have the most negative impact on the ecosystem of these two rivers. Results of water quality assessment have been shown the changes in ecological quality of water due to human activities; therefore, it is necessary to increase control and management of pollutant sources to improve the water quality of these two rivers.

Keywords: Macroinvertebrate, Monitoring, Ecological quality, Multimetric indices, Karaj and Jajrood rivers

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Introduction

The freshwater ecosystems especially rivers are usually passing through different lands ~~uses~~ such as agricultural, residential and industrial areas, which are most threatened by various human activities (OJija *et al*., 2017). Therefore, these activities have adverse effects on the water quality and ecological integrity of the rivers (Blakely *et al*., 2014) and also change the water physicochemical parameters. Therefore, physicochemical information should be collected continuously over a long period of time, which is very costly and time consuming. While living organisms' ecological data as biotic indices can be used to predict the information of water quality for a proper time interval (Krisanti *et al.,* 2017). In the recent years, biological assessments by the U.S.EPA have emphasized more biological integrity of aquatic systems rather than simple indicators (Young *et al*., 2014). The results of biotic indices are complementary to abiotic data for accurate monitoring of aquatic ecosystems and assessment of the ecological integrity of ecosystems (Liu *et al*., 2017). Recent water quality monitoring in Iran have been mainly based on the determination of physical and chemical parameters and biological assessment of rivers and it is very limited. While the study of macroinvertebrate can reveal occurrence or unrecorded chemical pollution incidents (Nemati *et al*., 2010). Macro-invertebrates are great indication for assessing the quality and the health of aquatic ecosystems due to the high diversity of Macro-invertebrates species, the presence in most aquatic ecosystems, low mobility, the ability to accumulate toxic substances, easy sampling and observation with the naked eye (Aschalew and Moog, 2015) and have been used in many studies as biotic indices for the health of freshwater (Mwedzi *et al*., 2016). These organisms can show the impacts of human activities on water quality through the presence of tourists, as Wimbaningrum *et al*. (2016) documented it properly. In Iran few studies have been conducted on macro-benthic indices, which can be referred to Aazami *et al.*(2015), Shokri *et al*. (2014) in Tajan River, Nemati *et al*(.2010) in Zayanderud River and Kamali and Esmaeel sari (2009) in Lasem River, also PiraliZefreh and Ebrahimi (2017), have been studied five indices for assessing the quality of rivers. Previous studies carried out in the study area recommended to do studies with more repetitions and more stations for better understanding of macro-benthos population structure (Khatami *et al*., 2007; Mahmoudi *et al.*, 2015; Parvandi *et al.*, 2015 b; Shirchi *et al.,* 2015).It should be noted, in the previous studies, both rivers have been studied separately and so far, these two rivers, both located in the central basin have not been studied at the same time. Since these rivers are located in different geographical, hydrological and climatic conditions. Therefore, the proper local index should be selected compatible to the conditions of the area (Chen *et al*., 2014). To check the accuracy assessment of the results, the measurements must be repeated monthly or yearly. In Iran, the use of multimetric biotic indices and suitable index for assessing the quality of surface water are rarely used (Aazami *et al*., 2015). In fact, water health assessment is often based on physicochemical parameters and abiotic indices. This study is the first research in Iran, which both physicochemical parameters of water and macroinvertebrates communities have been collected for three consecutive years in the Jajrood and Karaj rivers. Qualitative water levels also have been studied using physicochemical and biotic indices. Both of these ecosystems are among the rivers protected by the Department of Environment (DOE) of Iran, which are important hotspots for recreational and tourists purposes and are used to supply the drinking water of Tehran. Therefore, it is necessary to propose a suitable index using integrated and regular studies by biotic indices and abiotic parameters in this region.

Materials and methods

Study area

The Jajrood and Karaj Rivers are located in the East and West of Tehran city,respectively. These rivers are supplying a large portion of Tehran drinking water with more than 12 million people. The Jajrood River with a catchment area of 690 km^2 from northwest to southeast trend and length of about 140 km enters to the Latian Dam reservoir. Its minimum and maximum discharges are in September and May with 1197 and 2086 m^3 s^{-1}, respectively (Parvandi *et al*., 2015a). The Karaj River is located in the southern slopes of Alborz Mountain Range within the snow-rainy hydrological regime group with a catchment area of about 850 km^2 and length about 245 km . Among the Karaj River tributaries, Velayat Rood (stations K_4 to K_6) and Shahrestanak (stations $K_1$to K_3) have the highest discharge of 127.7 and 76.9 million cubic meters per year, respectively, (Khatami *et al*., 2007; Mahmoudi *et al.*, 2015). Figure 1 shows the geographic location of the study area and sampling points and Table 1 shows geographic coordinates of sampling stations.

