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Original Article

Investigation of Zayandeh River water quality based on Macrobenthos as biological indicators

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Abstract: To evaluate of water quality of the Zayandeh River using some macrobenthos as biological indicators, five sampling stations were selected upstream of the river. Sampling operations were done monthly for one year in all stations with three replications using a Surber sampler. Identification and counting of invertebrates were done using standard methods under a binocular microscope. To evaluate the water quality, four biological indicators, including Shannon-Wiener, Hilsenhoff, BMWP, and ASPT indexes were applied. Data analysis and calculation of studied indicators were done using Species Diversity and Richness version 4 (SDR4) software. Based on the results, the Zayandeh River water quality was evaluated in the range close to pollution. The Shannon-Wiener index categorized the Zayandeh River in the range of moderate pollution, the Hilsenhoff index assessed most of the stations with severe organic pollution, and the BMWP index classified the stations in the biologically acceptable range. In conclusion, the water quality of the Zayandeh River is classified as biologically acceptable but not stable.

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Introduction

Freshwater ecosystems are severely affected by various pollutants and human activities worldwide. Consequently, ecological conditions and indeed the species composition and diversity of aquatic organisms will be affected based on the type and quantity of the pollutants. Hence, water pollution and its consequences are amongst the most important and widespread concerns for human communities. Rivers are one of the main components of the global hydrological cycle and an important source of freshwater for human communities (Wetzel, 2015). The upstream water quality management is important for the fate of the whole freshwater ecosystem and any exploitation and management activity should have the least quality loss on the downstream. Therefore, it is necessary to address any exploitation program at the higher levels of decision-making (Chapman, 1996). The components of aquatic ecosystems, i.e., biological communities particularly, benthic invertebrates play a key role in materials and energy recirculation in the ecosystems. The abundance, composition, and diversity of biological communities can be used as biological indicators to investigate an aquatic ecosystem (Kamal et al., 2004).

The heavily exploited rivers, especially for agriculture and aquaculture activities, and tourist areas receive high quantities of organic materials. Changes in the trophic state, water quality, and the ecological conditions of the aquatic ecosystem are inevitable consequences (Minoo et al., 2016). The aquaculture effluents for example, have adverse effects on downstream water quality by adding suspended solids, pathogenic microorganisms, drugs and disinfectants, feces, and unconsumed food (Pérez et al., 2003; Gravningen, 2007; Dempster et al., 2014). The fate of an aquatic ecosystem can be affected by other factors like the geochemical conditions of the basin, industrial wastes, and urban sewage. Sustainable exploitation, the maximum exploitation of a water resource with imposing the least adverse ecological effects is the main concern of the managers. (Navarrete-Mier et al.,

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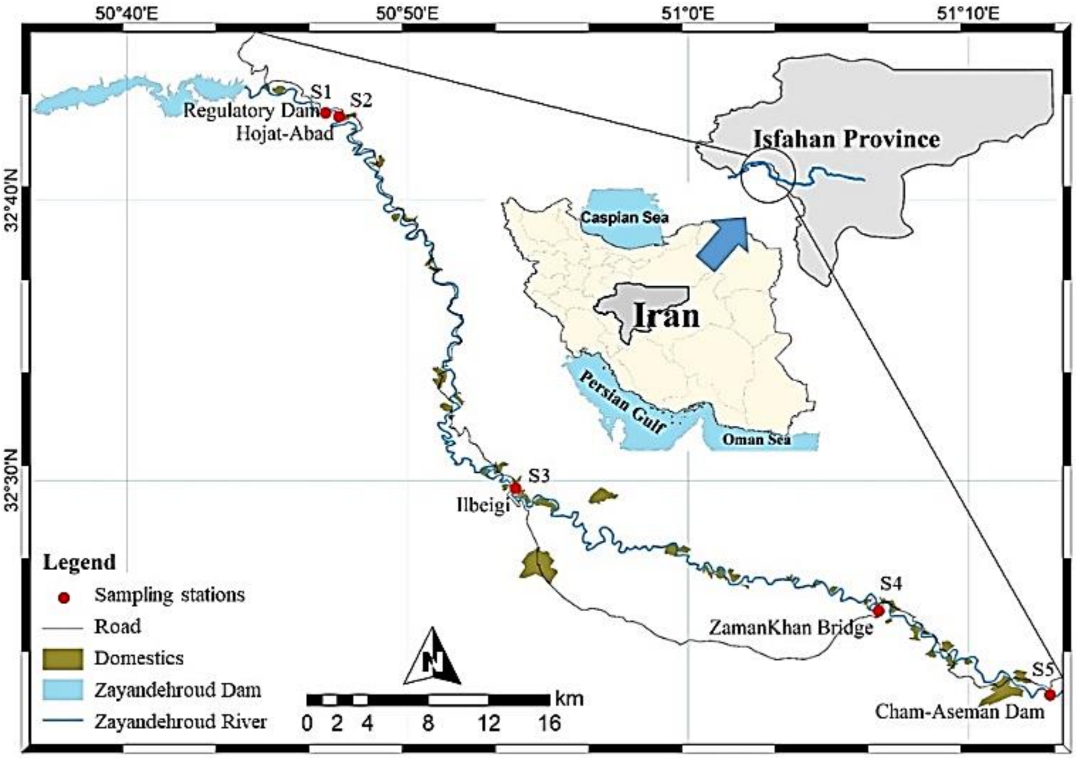

