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Research Article

Comparison of physicochemical and biotic indices to determine water quality in Jajrud River, Iran

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Abstract

Aquatic organisms are currently used as bio-indicators to determine the water quality of rivers in many countries. In this study, the results of Karun Macroinvertebrate Tolerance Index (KMTI) as a bioindicator and Revised Iranian Water Quality Index (RIWQI) as a physicochemical index were compared to evaluate water quality. For this purpose, water and benthic macroinvertebrate samples were collected from seven stations in four seasons in 2019. According to the RIWQI and KMTI index values, water quality at the stations was evaluated between 37.21 to 75.98 and 2.9 to 6.21, respectively, falling into poor, medium, and good categories. In this study, KMTI index had a significant correlation with RIWQI index ($p<0.01$). Also, both indices had a significant correlation with total dissolved solids (TDS), oxygen saturation (DO%), biochemical oxygen demand (BOD), nitrate (NO_3), phosphate (PO_4), turbidity (NTU), and fecal coliform ($p<0.01$). The values of KMTI index declined when these water quality parameters increased, which can be caused as a result of the parameters' impact on decline in sensitive species. The obtained results from KMTI and RIWQI indices demonstrated that tourism activities, restaurants, industries, and residential areas imposed a surplus of environmental burdens in some parts of Jajrud River. Therefore, river basin management must be implemented to rehabilitate the impacts due to human manipulation, improve the water quality, reduce public health risks, and proceed toward sustainable development.

Keywords: Benthic macroinvertebrates, Bioindicator, Jajrud River, Water pollution, Water Quality Index.

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Introduction

Domestic and industrial sewage, agricultural water drainage, land use change, and lack of proper management of pollutants are among the factors affecting river water quality. To evaluate the impact of these factors on surface water quality, measuring physiochemical and biological indicators can be performed. Physical and chemical measurements show the status of water quality only at the sampling time (Aazami *et al*., 2015). However, physicochemical parameters frequently change in water bodies as a result of a broad range of parameters such as the volume of discharges, frequency of rainfall, their self-purification potential, etc. (Tyagi and Malik, 2018). The physicochemical index estimation also requires a great deal of time, cost, and special tools (Alavaisha *et al*., 2019). In biological assessment approaches, the necessary tools for sampling and diagnosis of biological samples are more available, easy to operate, and relatively cost-effective (Elias, 2021). Therefore, biological assessment can simultaneously elucidate the qualitative status of water in a shorter time and lower cost compared to physicochemical assessment. In this regard, living organisms such as macroinvertebrates, fish, etc. present continuous evidence concerning the river's health status with significant sensitivity to numerous pollutants (Costa *et al*., 2021). Given this, biological indicators provide comprehensive information for monitoring of water quality (Akyildiz and Duran, 2021). The data obtained through sampling and analysis of benthic macroinvertebrates, fish, and diatoms forms the basis of many routine biological monitoring and assessment programs (Fathi *et al.*, 2022a). Benthic macroinvertebrates have different species and are found in different areas of the environment from clean to severely polluted (Cheimonopoulou *et al*., 2011). Therefore, their relative frequency changes can be used as an indicator to infer the pollution loading. Use of macroinvertebrates is based on the principle that in areas under pollution pressure, diversity of sensitive groups to pollution is less than the resistant groups (Carew *et al*., 2011). Regarding the use of macroinvertebrates to assess water quality, Trent Biological Index (TBI) was first introduced in UK (Woodiwiss, 1964). Afterward, an extensive strive to develop the use of macroinvertebrates as biological indicator was established, such as Biological Monitoring Working Party Score System (BMWP), Average Score per Taxon (ASPT), Hilsenhoff's Biotic Index (HBI), and Belgian Biotic Index (BBI) (Li *et al*., 2010). Biological indicators are introduced as a method to survey ecological quality of rivers dependent on macroinvertebrate population (Gabriels *et al*., 2005). Biotic index for rivers' pollution investigation is successfully applied in other countries (Surtikanti, 2017; Chen *et al*., 2022; Ezenwa *et al*., 2022; van der Meer *et al*., 2022).