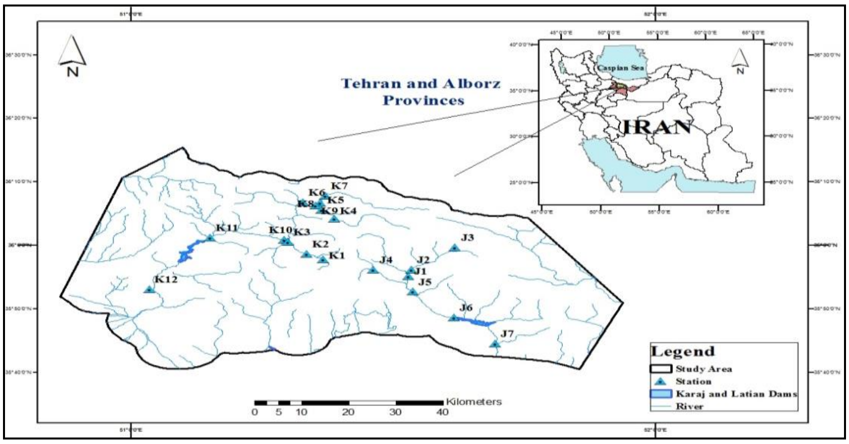

Figure 1: Study area and sampling points.

Table 1: the Karaj and Jajrood Rivers sampling stations geographic coordinates

River	Stations	Latitude	Longitude
Jajrood	J1	35°55'41.6"	51°31'36"
	J2	35°55'41.6"	51°31'36"
	J3	35°59'40"	51°37'6"
	J4	35°56'1.06"	51°27'49.37"
	J5	35°51'51.15"	51°32'40.4"
	J6	35°48'64"	51°36'58"
	J7	35°44'11"	51°41'37.86'
Karaj	K1	35°57'45.8"	51°21'86.7"
	K2	35°58'35.3"	51°20'6.9"
	K3	36°00'30.6"	51°18'2.7"
	K4	36°4'13.8"	51°23'19.6"
	K5	36°5'35.5"	51°21'52.8"
	K6	36°6'45.7"	51°19'42.6"
	K7	36°07'46.6"	51°22'17.0"
	K8	36°06'39.9"	51°21'38.5"
	K9	36°06'14.2"	51°21'09.8"
	K10	36°00'50.5"	51°17'33".2
	K11	36°·01'17.73"	51°09'9.19"
	K12	35°55'38. 12"	51°03'32.7"

Monitoring network

Considering land uses (the location of restaurants, villages, residential, industrial and agricultural areas), geological conditions, river length, vegetation and local climate conditions, 12 and 7 stations were selected in the Karaj and Jajrood Rivers, respectively. Physicochemical parameters including temperature (C°), pH, (DO, NO3, PO4, TDS, TSS, BOD5, COD, (mg L^{-1})), turbidity (NTU), EC (µs cm^{-1}), river depth, width and flow rates were measured during three years, seasonally (November 2015 and 2016 and September 2016 and 2017). Parameters such as DO, water temperature, depth, width and flow rates were measured at stations and other parameters were maintained by the APHA method and transferred to the laboratory. Simultaneously with the physicochemical data gathering, macroinvertebrates were sampled using a Surber sampler (with a mesh size of 250 µm and 30×30 cm cross section) with three replications at each station (Aazami *et al*., 2015). The samples were fixed at stations by 96% alcohol and transferred to the laboratory. The identification of macroinvertebrates was carried out using the identification key of aquatic invertebrates (Hartmann, 2007; Oscoz *et al*., 2011) under microscope and stereomicroscope.

Statistical analyses

Statistical analyses were performed using SPSS 16.0, PAST version 3 and R version 3.3.2 (Vegan) software packages. Before the analyzing, number of macro-invertebrates was normalized according to log (x+1) transfer (Arimoro and Unique, 2107). The data should be arranged in two completely matched matrices, called biotic matrix (dependent variables) and abiotic matrix (independent variables). In the biotic matrix, data on the abundance of macro-invertebrates (or biotic indices) in each station~~s~~ and in the abiotic matrix, data on physicochemical parameters are entered respectively in the same order. Then, the canonical correspondence analysis (CCA) was calculated in R software. CCA is the newest method for grouping and analyzing the relationship of species with environmental factors, in which regression and correlation tests can be used simultaneously and easily to show these relationships (Aazami *et al.*, 2015). The CCA analysis is done by the Vegan package. Pearson correlation analysis was used to determine the correlation between physicochemical parameters and macroinvertebrates abundance data. The Pearson correlation analysis was used to determine the suitable biotic index. The correlation of the biotic indices having the highest efficiency with the abiotic index $IRWQI_{SC}$ (Iranian Water Quality Index for Surface Water Resource-Conventional Parameters), which was calculated by the Pearson correlation analysis. Ecological software PAST was used to calculate biodiversity indices such as Shannon index.

Physicochemical index

The Ministry of energy of Iran developed a local index entitled $IRWQI_{SC}$ for the assessment of water quality (Nabizadeh *et al*., 2013).This index

$$IRWQI_{SC} = [\prod_{i=1}^{n} I_i^{Wi}]^{\frac{1}{\gamma}} \quad \gamma = \sum_{i=1}^{n} W_i$$

I_i = sub-index for each water quality parameter; W_i = weight associated with each water quality parameter; n = number of water quality parameters; y = the sum of the weight.

$IRWQI_{SC}$ indices are based on physicochemical parameters, (DO, NO3, PO4, BOD5, COD, pH, EC, Turbidity) which are evaluated in this study.