Figure 1. Zayandeh River map and the sampling stations.

2010; Mays, 2011).

Some reports noted the loss of water quality in some regional rivers that receive different sources of sewages for example, the Karun River in Khuzestan Province is severely affected by industrial, urban, and agricultural sewages (Moravej et al., 2017), high levels of heavy metals like nickel and chrome in the sediment of the Karun River near Ahvaz City has been reported (RastManesh et al., 2015) and the NSFWQY score of the Gorgan River dropped due to receiving Gorgan city sewage discharge (Ghazyani et al., 2020). The analysis of benthic invertebrate diversity and richness in the rivers of Gorbon Valley, Australia showed that the upstream and downstream areas of fish farms have significantly different species composition. Basically, larger fish farms had more adverse effects on river water quality (Webb, 2012).

As the main source of drinking water in Isfahan, the Zayandeh River is located in an area that more than 200,000 people inhabit upstream of the Zayandeh River dam, and there are also many villages and towns along the river bank to the Cham-Aseman pump station. In the spring and summer, many tourists are added to these pollution sources. Due to the geological structure of the region and lack of sewage treatment systems, almost all the sewage is finally discharged into the Zayandeh River. The biological indicators can be used as a scale to investigate water quality. Science living organisms provide a long-term response to pollution, they can more clearly reflect the water quality. The investigation of the potential consequences of the agricultural activities in the catchment area of the Zayandeh River, and the development of aquaculture activities, the biological indicators can be useful for pollution management. Benthic macroinvertebrates are well-accepted as biological indicators of water quality in running water ecosystems. The benthic macroinvertebrate's life cycle is proper for short-period study of environmental pollutants. As they move slowly, they can reveal short-term and medium-term changes in the aquatic environment (Shokri et al., 2014; Foomani et al., 2019). Therefore, the present study was carried out to investigate the composition and diversity of benthic macroinvertebrates of the Zayandeh River as biological indicators of water quality related to human

