Comparative Assessment of River Water Quality Using Multiple Biological Indicators: A Case Study of the Tigris River

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Abstract: Most of the rivers of Iraq suffer from the water contaminant problem. This problem is considered so difficult to get the water quality within the standard allowable limits for drinking, as well as for industrial and agricultural purposes. The Tigris is a primary source of water for millions of people in Iraq, directly affecting human health and living conditions. Water contamination can lead to waterborne diseases and other health issues. Moreover, rapid industrialization, population growth, climate change, and increased exploitation of surface waters, environmental pollutants are degrading the water quality of Tigris River at a dangerous pace. Though, there have been various methods and techniques for assessing the water quality, application of biological indicators for water quality assessment are more cost-effective than extensive chemical testing and sensitive to a wide range of pollutants. Therefore, this study aims to comparatively assess the water quality of Tigris River of Iraq using four biological indicators such as NAFWQI, BMWP, ASPT and HFBI. Water samples from different sampling stations of Tigris River were collected from April 2021 till March 2022. The findings showed that the average NAFWQI index indicated poor water quality, the BMWP index indicated moderate and poor water quality, the ASPT index indicated suspected pollution and pollution with medium levels, and the HFBI indicated relatively poor and poor water quality. Based on the results of this study, the comparative assessment of water quality show that Tigris River's water quality within low to moderate category.
Keywords: Tigris River, water quality, biological indicators, ASPT, BMWP

Introduction

Rivers have consistently been vital to human societies, with towns and industrial and agricultural hubs being established alongside them to utilize water resources. This fulfills essential requirements while also addressing agricultural and transportation demands. The escalating demand for water, improving living standards, and the contamination of water resources resulting from agricultural, urban, and industrial development have generated adverse environmental conditions and exacerbated water pollution, complicating effective management significantly (Bănăduc et al., 2022). Measuring the quantity and quality of pollutants, assessing the quality status, and offering an appropriate model for analyzing regional and temporal variations in pollutants are critical elements of water quality research (Chidiac et al., 2023).

The quality of water necessary for sustaining ecosystem health is mostly determined by natural background conditions. Certain aquatic ecosystems can withstand significant alterations in water quality without observable impacts on their composition and function, while others are susceptible to minor changes in the physical and chemical characteristics of the water, resulting in the degradation of ecosystem services and a decline in biological diversity (Al-Janabi et al., 2012). The deterioration of physical and chemical water quality resulting from human activities is frequently incremental, and the subtle adjustments of aquatic ecosystems to these alterations may not be easily observed until a significant change in ecosystem status transpires (Farhan et al., 2020). Water quality is often assessed by comparing the physical and chemical properties of a water sample against established guidelines or standards. Guidelines and regulations for drinking water quality are established to ensure the delivery of clean and safe water for human consumption, therefore safeguarding human health (Al-Janabi et al., 2012). These are often founded on scientifically evaluated tolerable toxicity thresholds for either people or aquatic species.

However, uses of biological indicators in water quality assessment are of particular importance because they can provide a logical and reasonable judgment of an ecosystem. Biological indicators (indices) are numerical expressions that combine quantitative measures of species diversity with qualitative information about the ecological sensitivities of each taxon relative to others (Chidiac et al., 2023). A score is assigned to classify pollution intensity based on the tolerance levels of indicator species to pollutants. The most commonly used biological index is Biological Monitoring Working Party (BMWP), which was first proposed by the Biological Monitoring Working Party of the UK Environmental Agency in 1978 (Paisley et al., 2014). It provides a reliable correlation between chemical classifications and biological scores, effectively measuring pollution impacts over time (Zeybec, 2014). The BMWP score can detect short-term pollution discharges often missed by chemical sampling1. Additionally, it reflects the sensitivity of macroinvertebrates to oxygen depletion, offering a comprehensive view of water quality (Zeybec, 2014).

The Average Score Per Taxon (ASPT) is also a widely used biological index, which was proposed by Armitage et al. in 1983 and was accepted as a more reliable index for assessing river water quality compared to the total BMWP score (Dewi & Wardhana, 2020). The procedure involves collecting samples from a water body, identifying the macroinvertebrate taxa present, and assigning each taxon a pollution tolerance score (Dewi & Wardhana, 2020). The ASPT is then calculated by dividing the total score by the number of taxa. This method is beneficial as it provides a simple, yet effective, measure of water quality, helps in detecting pollution levels, and supports environmental management decisions. Iwasaki et al. (2024) developed a multiple linear regression model to estimate ASPT using river macroinvertebrate data from 237 sites in Japan. The model, which included predictors like biological oxygen demand and urban area proportion, accurately predicted ASPT values at 2925 water quality monitoring sites, categorizing them into four levels of river environment quality. Moreover, Malvandi et al. (2021) evaluated the water quality of the Dehbar, Zoshk, and Kang rivers using various biological indices, including ASPT. The study found significant correlations between biological indices and water quality, highlighting the effectiveness of ASPT in reflecting the ecological status of these rivers.