Bio indices

In addition to three diversity indices namely Shannon-Wiener (H), Simpson (D) and Margalof (DMg), 16 indices are used, in the present study, to assess and classify water quality by macroinvertebrate indices. They are EPT[1], EPT/C[2], CDF[3], FBI[4], NJIS[5],

[1]Ephemeroptera, Pelecopter, Trichoptera
[2]Ephemeroptera, Pelecopter, Trichoptera/Chironomidae
[3]Percent Contribution of Dominant Family (%CDF)
[4]Hilsenhoff Family Biotic Index
[5]New Jersey Impairment Score (NJIS)

BMWP/ASPT[6], SIGNAL[7], TBI[8], BBI[9], MMIF[10], IBI[11], MBI[12], RBP IBI[13], EQR[14], MAIS[15], SCI[16], which are well documented already (Gabriels *et al*., 2010; Nemati *et al*., 2010; Shokri *et al*., 2014; Aazami *et al.,* 2015; Parvandi *et al*., 2015 b; Shirchi *et al*., 2015).

Result

In the Jajrood River, macro-invertebrates with 6667 abundance belong to 22 families and 8 orders and in the Karaj River, macro-invertebrates with 13246 abundance belong to 24 families and 8 orders were identified. The identified macro-invertebrates in the study area have been presented in Tables 2 and 3. The most abundant macroinvertebrates were identified in summers for both rivers. The most dominant families in the Karaj River were Chironomidae, Baetidae and Simullidae in November 2015 and 2016 and September 2016 and 2017.Baetidae is the most dominant family in all of the four sampling periods in the Jajrood River.

Table 2: Macroinvertebrates identified (present/absence) in the Jajrood River (2015-2017).

Order	Family	Genus	Station						
			J1	J2	J3	J4	J5	J6	J7
Ephemeroptera	Baetidae	*Baetis*	✓	✓	✓	✓	✓	✓	✓
		Acentrella	✓	✓	✓	✓	✓		✓
	Heptageniidae	*Heptagenia*			✓		✓		
		Ecdyonurus		✓					
		Rithrogena		✓	✓				
		Epeorus	✓		✓			✓	
Diptera	Chironomidae		✓	✓	✓	✓	✓	✓	✓
	Tipulidae		✓	✓		✓	✓	✓	
	Blephariceridae		✓	✓	✓				
	Simullidae		✓	✓	✓	✓	✓		
	Limoniidae				✓				
	Ceratopogonidae(nymph)			✓		✓			
	Stratiomyidae				✓				
	Empididae	*Clinocerinae*			✓		✓		
	Athericidae	*Atherix*	✓						
	Tabanidae		✓						
	Chaoboridae		✓						
Trichoptera	Hydroptiloidea				✓				
	Hydropsychidae		✓	✓	✓		✓	✓	
Coleoptera	Elmidae				✓	✓			
Oligochaete	Tubificidae			✓		✓			
	Lumbricidae		✓	✓	✓	✓	✓	✓	
Pleocoptera	Perlilodidae			✓		✓			
	Capniidae		✓		✓				
Hymenoptera	Agriotypinae		✓						
Crustaceae	Potamonidae								✓

[6]Biological Monitoring Working Party /Average score per taxon
[7]Stream Invertebrate Grade Number Average Level
8 Trent Biotic Index
[9]Belgium Biotic Index
[10]MultimetricMacroinvertebrate Index Flanders
[11]Integrity Biotic Index
[12]Macroinvertebrate Biotic Index
[13]Rapid Biassessment Protocol
[14]Ecological Quality Ration
[15]Macro invertebrate Aggregated Index for Streams
[16]West Virginia Stream Condition Index

Table 3: Macroinvertebrates identified (present/absence) in the Karaj River (2015-2017).

Order	Family	Genus	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
			Station											
Ephemeroptera	Baetidae	*Acentrella*						✓	✓	✓	✓	✓		✓
		Baetis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Heptageniidae	*Rhitrogena*			✓							✓		
		Heptagenia										✓		
		Epeorus	✓				✓	✓	✓	✓	✓	✓		
Coleoptera	Dytiscidae										✓			
	Elmidae		✓	✓	✓	✓			✓	✓	✓	✓		✓
Diptera	Athericidae	*Atherix*							✓					
	Empididae			✓	✓	✓	✓	✓	✓	✓	✓			✓
	Blephariceridae		✓				✓	✓				✓	✓	✓
	Chironomidae		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Tipulidae			✓	✓		✓	✓			✓	✓		✓
	Ceratopogonia (Nymph)					✓		✓	✓	✓	✓		✓	✓
	Thaumaleidae					✓								
	Limoniidae		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓
	Simuliidae		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Tabanidae				✓	✓								
	Stratiomyidae							✓	✓	✓	✓			
	Simuliidae (nymph)		✓			✓			✓	✓	✓			✓
	Sciomyzidae						✓							
Oligochaete	Lumbricidae		✓	✓	✓	✓	✓		✓		✓			✓
	Tubificidae		✓	✓	✓	✓	✓	✓						✓
Trichoptera	Hydropsychidae		✓	✓	✓		✓			✓	✓	✓	✓	✓
	Rhyacophilidae	*Rhyacophila*				✓								
Amphipoda	Gammaridae	*Gammarus*						✓						
Plecoptera	Taeniopterygidae	*Taeniopteryx*						✓		✓	✓			
Mollusca	Hydrobiidae												✓	

According to CCA plots (Figs. 2 and 3) and Pearson correlation results between the abundance of macroinvertebrates and physicochemical parameters in the Jajrood River, the main components of CCA are pH, BOD. In the Karaj River the main components of CCA are TSS, EC.