In recent years, various studies have been conducted on use of biological indicators to evaluate water quality in

Iran. Aghajari Khazaei *et al.* (2021) investigated diversity of macroinvertebrate communities and their relationship with environmental factors in Persian Gulf and Gulf of Oman. They stated that environmental factors such as dissolved Oxygen, turbidity, and chlorophyll-a directly or indirectly affected distribution and community composition of macroinvertebrates. Similarly, Foomani *et al*. (2020) investigated community structure of macroinvertebrates in Shanbeh-Bazar River of Anzali International Wetland and its correlation with water quality parameters. In this study, effect of pollutants on water quality of the river, as one of the significant sources of water supply for the province of Tehran (Gholikandi *et al.*, 2012) was evaluated by simultaneous application of biological and physicochemical indices, namely KMTI and RIWQI. Both of these indices were tested and compared with other indices and reported to be better than others for Iran (Fathi *et al.*, 2022a; Fathi *et al*., 2022b). Main objectives of this study were (1) to investigate human impacts on Jajrud River and (2) to compare the obtained results based on biotic and physicochemical indices.

Materials and methods

Study areas and sampling

Jajrud River with an approximate length of 140 km locates in Latian-Karaj basin (Ameri Siahouei *et al*., 2020). The average annual temperature is 26°C and average annual precipitation is 800 mm (Razmkhah *et al*., 2010). Jajrud River is one of the main sources of water supply in Tehran province (Khoshand *et al*., 2020). Furthermore, this river has created numerous recreational areas along its way and attracted tourism specifically in spring and summer seasons (Mirzaei *et al*., 2009).

Water and benthic macroinvertebrate samples were collected from seven stations as shown in Figure 1. Two upstream stations, S-1, and S-4, included areas with minimal pollution and the least anthropogenic activities (Fig. 1) were used as reference stations in this study.

The macroinvertebrate samples were collected seasonally in summer, autumn, winter, and spring of 2019 at each of the seven stations. Three samples were taken at each station with a surber sampler (250 µm mesh and area of 900 cm^2) (Surber, 1937; Williams and Williams, 1998). For this purpose, the surber floor framework was placed in the bed in opposite direction of the water flow. Then, benthic organisms were collected at a bed depth of 0–15 cm. The contents of surber net were poured into a pan and passed through a sieve with mesh size of 250 microns, and the contents of the sieve were transferred into 0.5 L sterilized plastic bottles. The samples were fixed with 4% formalin and transported to laboratory. In the laboratory, macrobenthic invertebrates were identified to genus or family level by appropriate taxonomical keys (Needham and Needham, 1941; Hartmann, 2007). Water physicochemical parameters, comprising temperature (°C), oxygen saturation (DO%), and pH were measured in the sampling sites using a multi-line probe (model HQ40d multimeter, HACH Company, USA). Turbidity (NTU), biochemical oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), total dissolved solids (TDS, mg/L), fecal coliform (n/100 mL), nitrate (NO_3, mg/L), phosphates (PO_4, mg/L) and pH were analyzed by standard method procedures in the laboratory (APHA, 2005).

Karun macroinvertebrate tolerance index (KMTI)

The Karun macroinvertebrate tolerance index (KMTI) (Fathi *et al*., 2022a) was calculated according to the calibration of Hilsenhoff Biotic Index (HBI) and using tolerance values (*TV*) which was developed based on the taxon's tolerance to pollution. The *TV* ranges from 0 to 10, where 0 is used for those taxa that are most sensitive and 10 for those taxa that are most tolerant. KMTI provides water quality classification with four categories, good, moderate, poor, and very poor (Table 1).

Table 1: Water quality classes corresponding to the KMTI values (Fathi *et al*., 2022a).

KMTI Index	Water quality assessment	Degree of pollution
0.00–4.30	Good	Clean and slightly polluted
4.31–5.30	Moderate	Moderate pollution
5.31–7.00	Poor	Relatively high pollution
7.00–10.00	Very poor	Severe pollution

Revised Iranian Water Quality Index (RIWQI)

Revised Iranian Water Quality Index (RIWQI) was calculated by the following equations (Fathi *et al*., 2022b):

$$OIWQI_m = \prod_{i=1}^{n} Q_i W_i$$

Where, W_i, n, and *Qi* stand for weight of each parameter, number of parameters, and value of quality level respectively. Table 2 demonstrates descriptive equivalence based on RIWQI.

Table 2: Descriptive equivalent of RIWQI (Fathi *et al*., 2022b).