Moreover, another key biological indicator of water quality assessment is the National Sanitation Foundation Water Quality Index (NSFWQI) of the National Health Organization in America (Noori et al., 2019). This index is one of the simplest and most widely used methods for evaluating water quality, which is calculated using 9 water quality parameters (Noori et al., 2019). Parastar et al. (2014) assessed the water quality of the Jajrood and Damavand rivers and the Mamloo dam in Iran using NSFWQI, finding that the water quality ranged from medium to good. Mirzaei et al. (2016) compared different WQI models, including NSFWQI, to assess water quality in various areas, demonstrating the utility of NSFWQI in providing a comprehensive water quality overview. The Hilsenhoff Biological Family Index (HFBI) is also another popular and cost-effective method used in America and Europe in current years (Choobkar et al., 2022). HFBI provides an assessment of water quality changes for each station by demonstrating pollution caused by nutrients using the resistance level of each taxon to pollution (Kabiri et al., 2018). Malvandi et al. (2021) assessed the water quality of the Dehbar, Zoshk, and Kang rivers in Iran using HFBI, finding significant correlations between biological indices and water quality. Arabi et al. (2013) used HFBI to determine the water quality of Gahar Lake in Iran, concluding that the lake's water quality was excellent and free from apparent organic pollution.

The examination of biological indicators and environmental factors demonstrated the impact of human activities on river habitats and confirmed that an increase in human activities leads to spatial and temporal changes in river habitats, resulting in alterations in the diversity and abundance of benthic organisms (Iwasaki et al., 2024; Kabiri et al., 2018; Noori et al., 2019; Parastar et al., 2014). Studies conducted on the Tigris River, by dividing the large population of benthic macroinvertebrates into six trophic groups including collector-gathering, collector-filtering, predator, scraper-collector, and scraper, have shown that the Tigris River has become more polluted from upstream to downstream due to stressful factors such as agricultural runoff, aquaculture farms, pollution caused by ecotourism and recreation (Al-Obaidy et al., 2015; Al-Sudani, 2021; Oleiwi & Al-Dabbas, 2022; Varol et al., 2010). These factors have caused changes in the communities of macroinvertebrates and their population structure in a specific spatial range. In this study of aquatic insect larvae, the dominant group of benthic organisms in the Tigris River was found to be composed of collector-gatherers (Sharifinia et al., 2012). However, there is a lack of studies that investigated the comparative water quality assessment of Tigris River by applying various biological indicators. Therefore, this study aims to evaluate the water quality of the Tigris River and classify it using the NSFWQI quality index and biological indices such as BMWP, ASPT, and HFBI.

Materials and Methods of Work

Introducing the Area

The Tigris River is a vital source of water for domestic and economic activities in Iraq. The assessment of water quality in Iraq has become a vital issue in recent years, especially due to concerns that fresh water will become scarce in the future and will always be at risk of pollution. The Tigris River is the second longest river in West Asia, with a length of 1850 kilometers, originating from eastern Turkey and entering Baghdad as part of the alluvial plain with an average flow rate of 540 cubic meters per second for the period 2005-2020.

Sampling

Water sampling was carried out in four stages at each station with three repetitions in an area where water mixing was fully done. Sediment sampling from the bedload of the river was carried out in 12 states with a frequency of once every 30 days (from April 2021 to March 2022) using a Surber sampler (dimensions 34 × 34 cm and mesh size of 300 microns) with three repetitions along a transverse profile perpendicular to the riverbank at both sides and middle part of the river. The collected sediment samples were transferred to special containers after separating unwanted materials on standard sieves with a mesh size of 60 microns, fixed with formalin solution (4%), and transferred to the laboratory. The location of sampling stations is shown on Figure 1, and their geographical coordinates are given in Table 1.