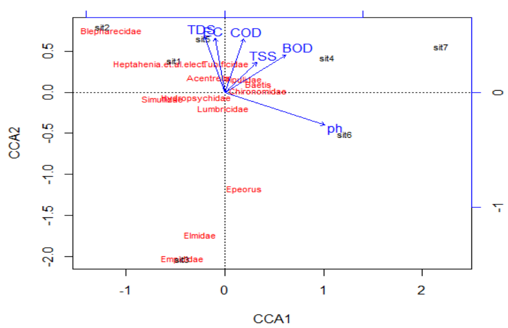

Figure 2: The relationships between Macro-invertebrate and Environmental variables in the Jajrood River.

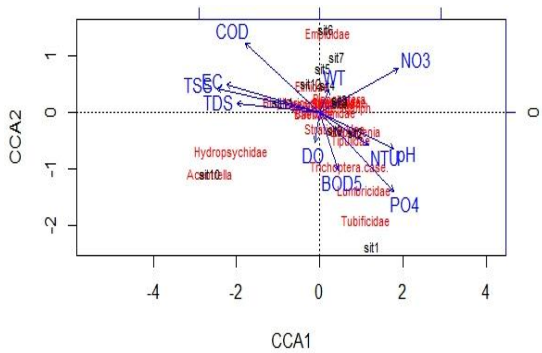

Figure 3: The relationships between Macro-invertebrate and Environmental variables in the Karaj River.

The CCA results based on the macro-invertebrates biotic indices are presented in Figs 4 and 5. The variances were calculated by $CCA_1$and CCA_2 for macro-invertebrate indices for the Karaj and Jajrood River are 0.90 and in 0.96.

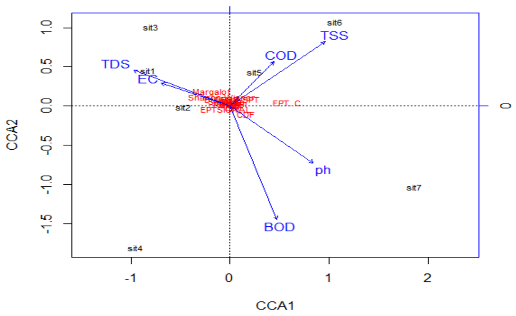

Figure 4: The feasibility measurements andselection of the best macro-invertebrate index in the Jajrood River. Proportion Explained by first and second CCA are 0.83 and 0.13 respectively.

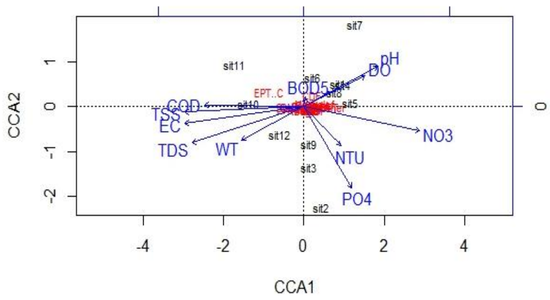

Figure 5: The feasibility measurements and selection of the best macro-invertebrate index in the Karaj River. Proportion Explained by first and second CCA are 0.76 and 0.14 respectively.

Table 4: Correlation coefficient between biotic indices and IRWQI index in two studied rivers.

Indices / River's Name	Jajrood	Karaj	
EPT/C	-0.331	FBI	-0.807**
EPT	0.330	MBI	-0.745**
BMWP/ASPT	0.400	EPT	0.706*
SIMPSON	-0.093	EPT/C	0.701*
CDF	0.011	CDF	0.127
MARGALOF	0.013	IBI	0.355
SIGNAL	0.130	TBI	0.533
MBI	-0.220	RBP-IBI	0.452
NJIS	0.333	SCI	0.494
SCI	0.082	MAIS	0.660*

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

To determine the efficiency of macro-invertebrate biotic indices and to select the suitable biotic index, correlation of these biotic indices with the abiotic index ($IRWQI_{SC}$) were calculated. The results of correlation coefficient of selected biotic indices with physicochemical index $IRWQI_{SC}$ are presented in Table 4.

In the Karaj River, the highest correlation of the physicochemical index IRWQISC with the biotic indices (Table 4), is related to the FBI index (r=0.80, R2=0.64). However, in the Jajrood River none of the selected indices showed a significant correlation with the physicochemical index. The highest correlation value is for BMWP/ASPT index with correlation coefficient of 0.4.

According to Table 4 FBI and BMWP/ASPT indices have the highest efficiency compared to other indices in the four sampling periods, which are presented in Figs 6 and 7 for each station in both rivers. The results of the $IRWQI_{SC}$ index for each station in both rivers are presented in Figs 8 and 9.