Index Value	Descriptive Equivalent
90-100	Excellent
70-89	Good
50-69	Medium
25-49	Poor
0-24	Very poor

Statistical analyses

Data analyses were performed with SPSS (Statistical Package for Social Science) software version 25.0. Means of three replicates and standard deviation were calculated. Significance of the results was determined using Spearman's statistical test, one-way ANOVA, and Duncan's multiple range tests (p<0.05).

Results

The results derived from physicochemical water measurements in the seven stations showed that the concentration of turbidity and TDS had significant difference in various stations in all seasons (p<0.05). Other parameters such as BOD and oxygen saturation (DO%) were significantly different (p<0.05) among stations in autumn. On the other hand, COD and pH were not significantly changed in the stations (p>0.05). The water temperature varied between 3.6-14°C depending on the sampling period. Stations 2, 3, 5, 6, and 7 showed high values of TDS, BOD, NO_3, PO_4, and fecal Coliform parameters (Table 3).

Table 3: Mean physicochemical characteristics of water samples from Jajrud River in 2019.

	Season	S1	S2	S3	S4	S5	S6	S7
Tem. (°C)	Spring	7±0^{a}	10.5±0.06^{d}	11.6±0.06^{e}	8.5±0.1^{b}	12.8±0^{f}	10.3±0.06^{c}	10.3±0.06^{c}
	Summer	8.3±0^{a}	13.5±0.12^{d}	13.8±0^{e}	9.8±0.06^{b}	14±0^{f}	13.5±0.06^{d}	13.3±0.06^{ab}
	Autumn	6.3±0.06^{a}	10.3±0.06^{d}	10.8±0.1^{e}	8.5±0^{b}	11.8±0.06^{f}	10±0^{c}	10.4±0.12^{d}
	Winter	3.6±0.1^{a}	5.7±0.06^{e}	5.8±0.06^{ef}	4.8±0.1^{b}	5.8±0.06^{f}	5.1±0.06^{c}	5.5±0^{d}
pH	Spring	8.4±0^{bc}	8.3±0.17^{b}	8.4±0.12^{bc}	8±0^{a}	8.4±0.06^{c}	8±0^{a}	8.4±0.06^{c}
	Summer	8.5±0.06^{b}	8.5±0.12^{b}	8.6±0.12^{b}	8±0^{a}	8.2±0.26^{a}	8±0^{a}	8.4±0.06^{b}
	Autumn	8.3±0.1^{b}	8.0±0.12^{a}	8.3±0.1^{b}	8.1±0.15^{a}	8.3±0.15^{b}	8.1±0.15^{a}	8.1±0.15^{a}
	Winter	8.3±0.29^{b}	8.1±0.15^{a}	8.3±0.06^{b}	8±0^{a}	8.1±0.15^{a}	8.2±0.17^{ab}	8.4±0.1^{b}
TDS (mg/L)	Spring	115.3±0.29^{b}	141.5±0.5^{e}	230±0^{j}	96.4±0.17^{a}	139.0±0.12^{d}	145.2±0.2^{f}	118.2±0.26^{c}
	Summer	120.3±0.2^{a}	195±0.06^{e}	232.3±0.6^{f}	124.2±0.8^{b}	192.5±0.87^{d}	158±0.25^{c}	310±0.0^{j}
	Autumn	99.4±0.21^{a}	132.1±0.3^{d}	187.5±0.5^{j}	114±0^{b}	174.6±0.58^{e}	126±1.73^{c}	181±1.73^{f}
	Winter	88.2±0.25^{a}	100.6±0.9^{c}	195.6±1.1^{j}	97.8±0.29^{b}	153.1=±1.0^{e}	122.3±0.9^{d}	183.1±1.26^{f}
BOD(mg/L)	Spring	7±0^{a}	11.2±0.25^{c}	9.83±0.15^{b}	7.17±0.29^{a}	27.2±0.46^{e}	26.1±0.29^{d}	28.7±0.25^{f}
	Summer	37±0^{b}	51.1±0.29^{f}	41±0^{d}	8.37±0.15^{a}	52.43±0.38^{j}	40.2±0.35^{c}	46.4±0.36^{e}
	Autumn	6±0^{a}	11±0.0^{c}	12.1±0.29^{d}	7.17±0.29^{b}	29±0^{j}	28±0^{f}	26.2±0.15^{e}
	Winter	6±0^{a}	9.6±0.1^{d}	9.23±0.25^{c}	7.4±0.1^{b}	24.5±0.17^{f}	18.4±0.36^{e}	24.6±0.1^{f}
DO%	Spring	98±0^{e}	97±0^{cd}	97±0^{cd}	97.6±0.6^{de}	96.4±0.06^{c}	95.2±0.25^{b}	91.8±0.76^{a}
	Summer	96±0^{e}	95.2±0.26^{cd}	95.5±0.5^{cde}	95.6±0.7^{de}	94.8±0.29^{c}	92.1±0.29^{b}	90.1±0.29^{a}
	Autumn	100±0^{j}	95±0.06^{d}	93.1±0.29^{b}	98.1±0.29^{f}	94±0^{c}	96.1±0.29^{e}	92±0^{a}
	Winter	98.3±0.58^{d}	98.1±0.15^{cd}	96.4±0.17^{b}	97.6±0.58^{c}	95.1±0.17^{a}	95.1±0.15^{a}	94.8±0.29^{a}
NO_3 (mg/L)	Spring	4.8±0.23^{b}	5.4±0.47^{b}	5.3±0.29^{b}	4.2±0.21^{a}	5±0.62^{b}	5.3±0.1^{b}	5±0^{b}
	Summer	5.7±0.1^{c}	8.2±0.17^{e}	6.8±0^{d}	4.5±0.25^{a}	5.8±0.29^{c}	6.5±0.06^{d}	5±0^{b}
	Autumn	3.2±0.25^{a}	4±0^{b}	5±0^{c}	3.4±0.29^{a}	4.1±0.35^{b}	4.1±0.15^{b}	4.8±0^{c}
	Winter	3.5]±0.12^{a}	5.5±0.12^{de}	5.8±0.12^{e}	4.1±0.29^{b}	4.5±0.5^{b}	5.3±0.32^{cd}	5±0^{c}
PO_4 (mg/L)	Spring	0.11±0.01^{a}	0.26±0.02^{c}	0.42±0.03^{d}	0.1±0^{a}	0.19±0.02^{b}	0.16±0.02^{b}	0.12±0^{a}
	Summer	0.12±0^{a}	0.29±0.02^{c}	0.51±0.01^{d}	0.12±0^{a}	0.26±0.02^{b}	0.28±0.03^{bc}	0.13±0^{a}
	Autumn	0.1±0^{a}	0.27±0.03^{d}	0.37±0.03^{e}	0.11±0.01^{a}	0.14±0.01^{c}	0.15±0^{c}	0.13±0.01^{b}
	Winter	0.11±0.01^{a}	0.24±0.02^{c}	0.33±0.03^{d}	0.1±0^{a}	0.14±0.01^{b}	0.14±0^{b}	0.11±0^{a}
Tur. (NTU)	Spring	3.±0^{b}	27.5±0.06^{f}	68.0±0.12j	2.4±0.1^{a}	5.3±0.15^{c}	9.8±0.06^{d}	21.8±0.29^{e}
	Summer	3.5±0^{b}	36.8±1.04^{e}	68.1±0.29^{f}	2.4±0.12^{a}	10.8±0.58^{c}	17.6±0.58^{d}	94±0^{j}
	Autumn	2.5±0.06^{b}	31.5±0.5^{f}	68±0^{j}	2.07±0.12^{a}	8±0^{c}	11±0.29^{e}	10.2±0.23^{d}
	Winter	3.5±0.06^{b}	15.2±0.25^{e}	68.4±0.4^{j}	3±0^{a}	8±0.2^{c}	14.5±0.25^{d}	26.1±0.15^{f}