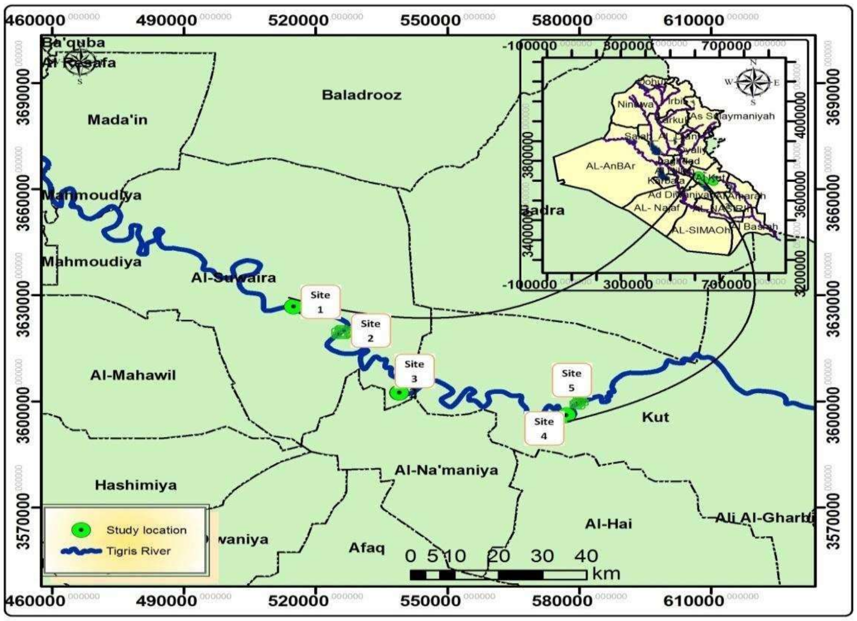

Figure 1: Map of the Tigris River and the study area (Used Arc-GIS Map Version 10.6).

Table 1: The geographical positions (GPS) of the sampling sites from the Tigris River.

Sites	Longitude (eastwards	Latitudes (northward)
S1: Al-Aziziyah	55°.9818′	55°.9050′
S2: Zubaidiyah	55°.9799′	55°.8850′
S3: Numaniyah	55°.9111′	75°.7080′
S4: Before Kut dam	51°.1551′	10°.5520′
S5: After Kut dam	51°.1595′	10°.1105′

Identification of Large Invertebrate Samples

After transferring the samples to the laboratory and washing them to separate any extraneous materials, the samples were identified using a loop and, if necessary, a microscope. The available identification keys were used to identify the specimens at the family level, and their numbers were counted (Choobkar et al., 2022).

Measurement of Physical and Chemical Water Parameters

Physicochemical parameters of water including dissolved oxygen, pH, electrical conductivity (EC), pH, biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, phosphate and turbidity at the station. Temperature was measured using a mercury thermometer with an accuracy of 1% Celsius degree, and dissolved oxygen was measured using a WTW-OXI 196 oxygen meter made in Germany. pH meter and EC meter were measured using digital meters model CORNING and CIBA made in America respectively. Turbidity was measured using a DRT-15CE turbidity meter. BOD and COD were measured by measuring the remaining oxygen after 5 days using an oxygen meter and digestion by reflux distillation method respectively, followed by colorimetric measurement (Muhaimin et al., 2022). Nitrate ions were measured by spectrophotometry using a colorimeter method (Brake et al., 1958). TDS was measured by filtering and using an electrical conductivity meter, while soluble phosphate was measured by colorimetry using a JENWAY 6400 spectrophotometer (made in UK). Fecal coliforms were also measured by MPN 9-tube method with a dilution factor of 1 to 100 by Ghaemshahr Water and Wastewater Laboratory (APHA,1992).

Indices for Water Quality Assessment

a) ASPT and BMWP Indices

All benthic macroinvertebrates collected at the family level (and some at the order level) were identified. Based on the scores assigned to each family in the modified BMWP scoring system in 1996 and 1997, a numerical score was assigned to each family (Walley & Hawkes, 1997). Finally, the scores of the families present in the sample were added together to obtain the BMWP score for that station. The ASPT index was calculated using equation 1 and water quality class based on tables 2 and 3.

$$ASPT = \frac{\sum BMWP\ Score}{Total\ Number\ of\ Scoring\ Taxa\ Present} \quad (1)$$

Table 2: Water quality classification based on the BMWP index (Walley & Hawkes, 1997).