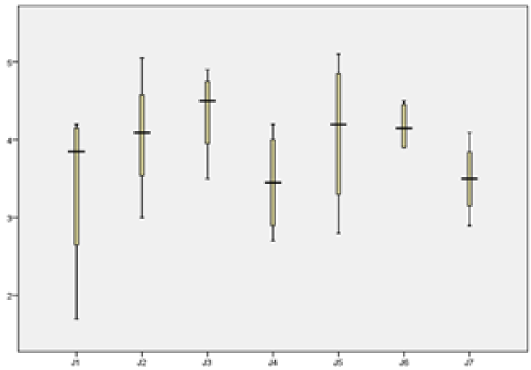

Figure 6: BMWP/ASPT index result for all stations in the Jajrood River (2015-2017).

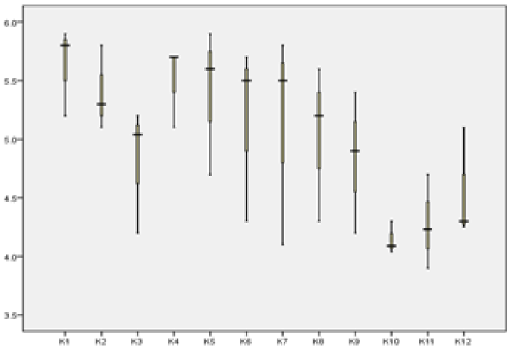

Figure 7: FBI index result for all stations in the Karaj River (2015-2017).

Based on the FBI index in the Karaj River, all the stations except K_{10} to K_{12} have moderate water quality. K_{10} to K_{12} stations in comparison to other stations have better water quality. Based on the BMWP/ASPT index in the Jajrood River all the stations except J_1, J_4 and J_7 have moderate water quality. J_1, J_4 and J_7 stations in comparison to other stations have lower water quality. Based on the results of Fig 8, at stations J3 and J4 water quality is relatively good and at other stations moderate. According to water quality in the Karaj River is relatively moderate in all stations, and in stations, K10 to K12 is relatively good.

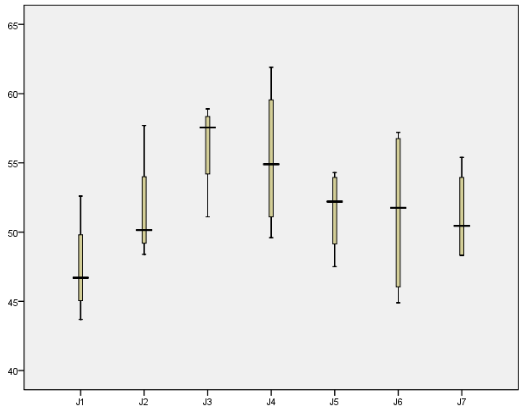

Figure 8: IRWQISC index result for all stations in the Jajrood River (2015-2017).

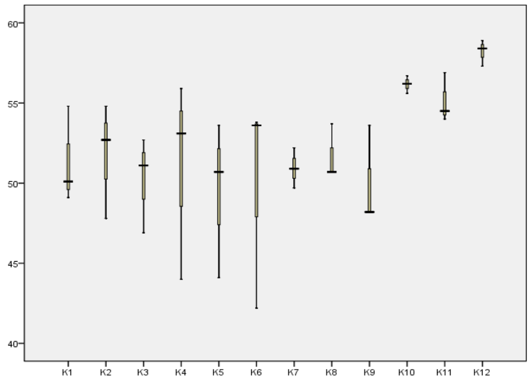

Figure 9: IRWQISC index result for all stations in the Karaj River (2015-2017).

The dendrogram classification of the Jajrood and Karaj River based on selected biotic indices and the abiotic index $IRWQI_{SC}$ are presented in Figure 7 to Figure 10. All the results were obtained by Ward Method and rescaled by distance cluster combine. In Figure 7 all the stations are divided into two main groups. According to Figure 8and Figure 10, stations K_{10} to K_{12} are in a separate level in comparison with other stations.

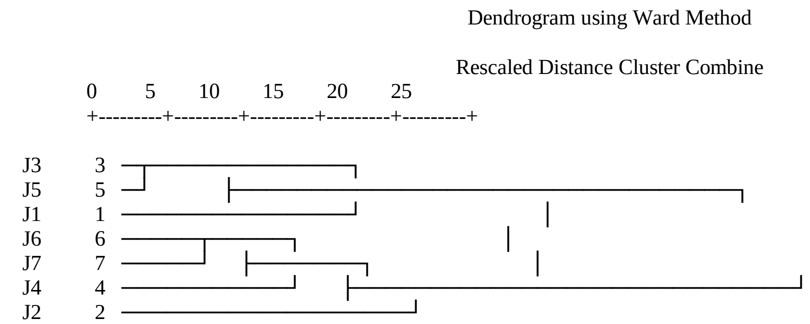

Figure 7: Dendrogram classification of the Jajrood River's stations based on Biotic Index- BMWP/ASPT.