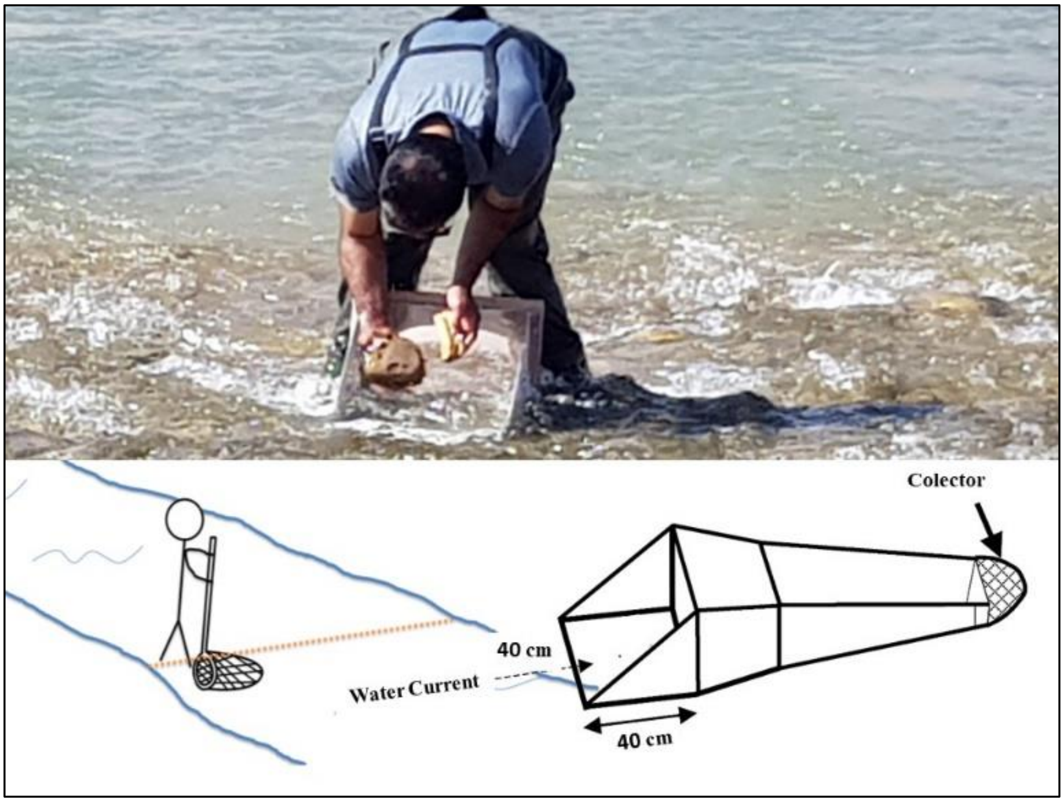

Figure 2. Macrobenthos sampling operation in Zayandeh River.

activities.

Materials and Methods

In this study, five sampling stations were selected along the 80 kilometers upstream of the Zayandeh River between the Zayandehd River dam and the Cham-Aseman treatment plant (Fig. 1). Sampling was done monthly for 12 months using a Surber sampler (Hauer and Lamberti, 2017). The Surber's frame dimensions were 40*40 cm and the trapping web mesh was 500 µm. The sampling operation was performed following the guidelines suggested by Stark et al. (2001). Three points of the riverbed were sampled in each station. In each case, after placing the Surber sampling frame, the riverbed was disturbed to a depth of 10 cm (Fig. 2). A fine brush was used to separate the attached macrobenthos with the least physical damage. The disattached samples were trapped in the Surber net. All the trapped samples were transferred into a container and immediately fixed using 96% ethanol. Then two drops of Rose Bengal dye were added to the samples. The 96% ethanol was replaced after 24 hours to ensure their complete fixation.

The identification of aquatic insects was done according to Quigley (1977), Winterbourn and Gregson (1981), Clifford (1991), Bouchard (2004), Hauer and Lamberti (2017), and the mollusks were identified based on Winterbourn (1973), Quigley (1977), Bouchard (2004), and Spencer et al. (2016). The data were analyzed using Species Diversity Richness 4 (SDR4) and Microsoft Excel. The ecological indicators Shannon-Wiener, Hilsenhoff, BMWP (Biological Monitoring Working Party), and ASPT (Average Score per Taxon) indexes were used to investigate the water quality. All statistical analyses were done in PAST using a Randomization Test (Two-sided test) with 1000 random permutations. Although some biological indicators were adopted for England and Ireland in the SDR software, they can also be used in other temperate climates of the world according to the software Instructions (Seaby and Henderson, 2006). In the case of benthic macroinvertebrate families identified in Zayandeh River that lacked the required scores in the SDR software, their score was calculated based on the score of the closest taxonomic groups and defined for the