Overall Index Score	Quality Class	Water Quality
0 -10	very bad	Severe pollution
11 - 40	Bad	Contaminated or affected by contamination
41 - 70	medium	Moderately affected
71 - 100	Good	Clean, slightly affected

Table 3: Water quality classification based on the ASPT index (Armitage et al., 1983).

water quality	ASPT
More than 6	Clean waters
5 - 6	Quality waters suspected of contamination
4 - 5	Waters with medium pollution probability
Less than 4	Highly polluted waters

b) Hilsenhoff index (HFBI)

The Helsinhoff index was estimated using Equation 2 and to evaluate the water quality, the resulting values were compared with the data in Table 4 (Hilsenhoff, 1988).

$$HFBI = \frac{\sum V_t \times n}{N} \quad (2)$$

Where, N = total number of samples in all families, n = total number of samples in each family, and V_t= the bearing value of each family.

Table 4: Water quality classification based on Hilsenhoff index (Hilsenhoff, 1988).

HFBI	Water Quality	Degree of Contamination with Organic Matter
3/75 – 0/00	Excellent	No pollution
3/76 – 4/25	very good	Very little pollution
4/26 – 5/00	Good	Low pollution
5/1 – 5/75	medium	Moderate pollution
5/76 – 6/50	weak	A lot of pollution
6/51 – 7/25	Bad	Too much pollution
7/26- 10/00	very bad	Very heavy organic pollution

c) NSFWQI

NSFWQI index is calculated using quality measurement parameters including pH, BOD, COD, nitrate, phosphate, temperature variations, turbidity, dissolved solids and fecal coliform in different stations during each season. The quality classification of water is determined using Table 5.

$$NSFWQI = \sum_{i=1}^{n} W_i \times Q_i \quad (3)$$

Where, W_i = weighting factor of each parameter and Q_i = sub-index of each parameter.

Table 5: The overall ranking of the NSFWQI Index (Landwehr & Deininger, 1976).

Numerical Value of Index	Water Quality Feature
0 -25	so bad
25 -50	Bad
50 - 70	medium
70 - 90	Good
91 - 100	great

Statistical Analysis

Statistical analyses were performed using SPSS software (Version 18.0). Firstly, the normality of the data was checked using the Kolmogorov-Smirnov test and the uniformity of variances was examined using the Levene test. One-way ANOVA was used to compare differences between stations and different sampling stages. The Duncan method was used for mean comparison at a 90% confidence level. Pearson correlation was used to examine the correlation between water quality indicators and parameters (Kotani et al., 2015) due to the normal distribution of data. Finally, Box and Whisker plots were drawn using Statgraphics software (Version 19.0) to investigate spatial and temporal changes in data and obtain an overall view of their variations in the Tigris River.

Results

Based on the results of this study, a total of 9 families of macroinvertebrates belonging to 7 orders and 3 classes were identified in the marshes of the Tigris River. The identified samples along with their presence in different stations are reported in Table 6.

Table 6: List of Macroinvertebrates identified in four stations of Tigris River

Class	Order	Family	1	2	3	4
		Baetidae	+	+	+	+
	Ephemeroptera	*Caenidae*	+	+	+	+
Insecta	*Plecoptera*	*Nemouridae*	+	+	+	+
	Trichoptera	*Hydropsychidae*	+	+	+	+
	Diptera	*Chironomidae*	+	+	+	+
	Pulmonata	*Physidae*	+	+	+	+
Gastropoda	*Porosobranchiata*	*Valvatidae*	+	+	+	

Oligochaeta	*Tubificida*	*Tubificidae*	+	+	+	+
		Naididae		+	+	+

Changes in BMWP index at different stations and sampling times are shown in Figure 2. As observed, the comparison of means did not show a significant difference (P=%402) in the values of this index between different stations. The highest and lowest values of this index, which actually indicate the number of identified benthic families, were observed in stations 1 and 4, respectively.