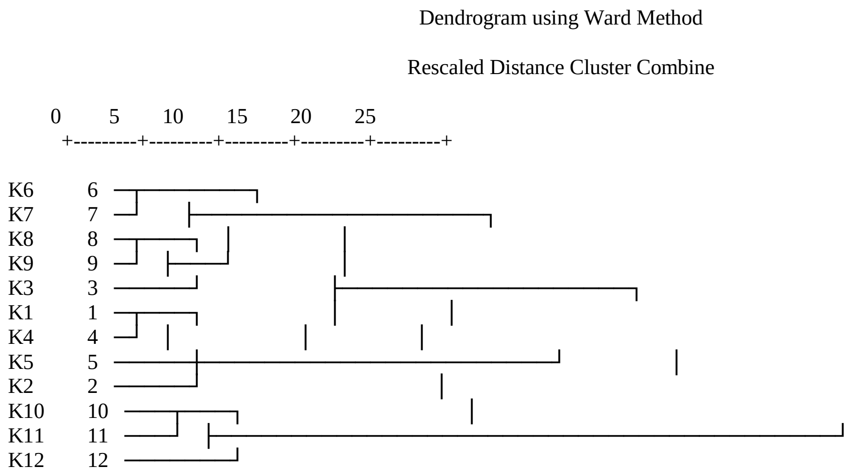

Figure 8: Dendrogram classification of the Karaj River's stations based on Biotic Index- FBI.

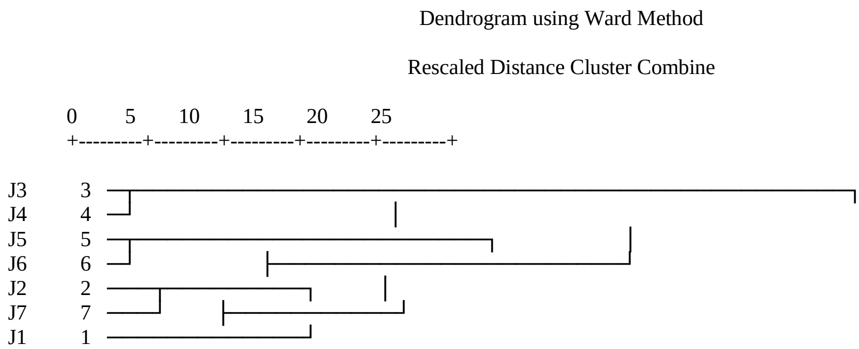

Figure 9: Dendrogram classification of the Jajrood River's stations based on Abiotic Index-IRWQI$_{SC.}$

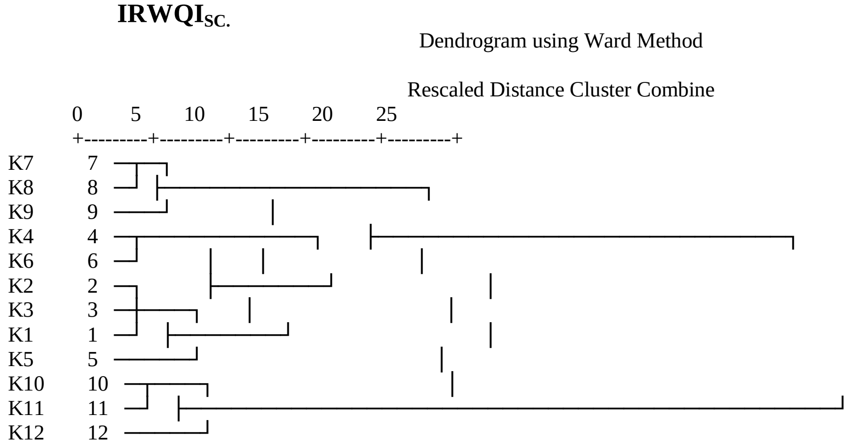

Figure 10: Dendrogram classification of the Karaj River's stations based on Abiotic Index-IRWQI$_{SC.}$

The results of the biodiversity indices showed that the mean values of Shannon-Wiener (H) index are varied in the four sampling periods in the Karaj River between 2.04±0.11 to 2.5±0.06 and, in the Jajrood River between 1.4±0.22 to 2.40±0.42. Based on the results of Shannon-Wiener (H) index, all stations in the Jajrood and Karaj rivers have moderate pollution and values of Shannon-Wiener (H) index in none of the stations is higher than 3, which means no pollution. The Simpson index (D) in both rivers tends to one. Based on the result of Margalof (DMg) index results, station J_7 and J_3 have the lowest and highest species diversity, respectively.