Table 3 (continued):

Season	S1	S2	S3	S4	S5	S6	Season	S1
COD (mg/L)	Spring	<0.01^{a}	<0.01^{a}	<0.01	<0.01^{a}	<0.01^{a}	<0.01^{a}	<0.01^{a}
	Summer	<1^{a}	13.3±1.5^{d}	<1^{a}	<1^{a}	4.8±0.15^{c}	3.5±0.12^{b}	29.5±0.5^{e}
	Autumn	<0.01^{a}	<0.01^{a}	<0.02^{a}	<0.02^{a}	<0.03^{a}	<0.03^{a}	<0.04^{a}
	Winter	<0.01^{a}	<0.01^{a}	<0.02^{a}	<0.02^{a}	<0.03^{a}	<0.03^{a}	<0.04^{a}
FC (n/100ml)	Spring	0±0a	>2400^{b}	>2400^{b}	0±0^{a}	>2400^{b}	>2400b	>2400^{b}
	Summer	12±0^{a}	>2400^{c}	>2400^{c}	54±1^{b}	>2400^{c}	>2400^{c}	>2400^{c}
	Autumn	36±0^{a}	>2400^{c}	>2400^{c}	132±0^{b}	>2400^{c}	>2400^{c}	>2400^{c}
	Winter	0±0^{a}	1100±0^{d}	1100±0^{d}	30±0^{b}	460±0.0^{c}	1100±0^{d}	>2400^{e}

Note: Tem. (temperature); Tur. (turbidity); FC (fecal Coliform) and different letters indicate significant differences (p<0.05).