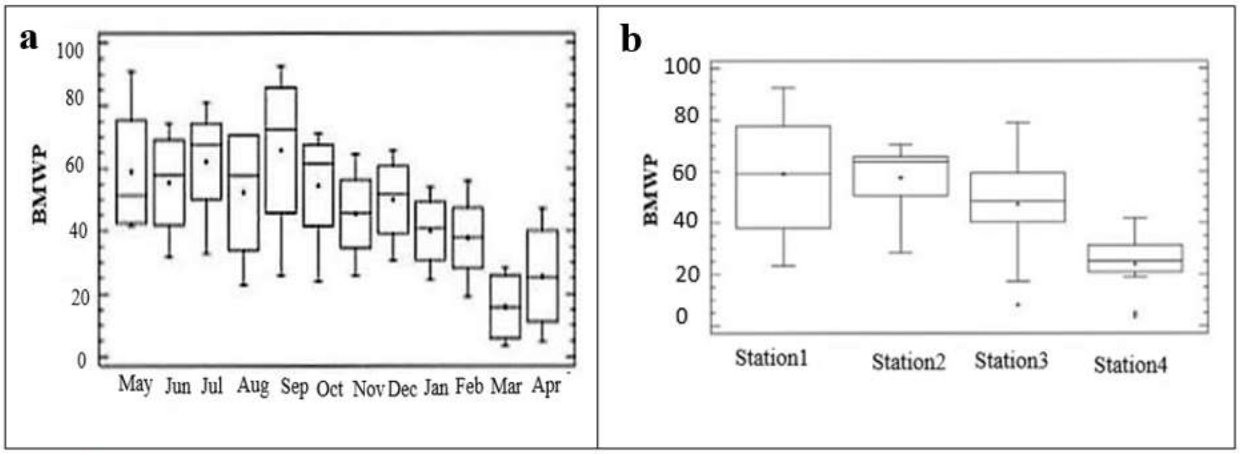

Figure 2: Changes in the BMWP index at (a) sampling times (b) sampling stations in Tigris River.

Also, no significant difference was observed between different stages of sampling (Figure 2-a). In this graph, a decrease in the number of large families of benthic invertebrates was observed in the cold months of the year. The trend of ASPT index changes in the sampling stations is shown in Figure 3-b. As can be seen, there is a significant difference ($p < 0.05$) in the average level of ASPT index between the studied stations. The highest value of this index was estimated at stations 1 and 2 and the lowest at station 4.

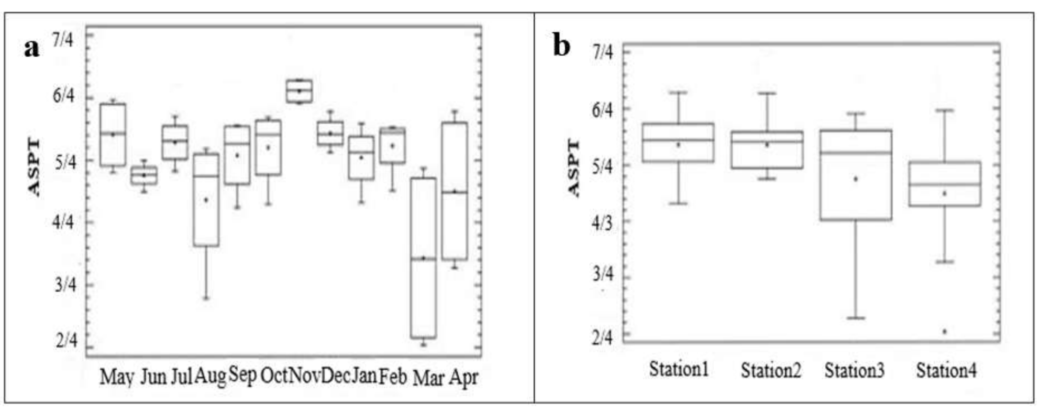

Figure 3: Changes in the ASPT index at (a) sampling times (b) sampling stations in Tigris River.

The recorded changes in the ASPT index during sampling times in Figure 3-a indicate a significant difference ($p<0.05$) between sampling times. Based on the results, the highest amount value of this index was calculated observed in November and the lowest in December. Changes in the HFBI Helson-Hubbard biological index at stations and sampling times are shown in Figure 4. As observed, there is a significant difference ($p<0.001$) between stations (Figure 4-b). The lowest average value of this index was recorded at station 1 and the highest at station 4.