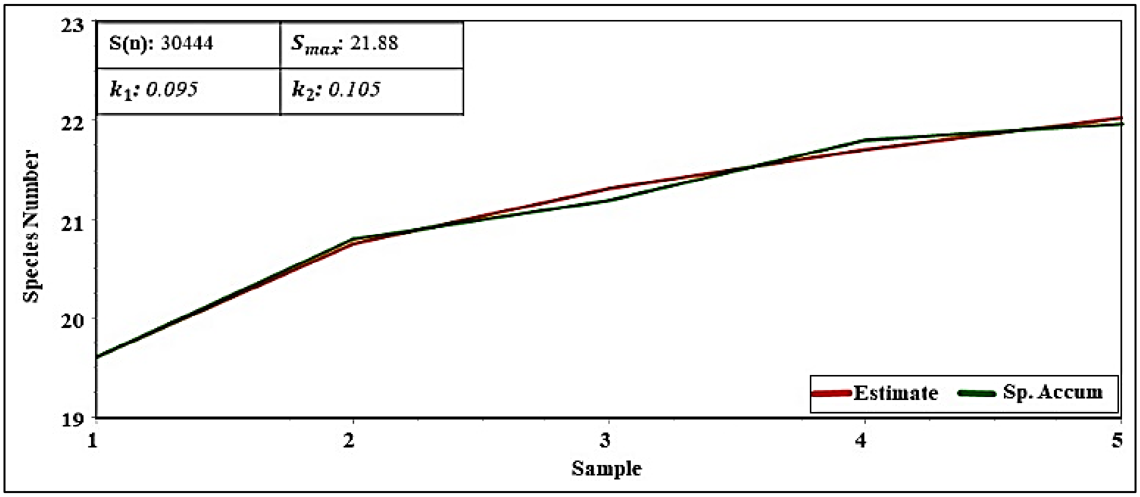

Figure 3. Annual Henderson index diagram related to five sampling stations on Zayandeh River in Isfahan province.

software.

Results

A total of 30444 samples of benthic macro-invertebrates belonging to 22 families were identified (Table 1). Accordingly, the most abundant families were Gammaridae (18423), Chironomidae (7388), Glossiphoniidae (1100), and Heptageniidae (927), respectively. The least abundant families were Muscidae, Tipulidae, and Gomphidae, respectively. Hence, the highest average frequency of benthic macroinvertebrates was found in Hojjat Abad (S2) 445.41, regulatory dam (S1) 436.8, Zamankhan Bridge upstream (S4) 207.68, Cham Aseman Dam pumping station (S5) 167.59, and Ilbegi station (S3) 126.32.

Henderson indicator: The number of permanent resident taxa was estimated at 21.88 and the approximate number of new visible samples after 999 resamplings (the number of random selections) was estimated as 0.11. In other words, at least 10 more sampling times are required to find 1.1 new samples. Therefore, it can be concluded that the sampling was enough to observe the biological taxa living in the Zayandehd River (Fig. 3).

Shannon-Wiener index: The Shannon-Wiener Index increased from upstream to downstream (Table 2). The highest values of the Shannon-Wiener index were observed in stations 3 and 5, respectively (Fig. 4). Comparison of the Shannon-Wiener indexes based on the Randomization Test (Two-sided test) with 10000 resampling's showed significant differences between all stations ($P<0.05$). Station S1 has the lowest index in all seasons, which indicates the lowest diversity. From a total of 18 taxa observed in this station, the Gammaridae family accounted for ~93% and the other 17 taxa accounted for 7% of the total abundance.

Hilsenhoff index: According to the calculated Hilsenhoff indexes, the organic pollution ranged from relatively severe to very severe in all stations and seasons (Fig. 4).

BMWP index: Although there are some seasonal fluctuations in water quality scores based on the BMWP values, the annual score chart shows a minor pollution load (Fig. 5).

ASPT index: Despite the general similarity of this index to the BMWP index, stations S1 and S3 obtained low ASPT quality scores (Fig. 5). In stations, S4 and S5, the water quality is improving. According to the pattern, it can be inferred that the water quality at station S5 is near to being stable.