Discussion

In this study, the most abundance and diversity of macro-invertebrate communities were in the summer that is the result of increasing of water volume and weather temperature. Therefore, by increasing temperature, the production of phytoplankton increases and more nutrients is available to macro-invertebrates. According to the results of Sharbati *et al*. (2013) density and abundance of macro-invertebrate are increased in the summer due to the high biological activities such as feeding and reproduction. Based on the previous studies and obtained results, summer and autumn are the best seasons for sampling of macro-invertebrates due to low flow rate and macro-invertebrates life cycle (Beatty *et al.,* 2006; Mahmoudi *et al.,* 2015; Parvandi *et al.*, 2015b). The dominant families identified in this study area are similar to the results of previous studies (Khatami, 2004; Parvandi *et al*., 2015b; Shirchi *et al*., 2015). Sensitive Taxon is dominant in the rivers which are less affected by the pollutants and on the contrary the rivers which are under greater pollution, the resistant species are dominant with less varieties and abundance (Ortiz *et al*., 2007). Chironomidae family is considered resistant macro-invertebrates to pollution, indicates poor water quality (generally due to low soluble oxygen and high nutrients) (Langdon *et al.,* 2006). Therefore, the presence of a large number of Chironomidae family indicates negative environmental impacts to the river ecosystem (Kamali and Esmaeel sari, 2009). According to Figs 2 and 3 severity effect on macroinvertebrates distribution can be seen from the length of each variables (Parvandi *et al*., 2015b). The highest effect is related to parameters, pH and BOD in the Jajrood River. These variables have a significant effect on the distribution of macro-invertebrates. When the length of the vectors is almost equal, it means the distribution of most family is affected by all the components. The results obtained from the CCA plots are consistent with the results of Obot *et al*. (2014) and Yazdian *et al.* (2014) which are shown the diversity and abundance of macro-invertebrates are strongly influenced by environmental parameters on the ecosystem. The previous study Parvandi *et al*. (2015a) in the Jajrood River has indicated that NO_3 , DO, PO_4, TSS, Phosphorus, BOD, water flow and depth had a significant effect on the distribution of macro-invertebrates which are consistent with the results of this study. Based on the calculated results of the 16 biotic indices in CCA plots (Figure **4**) MARGALOF, SIGNAL, SCI, BMWP/ASPT, NJIS, EPT, EPT/C, CDF, SIMPSON, and MBI have shown significant correlation with physicochemical parameters in the Jajrood River. Finally, to select the most suitable biotic index, the correlation of the mentioned biotic indices with the abiotic index IRWQISC was calculated (table 4)

The results of this correlation have shown the BMWP/ASPT index in the Jajrood River were the most effective index in comparison to other ones. Considering differences in physicochemical parameters and land uses, only a few number of indices are applicable to each area and all indices cannot be expected to have the same performance in different area (Yazdian *et al.*, 2014).The BMWP/ASPT index is one of the indices which is widely used in ecological assessment of rivers. The BMWP index has been developed for the ecological assessment of rivers in England and has been successfully used in other countries such as Spain, Italy, Thailand, Poland, Portugal, Brazil, Malaysia, Greece, and Egypt. The results of Nemati *et al*. (2010) on the Zayandehrud River in Iran also have shown BMWP/ASPT index had the highest correlation with physicochemical parameters (Nemati *et al*., 2010; Yazdian *et al*., 2014). According to the results of previous studies on the Jajrood River, EPT, SIMSON, MARGALOF, EPT/C, BMWP/ASPT and FBI indices are suitable for assessing water quality (Parvandi *et al.*, 2015b; Shirchi *et al.*, 2015) which is similar to the results of this study. The results of water quality assessment based on the selected biotic indices and IRWQISC index in the Jajrood River indicates that the most stations have unsuitable water qualitative status (Figs. 6 and 8).

Due to the fact that, these stations are located at the downstream of the villages, residential areas and high tourism density locations. Sewage discharges directly into the rivers due to the area's being mountainous and the high slope of residential areas in the riverside. As a result, water quality and, consequently, macro-invertebrate species have been adversely affected by physicochemical factors in this area. Station J_7 has the lower water quality compared to other stations. In Figure 7, the classification of stations based on BMWP/ASPT index is entirely consistent with the results of CCA (Figure 4). Stations J_6 and J_7 are in the same class and components of the CCA. Based on the results of the Margalf index, station J_7 has the lowest biodiversity, which is consistent with the results of other studies (Parvandi *et al*., 2015a). The Margalaf index has direct relationship with the water quality, which by increasing the water quality the value of this index also increases. The species abundance index in an ecosystem states that there are suitable environment conditions and proper habitat, because suitable environmental conditions increase the presence of species (Bagheri Tavani, 2015). Since J_7 station is located in downstream of Latian Dam and this dam, as a physical factor has been completely changed the river ecosystem. It has resulted in decreasing the abundance and diversity of macro-invertebrates in this station. Generally, dams influence the diversity and abundance of macro-invertebrates (Li *et al.*, 2013; Mwedz *et al*., 2016).

In the Karaj River according to Fig. 3, TSS and EC have the most effects on the distribution of macro-invertebrates. The presence of turbidity, TSS and BOD parameters in the results are caused by construction activities around the rivers, erosion of colloidal materials such as mud, silts, pebbles and sewage discharge. Nitrate concentration of water increases by sewage discharge from residential areas and villages and riverside orchards and high usage of fertilizers in agricultural area around the rivers (Zaabar *et al*., 2015). According to fig 8 and fig 9 the results of the physicochemical Index IRWQISC in the majority of stations in the residential areas have shown moderate water quality.