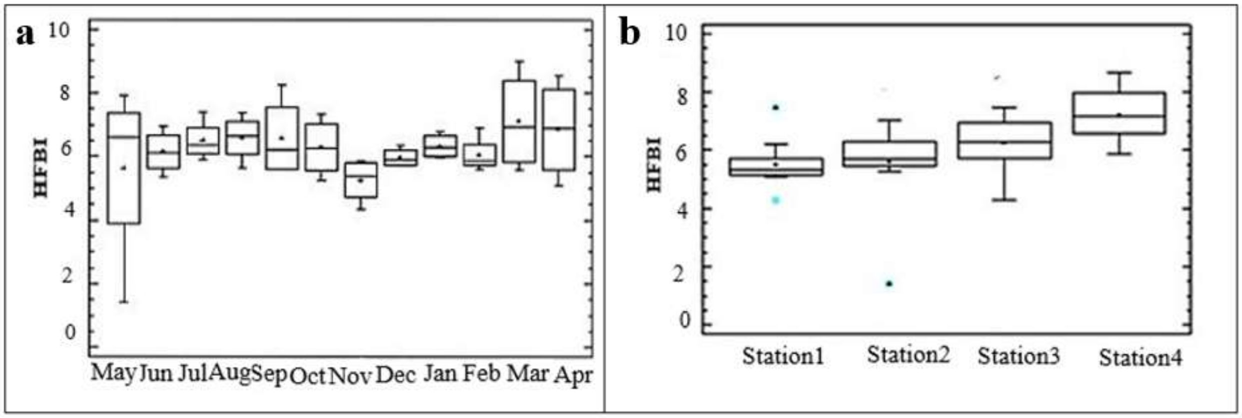

Figure 4: Changes in the HFBI index at (a) sampling times (b) sampling stations in Tigris River.

According to the HFBI index, the water quality of the river is suitable in November, weak in December and January, and relatively weak in other months. Figure 5 shows the changes in NSFWQI index values at the examined stations. As observed, water quality of the river showed a decreasing trend from upstream to downstream. This decrease is more apparent at station 2. Although the variance analysis test did not show a significant difference between different stations ($p = 0.866$).

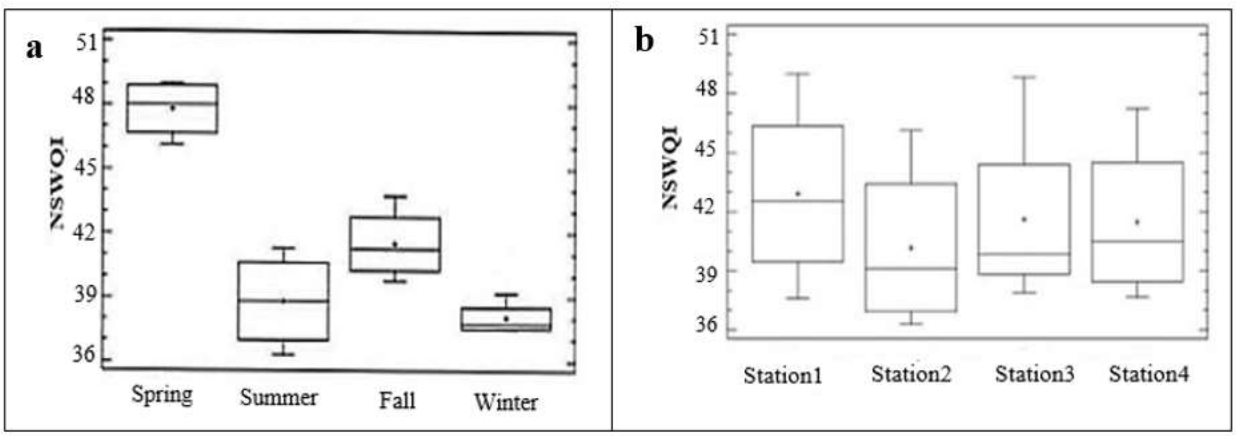

Figure 5: Changes in the NSFWQI index at (a) sampling times (b) sampling stations in Tigris River.

On the other hand, changes in NSFWQI index in different seasons showed a statistically significant difference ($p > 0.05$) between different seasons of the year (Figure 5-a). According to this index, the river water quality in the studied area is bad in the spring season and very bad in other seasons. The correlation coefficients of the calculated indicators and quality parameters of Tigris River water in this study are reported in Table 7.

Table 7: Correlation coefficients of calculated indices and water quality parameters of Tigris river.

Quality Parameters Water	ofBMWP	ASPT	NSFWQI	HFBI
COD	0/514	-0/046	-0/305	0/372
BOD5	0/547	-0/059	-0/242	0/417
Nitrate	-0/125	0/074	-0/769**	-0/247
Phosphate	0/437	-0/166	-0/334	0/475

TDS	-0/908**	-0/331	-0/621*	-0/236
pH	-0/655*	-0/067	-0/328	-0/331
EC	-0/760**	-0/010	-0/392	-0/528
temperature	0/600*	0/224	-0/200	0/096
DO	0/192	0/475	0/788**	-0/406
Turbidity	-0/895**	-0/257	-0/537	-0/316
Faecal coliform	-0/912**	-0/348	-0/569	-0/231

* meaningful on the surface 0/05

** meaningful on the surface 0/01

In contrast to the changes in the NSFWQI index in different seasons, a significant statistical difference ($p < 0.05$) was shown between different seasons of the year (Figure 5-a). Based on this index, river water quality in the study area was poor in spring and very poor in other seasons of the year. The correlation coefficients of the calculated indices and parameters of Tigris River water quality in this study are reported in Table 7.