It confirmed that the obtained values can be affected by the discharges of human sewage (Fig. 1).

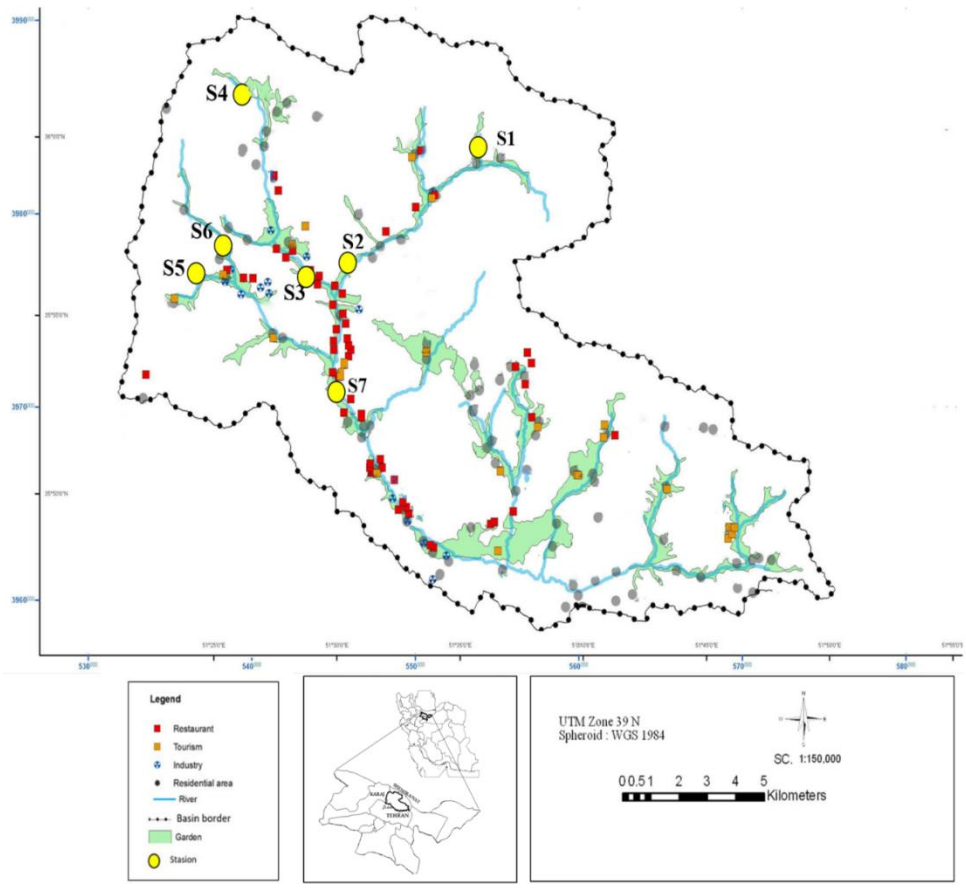

Figure 1: The study area and sampling locations in 2019.

A total of 5303 macroinvertebrates belonging to 3 classes, 8 orders and 34 families identified in Jajrud River during the study period (Tables 4 and 5).

The results disclosed that Chironomidae was the most abundant in the studied region (24.85 %), followed by Baetidae (13.46 %) and Tubificinae (12.95 %).

The families Taeniopterygidae (2.41 %) and Perlodidae (1.41%) were only observed at two stations (sampling stations 1 and 4). whereas the family Gammaridae (0.64%) was seen in sampling stations 3, 5 and 6.

Table 4: Abundance of the identified benthic macroinvertebrates in spring and summer 2019.