Discussion

Regarding the importance of taxonomy position, some researchers believe that lower taxonomic levels like species can offer better results in similar studies (Lenat and Resh, 2001) but on the other hand, some researchers believe that lower taxonomic levels are time-consuming and costly and higher taxonomic levels (e.g. Family) can offer results with acceptable

Table 1. The benthic macroinvertebrates in Zayandeh River, Isfahan Province.

	Family	S1	S2	S3	S4	S5	Total	mean
1	Muscidae	0	2	0	0	0	2	0.4
2	Tipulidae	0	0	0	2	8	10	2.0
3	Gomphidae	2	1	1	7	3	14	2.8
4	Leuctridae	1	27	2	1	0	31	6.2
5	Limoniidae	0	8	2	24	5	39	7.8
6	Hygrobatidae	5	12	15	6	8	46	9.2
7	Tabanidae	0	9	1	28	4	42	8.4
8	Valvatidae	32	6	4	6	15	63	12.6
9	Lumbriculidae	11	3	13	10	40	77	15.4
10	Hydrobiidae	24	5	1	25	45	100	20.0
11	Caenidae	1	75	5	5	21	107	21.4
12	Hydropsychidae	47	31	9	38	69	194	38.8
13	Lumbricidae	35	13	15	6	74	143	28.6
14	Hydrophilidae	2	5	124	12	60	203	40.6
15	Sphaeriidae	8	1	128	14	34	185	37.0
16	Physidae	49	26	28	32	246	381	76.2
17	Simuliidae	4	255	39	2	12	312	62.4
18	Baetidae	44	159	209	24	41	477	95.4
19	Heptageniidae	134	503	326	106	38	1107	221.4
20	Glossiphoniidae	55	195	268	77	505	1100	220.0
21	Chironomidae	233	2244	424	3812	675	7388	1477.6
22	Gammaridae	8923	6219	1165	332	1784	18423	3684.6
	Total	9610	9799	2779	4569	3687	30444	
	Mean	436.8	445.41	126.32	207.68	167.59		276.76

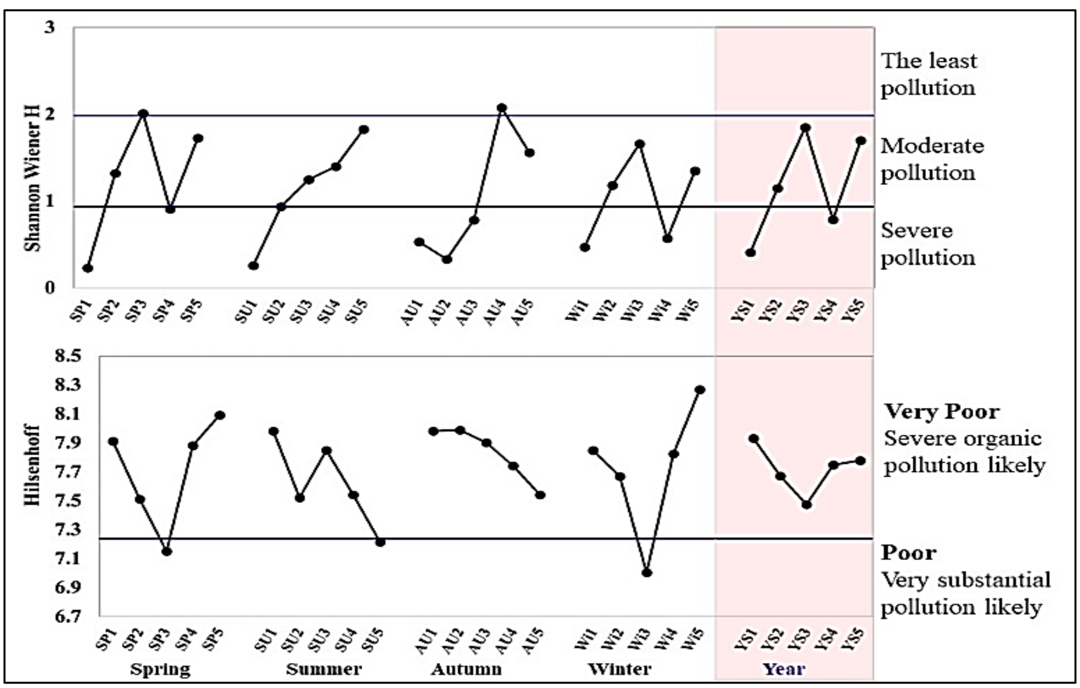

Figure 4. The Shannon-Wiener and Simpson indices and the classification of the water quality in Zayandeh River based on (Shannon and Weaver, 1949, Hilsenhoff, 1988).