Discussion

Reduced rainfall, uncontrolled harvesting in highland areas, resulting in reduced river flow and warming of the air in summer, as well as the entry of urban, agricultural and industrial wastewater into rivers, pose a major threat to the downstream river ecosystem. All these factors cause extensive changes in the physical and chemical properties of water, including reduced oxygen, increased TDS, BOD, COD and TDS (Al-Ani et al., 2019; Abbas et al., 2019; Mensoor, 2022). The BMWP index (Figure 2) classified the quality of Tigris River water as moderate during the study period. Among the stations surveyed, station 4 was classified as poor in terms of this index. The reason for the decrease in this index at station 4 is due to the presence of pollution-resistant benthic organisms, especially oligochaetes and chironomids, which have resulted from increased pollution load due to the entry of dissolved nutrients and suspended solids from domestic, agricultural and industrial wastewater (Onana et al., 2019; Ramos, 2016). An increase in pollution-resistant species such as oligochaetes and chironomids due to environmental pollutants has been proven in similar studies (Krisanti et al., 2020; Sahidin et al., 2021).

On the other hand, the decrease in BMWP index during the cold months (Figure 2-a) is due to the sensitivity of this index to the number of families of benthic organisms, which can be due to the decrease in water temperature for oligochaetes and due to their life cycle for chironomids. Based on this index, water quality of the river was evaluated as average from April to December and poor in other months of sampling. Also, considering the significant and highly significant correlation between BMWP index and parameters such as pH, temperature, fecal coliforms, turbidity, EC and TDS that play an important role in estimating water quality index (NSFWQI) (Table 7), it can be concluded that it is possible to evaluate the water quality of Tigris River using this index. In similar studies, Azrina et al. (2006) reported Langat River in Malaysia as having 4 classes of good, moderate, poor and very poor using BMWP index. Varnosfaderany et al. (2010) evaluated the biological status of Zayandehrud River of Iran using a large-scale study of benthic macroinvertebrates and physical and chemical factors. The results showed that BMWP index was a suitable tool for assessing the water quality status of Zayandehrud River and classified the study area into three classes: suspiciously polluted, moderately polluted and severely polluted. The ASPT index (Figure 3) classified Dez River water quality along its flow path generally into two classes: suspiciously polluted and moderately polluted. The imprecise delimitation of the assessed quality range is due to some biological indices calculated at family level having some weaknesses and problems in distinguishing between taxa or different times (Azrina et al., 2006).

In addition, due to the life cycle of large benthic macroinvertebrates (approximately 1 to 5.1 years) and their duration in aquatic habitats, it is not possible to accurately comment on the trend of changes in biological indicators with one-year monitoring (Pittwell, 1976). Overall, the ASPT index, like the BMWP index, showed a decrease in water quality towards downstream stations and estimated its ecological conditions as undesirable. This is while the river water quality during the study period (Figure 3-a and Table 3) was classified into four categories: suspicious pollution, severe pollution, moderate pollution, and clean. These fluctuations indicate the severe impact of environmental factors, especially different human land uses on the water quality of the Tigris River. Additionally, it seems that the ASPT index has been more sensitive than the BMWP index and has better demonstrated changes in river water quality.

The HFBI index varies differently than other indices, and lower numbers indicate better water quality. Table 4 and Figure 4-b show that stations 1, 2, and 3 are poor, whereas station 4 is poor. The HFBI index showed that this river had a low-quality index at the examined stations, with an estimated average HFBI index of 5.76–7.20. Compared to other rivers entering the Caspian Sea, this river has more organic matter and severe pollution (Ramadhan et al., 2018). Other studies found that HFBI indicator is more accurate than others for river water quality since it is related to organism tolerance (Gonçalves & de Menezes, 2011; Malvandi et al., 2021).

Figure 5 shows Station 2 has the lowest NSFWQI index. This urban station is influenced by sewage and wastewater discharge. Thus, this station had the lowest NSFWQI index. This index rated all stations bad. Station 2, having the lowest index, fared better. However, NSFWQI index changes differed significantly across seasons ($p < 0.05$) (Figure 5-b). Nine factors decrease along the river due to high nitrates and phosphates, turbidity, and fecal coliforms, affecting this index. Domestic, agricultural, and industrial wastewater enters aquatic habitats at high rates, affecting turbidity, pH, BOD, and COD and accumulating decomposable organic matter that degrades substrate (Agrawal et al., 2020; Bukola & Zaid, 2015). All these elements affect biological community quality and quantity. These chemicals increase organic matter load in aquatic settings within a narrow range, improving benthic nutrition. Changes in substrate structure may increase aquatic plant emergence and growth, creating new habitats for biological populations.