Class	Order	Family	Spring							Summer						
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
Insecta	Plecoptera	Taeniopterygidae	25	-	-	-	-	-	-	48	-	-	15	-	-	-
		Perlodidae	17	-	-	-	-	-	-	14	-	-	6	-	-	-
		Chloroperlidae	5	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ephemeroptera	Baetidae	60	-	6	38	41	16	38	30	28	55	62	54	8	14
		Heptageniidae	19	-	3	12	4	30	-	40	-	-	9	-	-	-
	Trichoptera	Glossosomatidae	3	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydropsychidae	-	-	2	-	12	1	1	-	33	45	12	28	58	35
		Lepidostomatidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		Polycentropodidae	-	-	-	-	-	-	-	-	12	10	-	14	25	18
		Psychomyiidae	25	5	-	-	-	-	-	8	-	-	5	-	-	-
		Rhyacophilidae	13	-	-	10	-	-	-	-	-	-	-	-	-	-
	Diptera	Culicidae	1	-	-	-	-	-	-	1	-	-	-	-	-	-
		Athericidae	-	-	-	-	-	-	-	4	-	-	-	-	-	-
		Blephariceridae	11	-	-	14	-	-	-	15	-	-	-	-	-	-
		Ceratopogonidae	-	-	-	-	-	-	-	-	39	65	-	22	10	83
		Chironomidae	12	45	146	5	36	14	57	70	52	101	20	70	55	160
		Dolichopodidae	2	-	-	-	-	-	-	4	-	-	-	-	-	-
		Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Limoniidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Muscidae	1	-	-	-	-	-	-	-	-	-	-	-	-	-
		Psychodidae	-	-	-	-	-	-	-	-	-	35	-	55	56	55
		Simuliidae	10	-		-	-	-	-	61	38	45	27	-	43	15
		Stratiomyidae	-	-	-	-	-	-	-	-	-	-	5	15	5	5
		Tabanidae	10	10	-	-	-	-	-	-	44	26	22	14	25	13
		Tipulidae	-	-	-	-		-	-	-	-	-	-	1	6	-
	Coleoptera	Chrysomelidae	2	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydrophilidae	15	10	-	-	-	-	-	-	-	-	15	-	-	-
		Dytiscidae	-	-	-	-	-	-	-	-	-	-	10	-	30	-
		Noteridae	2	-	-	-	-	-	-	-	-	-	2	-	-	-
		Agriotypidae	1	-	-	-	-	-	-	-	-	-	3	-	-	-
		Elmidae	-	-		-	-	-	-	-	10	15	24	20	62	72
Oligochaeta	Lumbricida	Lumbricidae	-	-	-	-	3	3	-	-	45	46	14	-	-	53
	Tubificida	Tubificinae	-	-	-	-	1	-	-	-	160	115	-	65	54	90
Crustacea	Amphipoda	Gammaridae	-	-	-	-	-	-	-	-	-	-	-	-	-	

RIWQI index has been used for surface water classification, based on the use of standard parameters for water characterization (Fathi *et al*., 2022b). The index was calculated concerning measured parameters in the sampling stations. To compute the water quality index of the river, several qualitative parameters have been utilized namely, pH, TDS, BOD, COD, DO%, turbidity, nitrates, phosphates, and fecal coliform.

Table 5: Abundance of the identified benthic macroinvertebrates in autumn and winter 2019.