Table 2. The seasonal and annual calculated biological indicators in Zayandeh River.

	Stations	Indicators			
		Shannon Wiener H	Hilsenhoff	BMWP Score	ASPT
Spring	SP1	0.23	7.91	48.50	4.41
	SP2	1.32	7.51	77.60	5.17
	SP3	2.01	7.15	68.50	4.89
	SP4	0.91	7.88	70.80	4.72
	SP5	1.73	8.09	81.70	4.81
Summer	SU1	0.26	7.98	49.30	4.48
	SU2	0.94	7.52	36.80	4.60
	SU3	1.25	7.85	49.60	4.13
	SU4	1.40	7.54	54.90	4.99
	SU5	1.83	7.22	63.40	4.88
Autumn	AU1	0.53	7.98	56.50	4.71
	AU2	0.33	7.99	47.00	4.70
	AU3	0.78	7.90	33.40	4.18
	AU4	2.08	7.74	54.00	4.50
	AU5	1.56	7.54	87.20	4.84
Winter	WI1	0.47	7.85	63.00	4.50
	WI2	1.18	7.67	83.90	4.94
	WI3	3.82	7.00	52.80	4.80
	WI4	0.57	7.83	74.30	4.64
	WI5	1.35	8.27	64.90	4.64
Yearly	YS1	0.41	7.93	70.10	4.67
	YS2	1.15	7.67	87.50	4.86
	YS3	1.85	7.48	81.70	4.81
	YS4	0.79	7.75	87.20	4.84
	YS5	1.70	7.78	87.20	4.84