Based on the calculated results of the 16 biotic indices in CCA plots (Fig. 5), IBI, CDF, RBP-IBI, MAIS, SCI, EPT, EPT/C, FBI, MBI and TBI have been shown a correlation with 99% confidence with physicochemical parameters in the Karaj River. The correlation of the mentioned biotic indices with the abiotic index IRWQISC was calculated. Results of this correlation (Table 4) have shown FBI index in the Karaj River was the most effective index in comparison to other indices. According to studies carried out by Mahmoudi *et al*. (2015), Kamali, and Esmaeeli Sari (2009) the most suitable index for water quality assessment of the Karaj River is FBI index, which is perfectly consistent with the results of this study. In the study carried out by Pirali Zefreh and Ebrahimi (2017) five indices of EPT, ASPT, FBI, BMWP and SHANNON-WIENER for assessing the quality of rivers have been analyzed. The results have shown for better assessing the quality of the rivers ASPT and FBI indices can be used because the resistance and quantitative data of the population of macro-invertebrates. The use of the FBI index is more cost-effective and convenient due to the easier calculation and need for less taxonomic information (Czerniawsla-Kusza, 2005). The Hissenhoff Family Biotic Index (FBI) is used often as a water quality index (Young *et al*., 2014). Increase the water quality levels in the Hilsenhoff biotic index has shown FBI index is the most suitable index for water quality assessment in the Karaj River.

Based on the results of Fig. 7 in the Karaj River, the trends of selected FBI and abiotic indices are similar to each other and have a meaningful correlation. According to the mentioned indices, the quality of water is moderate in all stations and the reason for the higher water quality in the stations of the Karaj River (K10, K11, K12) compared to the tributaries of Shahrestanak, VelayatRoud and VarangehRoud is the self-refinement ability of the Karaj River. One of the characteristics of the Karaj River is self-refinement ability, which has been caused by passing water through rocky and rough stone areas. Therefore, water is saturated with oxygen in most places. In spite of the high exploitation of the river and its location in one of the important recreational centers, the contamination is not a big issue yet (Jafari, 2005). However, due to the growing number of recreational places such as hotels, restaurants, villas and other recreational centers in the river area, the risk of pollution is very high (Shayan *et al*., 2013). The results of CCA (Fig 5) has shown complete consistent with the results of the stations classification based on the FBI and the IRWQISC indices. On the other hand, the CCA' components has shown that stations 10, 11 and 12 were separated from other stations (Figure 8 and Figure **10**).The Simpson Index shows the degree of dominance and the Simpson Biodiversity Index shows the assessment of water quality which in the study area at all stations Simpson index tends to one.

Usually, the greater the dominance of a species in the community, the more it tends toward one. On the contrary, the more uniform the distribution of individuals among the species, the more it tends toward zero (Tello *et al*., 2010). The results of macro-invertebrates identified in Jajrood and Karaj Rivers (Table 2 and 3) as well as biodiversity indices indicate that the two regions are similar in terms of macro-invertebrate fauna and biodiversity. Since these rivers both are located in the Iran's central plateau basin, due to the similarity of the physicochemical, geological and climatic conditions such as bedrock type, elevation, rainfall, pH, and fauna, the results obtained from these studies are almost the same for both rivers (Mahmoudi *et al.*, 2015). The abundance of species identified species (19913 macroinvertebrates) in the Jajrood and Karaj rivers indicates the existence of biodiversity and the importance of conservation. On the other hand, this biodiversity indicates changes variation along the rivers (Parvandi *et al*., 2015b). The Karaj and Jajrood Rivers are one of the tourist destinations near Tehran city. The results of this study is similar to the results of a research has done in Indonesia which have shown the ASPT and FBI indices are suitable for the East Java tourist areas (Wimbaningrum *et al.*, 2016). Threatening factors and contamination for both rivers ecosystems are human activities. As it was mentioned before, the location of these rivers is one of the most important tourist attractions of Tehran. In addition, the results of biotic and physicochemical indices showed that stations located in residential and tourism areas are the most polluted stations.

The most important feature of this study is the measurement of the greatest number of biotic indices of macro-invertebrates in Iran and suggestion of suitable biotic indices for assessing the water quality in the Jajrood and Karaj rivers, as well as simultaneous measurement of these two rivers for three consecutive years using biotic indices of macro-invertebrates, biodiversity and physicochemical indices. The results of this study indicate that the the Jajrood and Karaj rivers are affected by human activities and the effects of these activities, such as dam's construction, dumping waste material, discharge of domestic sewage to the rivers and the presence of tourists, especially in summer time, can reduce~~s~~ ecological water quality. The results of this study indicated that biotic indices BMWP/ASPT in the Jajrood River and FBI in the Karaj River are the most appropriate biotic indices for water quality assessment. Ecological monitoring using macro-invertebrates biotic indices as a complementary or alternative to physicochemical methods is proposed by Iran's water quality resources monitoring programs and provides more accurate water quality results in comparison to the use of physicochemical methods. Since Jajrood and Karaj rivers are two of the most important aquatic ecosystems in terms of biodiversity, and supplying drinking water to Tehran city, it is advised to take the necessary precautions for the ecological health of water and to plan regulated studies. Considering the fact that Iran is in a relatively warm and dry region and its water resources are limited. Since it is necessary to develop its local and specific indices for each region, it is suggested that based on local climate and environmental conditions of Iranian rivers, subsequent researchers make an effort to provide an appropriate index.

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