Class	Order	family	Autumn							Winter						
			S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4	S5	S6	S7
Insecta	Plecoptera	Taeniopterygidae	28	-	-	12	-	-	-	-	-	-	-	-	-	-
		Perlodidae	10	-	-	-	-	-	-	28	-	-	-	-	-	-
		Chloroperlidae	4	-	-	-	-	-	-	-	-	-	-	-	-	-
	Ephemeroptera	Baetidae	54	12	17	60	11	10	10	10	16	13	18	11	16	6
		Heptageniidae	27	-	-	13	-	-	-	-	-	-	-	-	-	-
	Trichoptera	Glossosomatidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydropsychidae	2	-	-	-	1	-	-	-	-	-	-	-	-	-
		Lepidostomatidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Polycentropodidae	3	14	13	1	10	-	-	-	-	-	-	-	-	-
		Psychomyiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Rhyacophilidae	11	-	-	10	-	-	-	11	-	-	16	-	-	-
	Diptera	Culicidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Athericidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Blephariceridae	11	-	-	-	-	-	-	-	-	-	-	-	-	-
		Ceratopogonidae	-	-	-	-	18	15	10	-	-	-	-	-	-	-
		Chironomidae	18	21	59	17	17	20	14	33	172	56	-	16	24	8
		Dolichopodidae	2	-	-	-	-	-	-	-	-	-	-	-	-	-
		Empididae	2	3	1	11	3	-	4	-	-	-	-	10	-	-
		Limoniidae	5	-	-	6	-	-	-	-	-	-	-	-	-	-
		Muscidae	2	-	-	-	-	-	-	5	-	-	-	-	-	-
		Psychodidae	-	-	22	-	10	15	25	13	-	-	-	-	-	-
		Simuliidae	19	-	4	12	-	-	-	15	-	-	-	-	-	-
		Stratiomyidae	4	-	4	3	-	-	-	3	-	-	-	-	-	-
		Tabanidae	1	1	-	-	-	-	-	-	-	1	-	-	-	-
		Tipulidae	-	1	-	-	2	2	-	-	-	-	-	-	-	-
	Coleoptera	Chrysomelidae	3	-	-	-	-	-	-	-	-	-	-	-	-	-
		Hydrophilidae	5	-	-	-	-	-	-	-	-	-	-	-	-	-
		Dytiscidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Noteridae	2	-	-	-	-	-	-	-	-	-	-	-	-	-
		Agriotypidae	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	Lumbricida	Elmidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Lumbricidae	2	12	12	-	11	5	4	3	-	12	-	-	4	-
	Tubificida	Tubificinae	-	-	68	-	55	33	33	-	13	-	-	-	-	-
	Amphipoda	Gammaridae	-	-	2	-	11	5	-	-	-	12	-	-	4	-

RIWQI index results are reported in Table 6. The highest RIWQI index value was equal to 75.98 (good water quality) in sampling station 1 in winter. The lowest RIWQI index value was determined as 37.21 (poor water quality) in sampling station 7 in summer. Also, in Table 6, the quality classes corresponding to KMTI are presented. The highest biotic index value was equal to 6.21 (poor water quality) in sampling station 2 in winter. The lowest biotic index value was determined as 2.91 (good water quality) in sampling station 1 in autumn (Table 6).

In this study, KMTI index had a significant correlation with RIWQI index (p<0.01). Additionally, both indices were significantly correlated with TDS, DO%, BOD, NO_3**,** PO_4, turbidity, and fecal Coliform (p<0.01) (Table 7).

Table 6: Results of water quality based on RIWQI and KMTI indices.

Station	KMTI index		RIWQI index	
	KMTI value	water quality	RIWQI value	water quality
Sp1	4.03^{a}	Good	72.00^{d}	Good
Sp2	5.28^{d}	Moderate	41.65^{a}	Poor
Sp3	5.84^{e}	Poor	42.87^{b}	Poor
Sp4	4.22^{b}	Good	73.38^{e}	Good
Sp5	5.78^{f}	Poor	43.38^{bc}	Poor
Sp6	4.89^{c}	Moderate	43.72^{c}	Poor
Sp7	5.93^{j}	Poor	42.09^{a}	Poor
Su1	3.54^{a}	Good	58.06^{e}	Medium
Su2	5.52^{j}	Poor	38.88^{b}	Poor
Su3	5.34^{f}	Poor	37.38^{a}	Poor
Su4	4.34^{b}	Moderate	67.44^{f}	Medium
Su5	5.41^{e}	Poor	42.07^{d}	Poor
Su6	5.32^{c}	Poor	41.45^{c}	Poor
Su7	5.38^{d}	Poor	37.21^{a}	Poor
Au1	2.91^{a}	Good	75.14^{f}	Good
Au2	4.39^{c}	Moderate	42.37^{c}	Poor
Au3	5.35^{d}	Poor	39.30^{a}	poor
Au4	3.23^{b}	Good	68.74^{e}	Medium
Au5	5.44^{f}	Poor	43.46^{cd}	Poor
Au6	5.41e	Poor	44.04^{d}	Poor
Au7	5.51^{j}	poor	43.23^{c}	Poor
Wi1	4.21^{b}	Good	75.98^{j}	Good
Wi2	6.21^{j}	Poor	55.48^{e}	Medium
Wi3	6.02^{e}	Poor	51.21^{c}	Medium
Wi4	4.12^{a}	Good	71.78^{f}	Good
Wi5	6.12^{f}	Poor	53.45^{d}	Medium
Wi6	5.87^{d}	Poor	50.12^{b}	Medium
Wi7	5.81^{c}	Poor	42.03^{a}	Poor

Note: Sp (Spring), *Su* (*Summer*), Au (Autumn), Wi (Winter) and different letters indicate significant differences (p<0.05).