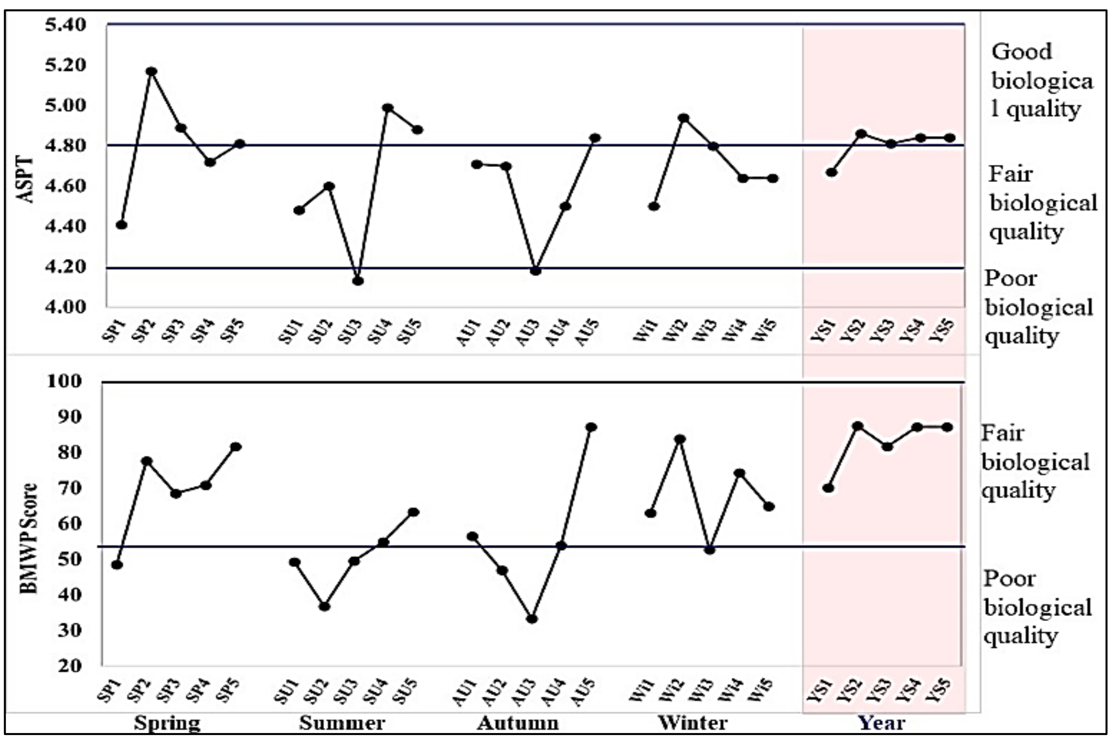

Figure 5. Annual and seasonal BMWP Score and ASPT index diagram in the Zayandeh River.

accuracy (Wright-Stow, 2001). In addition, a study on the effect of taxonomic level on the accuracy of the results based on the macrobenthos of Australia, Yemen, and North America, revealed that there are no significant differences between genus and higher taxonomic levels (Bowman and Bailey, 2011). Accordingly, the taxonomic level (Family) that we used in this study was satisfactorily suitable.

In stations S3 and S5 which showed the highest values of Shannon-Wiener index, the hydrological conditions of the river were highly stable. Soft sediments of the river bed in station S4 were due to the decrease in water flow speed and consequently provided the possibility of sedimentation. The presence and domination of the family Chironomidae (83%) in this station is expected. According to the observed fluctuations in biological indexes, the river is under moderate or severe stress, but the increasing trend of this index in downstream stations indicates that the auto-purification capability of the river can neutralize or improve the inadequate water quality conditions.

Since the Hilsenhoff index is known as an index of uniformity, it can be concluded that in most stations, the uniformity of macrobenthos communities were increasing to station S3. Accordingly, it seems that from station S3 to S5 the water quality getting better but not as good as S1. The genus *Gammarus* has a high reproductive capacity and adaptability to new environments, a wide feeding range, and the ability to migrate and settle in new ecosystems. It is also an indicator of good quality water (Clifford, 1991; Gerhardt et al., 2011). Considering the high density of submerged plants in the regulatory dam upstream the station S1, the observed dominance of *Gammarus* in this station can be related to releasing and washing from the regulatory dam.

The low BMWP score of station S1 is due to receiving plenty of *Gammarus* from the regulatory dam that lowers the scores unusually. The seasonal pattern of changes in the BMWP index in the Zayandeh River shows that in the winter and spring, the water quality of the middle stations decreases, but improves in the downstream stations. The river bed in all stations consisted of gravel except S4, which was a combination of soft sand and gravel. The hydrological conditions (especially water discharge) of the river were continually affected by seasonal fluctuations and management decisions. A study on the effects of floods on macroinvertebrate communities in the Zarin-Gol River, northern Iran confirmed that the hydrological phenomena e.g. flooding can significantly decrease their diversity and abundance and finally affect the accuracy of biological indicators to analyze the water quality (Gholizadeh, 2021).

It is obvious that the water quality is highly related to the water discharge. The stations S1 and S2 receive clean water mainly from the main Zayandeh River dam but the middle stations receive muddy water from tributaries and the last station receives clean water from the regulatory dam. In all stations, there are many fluctuations in the indicator scores. This fluctuation may be due to receiving different types and amounts of pollutants e.g. from a big-scale aquaculture center (station S2) or residential pollution (stations S3 and S4). This fluctuation can show us how well a biological indicator can reflect the population situation of a given station. In a study on fish farm effluents on macroinvertebrates in the Tajan River, north Iran, water can severely be affected by releasing aquaculture sewage in the fluvial system (Imanpour Namin *et al.*, 2013).

According to the results of the biological indicators, the Zayandeh River water quality was evaluated in the range close to pollution. The Shannon-Wiener index categorized the Zayandeh River water quality as the range of moderate pollution, the Hilsenhoff index assessed most of the stations with severe organic pollution, and the BMWP index classified the stations in the biologically acceptable range.

As a conclusion, based on the results, the water quality conditions of Zayandeh River in the studied area were evaluated as acceptable but unstable. Considering the use of this water for drinking, it is necessary to implement practical programs to prevent the entry of more organic load and more wastewater into the river.

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