According to the Table 7, the BMWP index correlated negatively with TDS, EC, turbidity, and fecal coliform factors at 1% and positively with temperature and saturation factors at 5%. The pH component also correlated negatively at 5%. The BMWP index is affected by benthic community family numbers and all water physical and chemical characteristics. Other researchers have found that the BMWP index has a negative association with fecal coliform, TDS, EC, and BOD5 parameters and positive correlation with oxygen saturation percentage and pH (Gudiño-Sosa et al., 2023; Vega-Garzón et al., 2024). Saturation was likewise positively correlated with the ASPT index at 5%. Some studies have found that the ASPT index correlates negatively with water chemical characteristics and positively with slope, height, and discharge (Kebede et al., 2020). The HFBI index correlated positively with BOD5 and COD but not significantly. The NSFWQI score correlated negatively with nitrate at 1% and TDS at 5%. Other researches have found that the NSFWQI index correlates negatively with fecal coliform, EC, TDS, phosphate, nitrate, and BOD and positively with oxygen saturation percentage and pH (Alum et al., 2021; Parween et al., 2022).

Comparison

From the above results and discussion, the findings reveal significant variations in the performance of different biological indicators—BMWP, ASPT, HFBI, and NSFWQI—when assessing river water quality in the presence of anthropogenic pollution. The BMWP index primarily gauges the health of benthic macroinvertebrates, which are highly sensitive to pollution. However, it appears to be less reliable in colder months, as benthic organism families are fewer, especially pollution-resistant species like oligochaetes and chironomids, which can skew the results during low-temperature periods. In contrast, the ASPT index, while also focusing on benthic organisms, shows a greater sensitivity to environmental changes. This heightened sensitivity allows ASPT to reflect more accurate shifts in water quality across downstream stations, showing that it might offer a more precise assessment of pollution levels compared to BMWP. However, ASPT's reliance on family-level identification can introduce inaccuracies, especially in distinguishing between different species that are similarly affected by pollutants (Azrina et al., 2006; Onana et al., 2019).

The Hasselhoff Family Biotic Index (HFBI) provides a distinct approach by focusing on the tolerance levels of organisms to organic pollution, with lower HFBI scores indicating better water quality. Compared to the BMWP and ASPT, the HFBI is highly effective in identifying the presence of organic matter and can offer more robust insights in cases where the pollution is organic in nature (Gonçalves & de Menezes, 2011). However, it is limited in addressing the broader impacts of inorganic pollutants, such as heavy metals or industrial discharge. On the other hand, the NSFWQI offers a broader assessment by considering multiple water quality parameters such as turbidity, pH, nitrates, and fecal coliforms. This makes it advantageous in capturing the effects of a wide range of pollutants. However, its performance fluctuates significantly across seasons, rendering it less stable than indices focused on specific biological indicators. Given the strengths and weaknesses of these indices, ASPT appears to be more reliable for tracking water quality fluctuations due to its sensitivity to environmental stressors, while NSFWQI provides a comprehensive picture but may be more suitable for long-term or multi-seasonal studies.

Conclusion

Along with the general agreement among indicators in evaluating the quality of the Tigris River, limitations were identified in using biological indicators to interpret temporal changes in water quality. The reasons for these limitations can be attributed to factors such as changes in the riverbed during the study period, short study duration relative to the life cycle and presence of large populations of benthic macroinvertebrates in the riverbed, inaccurate compatibility of indicators with Iraqi conditions due to lack of fundamental studies in this area, and other ecological factors that can affect the structure of benthic macroinvertebrate communities.

Overall, the results of this study indicate that the water quality of the Tigris River is classified as moderate to poor based on the BMWP index, suspected pollution to moderate pollution based on the ASPT index, and relatively poor to poor quality based on the Hilsenhoff Family Biotic Index. Additionally, the NSFWQI index placed all stations in the bad quality category. These findings suggest that the Tigris River is increasingly affected by human activities and, due to its low flow rate, excessive use for agricultural purposes, receiving agricultural wastewater, discharging domestic and industrial sewage, has undergone a gradual deterioration in water quality. If proper management is not implemented to regulate and maintain its quality, it will face a high risk of severe pollution in the near future and its biodiversity will be threatened with extinction.

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