Table 7: Spearman correlation coefficients between physicochemical parameters RIWQI and KMTI.

	RIWQI	KMTI
Temperature	-0.754**	-0.021
pH	-0.345**	-0.137
TDS	-0.804**	0.355**
BOD	-0.757**	0.228**
DO%	0.707**	-.279**
NO_3	-0.575**	0.384**
PO_4	-0.667**	0.363**
Turbidity	-0.812**	0.430**
COD	-0.439**	0.109
Fecal Coliform	-0.887**	0.315**
RIWQI	1.000	-0.289**
KMTI	-0.289**	1.000

** Correlation was significant at the 0.01 level

Discussion

In this research, the richness of macroinvertebrates communities was highest in summer and lowest in winter (Tables 4 and 5), which could be due to the effect of water temperature on the production of phytoplankton, and water nutrients (Taban *et al*., 2020). As the water temperature increases, the concentration of phytoplankton increases, and more nutrients are available to macroinvertebrates. Nutrients such as phosphate and nitrate were high in summer (Table 3) and therefore, affected macroinvertebrate communities. Chironomidae, which is tolerant to water pollution (Cheimonopoulou *et al*., 2011), was the most abundant family in summer (Table 4). These results are similar to the findings of Sharbati *et al*. (2013) who observed increased Chironomidae diversity in the summer. Some macroinvertebrates are extremely sensitive to changes in environmental condition and are low pollution tolerant (Mykrä *et al*., 2012; Johnson and Ringler, 2014). In this study, sensitive taxa such as Perlodidae and Taeniopterygidae were only observed at stations 1 and 4 (Tables 4 and 5). The first evidence regarding the contamination of aquatic ecosystems reveals the extensive mortality in sensitive organisms (Aazami *et al*., 2015). Pollution, human activities, and effluents can affect biological communities of organisms (Edegbene *et al*., 2020). Furthermore, presence or absence of the intolerant taxon provides ample information about the state of the aquatic environment (Sharifinia *et al*., 2012).

The response of macroinvertebrates communities to anthropogenic disturbances is evaluated using metrics that measure biological conditions using the structure and function of these communities (Clapcott *et al*., 2017).

According to the RIWQI and KMTI values, water quality at the stations was evaluated between 37.21 to 75.98 and 2.9 to 6.21, respectively, which were classified as poor, medium, and good (Table 7). Based on both indicators, stations 1 and 4 had good quality in spring, autumn and winter. But stations 3, and 7 did not have good quality in these seasons. Interestingly, these stations are located downstream of the residential areas, restaurants, and tourism locations (Fig. 1). Due to the region's rugged terrain and the steep slope of residential areas along the river, wastewater discharges directly flow into the river. Therefore, physical and chemical variables in this region have negative impact on the water quality and, as a result, the species of macro-invertebrates.

In other stations (2, 5, and 6), in winter, based on RIWQI index, water quality was medium. It can be due to reduction of tourist activities in this season. These results are consistent with the findings of Razmkhah *et al*. (2010) who stated that wastewater discharge, agricultural activities, urban runoff, and excessive tourism activity can be considered the main reasons for the water quality decrease at stations that were located in the neighborhood of residential areas.

In this study, KMTI index had significant correlation with RIWQI index (p<0.01) (Table 7). Additionally, both indices had significant correlation with the amount of TDS, DO%, BOD, PO_4, turbidity, and fecal Coliform (p<0.01). The values of KMTI index declined when these water quality parameters increased, which can be caused as a result of the parameters' impact on decline in sensitive species.

In summary, the water quality of Jajrud River decreased in some parts, especially in the vicinity of tourism activities, restaurants, industries, and residential areas, indicating the detrimental role of human sewage discharge. Therefore, fulfilling and exploiting of sewer network would have a favorable influence on the water quality of the river. Also, river basin management must be implemented to rehabilitate the impacts due to human manipulation, improve the water quality, reduce public health risks, and proceed toward sustainable development. This investigation approved that application of KMTI and RIWQI indices can present the most straightforward pathway to achieve comprehensive information concerning the quality condition of rivers in Iran. Benthic invertebrates and KMTI biological index can be used as complementary or alternative to physicochemical methods in Iran's water quality monitoring programs.

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