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Spatiotemporal Analysis of Water Quality Using Water Quality Index and Heavy Metal Pollution Index: A Case Study of Al-Diwaniyah River, Iraq

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Abstract

The current study aims to assess the water quality of the Al-Diwaniyah River in the city of Al-Diwaniyah to drink in terms of chemical properties and heavy metals and their impact on the health of the local population. The results showed that most of the parameters in the river water are of low concentrations due to the limited human activities in polluting the river water. The study concluded that the water quality is suitable for drinking depending on major cations and anions in all seasons. The Heavy Metal Pollution Index (HPI) showed that the river water was clean and safe, except two slightly polluted samples. The study concluded that river water for drinking or various domestic uses does not pose any danger to human health if there are no other polluting factors.

Keywords: Al-Diwaniyah River; major ions; heavy metals; water quality index; heavy metal pollution index.

التحليل المكاني والزماني لنوعية المياه باستخدام مؤشر جودة المياه و مؤشر لعناصر الثقيلة المركب: دراسة حالة لنهر الديوانية، العراق

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الخلاصة

تهدف الدراسة الحالية إلى تقييم جودة مياه نهر الديوانية لغرض الشرب من ناحية الخصائص الكيميائية والفلزات الثقيلة وتأثيرها على صحة السكان المحليين. أظهرت النتائج أن اغلب المعلمات في مياه النهر هي ذات تركيزات منخفضة بسبب محدودية الأنشطة البشرية في تلوث مياه النهر. توصلت الدراسة إلى أن نوعية المياه تناسب اغراض الشرب اعتمادًا على وجود الايونات الموجبة والسالبة الرئيسية في جميع فصول السنة. لقد بين مؤشر تلوث الفلزات الثقيلة (HPI) ان مياه النهر نظيفة وآمنة باستثناء عينتان كانتا ملوثتان بشكل طفيف. خلصت الدراسة إلى أن استخدام مياه الأنهار للشرب أو الاستخدامات المنزلية المختلفة لا يشكل أي خطر على صحة الإنسان إذا لم تكن هناك عوامل ملوثة أخرى.

1. Introduction

The soil fertility and the abundance of water for different human uses make the river banks a most favourable living environment with a high density of population [1]. Water is a precious gift from nature to humanity and all living creatures, and the excessive use of pollutants by humans has made water a rare commodity in most parts of the world [2].

The quality of river water is a function of several factors, including the rock composition of the river basin, atmospheric inputs, urban, industrial, and agricultural activities and severe consumption of water resources, as well as the amount of rainfall, which lead to deterioration of the river water quality [3].

Water is one of the main requirements for human life development, and it is the most land resource vulnerable to pollutants as it is exposed to sewage. Further, the various biological, agricultural and industrial activities, which invest in water resources, and the impact of natural factors such as rain, erosion and weathering lead to a deterioration in the quality of water and affect its suitability negatively for uses [4-7].

Rapid urbanisation highly impacts the environment, including water quality [5]. The process of monitoring the quality of river water aims in the first place to find out the causes of pollution, whether human or natural. The quality of river water is greatly affected by the rise in nutrients, acids and radioactive emissions, especially when the sources of pollution are unspecified, a matter that has become a problem in recent decades[6, 7]. The characteristics of river waters vary temporally and spatially, as many researchers have documented them according to the physicochemical dynamics of rivers; this variation has been studied in many rivers in different parts of the world [8]..

The Water Quality Index (WQI) gives an idea of water quality. It is a mathematical equation that depends on a large amount of data. The value of this indicator ranges from 0 to 100 [9-12]. The WQI was used to assess the river water quality and to help study the water eco-management based on physicochemical parameters [13, 14].

The sources of pollution of the water system with heavy metals, chemical elements and biological compounds are represented by several factors such as rock weathering, rainfall, the interaction between water and soil, and the wastewater of human activities [15, 16]. Even some trace elements are crucial to human health, and their accumulation in water in high quantities can cause health problems. Therefore, studying and identifying water pollution levels with these elements is essential to assess water quality for various purposes [17].

In Iraq, the sewage, agricultural and industrial wastes mostly reach the rivers without treatment. Consequently, this leads to the deterioration of the water quality and their uses for drinking and domestic purposes, adding to that their negative impacts on the balance of the aquatic environment system [18].

This study focused on investigating the characteristics of the water of Al-Diwaniyah River, which represents a main source of water used for different uses. The current study aims to assess the quality of river water for drinking purposes based on WQI and WHO standards and assess the risks of heavy metal concentration on the health of the local population.

2 Study area

Al-Diwaniyah River is branch of Euphrates River flows through the area of Al-Qadisiyah governorates along 120 km, between 31°30´- 32°14´ N and 44°42´- 45°16´ E, passing through four districts, Al-Saniyah, Al-Diwaniyah, Al-Sader and Al-Hamza (Figure 1). The river's depth varies between 2 and 4 m [19]. Al-Diwaniyah River feeds about 98% from rainfall and snow melt upstream of the Euphrates River basin in Turkey and Syria. The average water discharge of the river is about 50 m^3/s for the period 2010-2020 [20]. The area of the river course locates within the desert climate region characterised by high temperature and drought during summer and moderate heat and rainfall during winter [20]. The geological setting is covered by quaternary sediments of loos sands and sabkha of mud with salty crust on the west bank of the river, representing one of the pollution sources during the rainy season [21]. Some factories, such as textile and rubber factories in the study area, discharge their waste to the river. The decline in agricultural activity reduces the possibility of pollution of rivers with chemical elements. Household waste is still a potential source of biological pollution.

3. Materials and methods of analysis

Twelve river water samples were collected during different seasons, and chemical analysis was carried out to identify the concentration of chemical elements and heavy metals. The results are compared with the WHO and Iraqi standards. The WQI and HPI indices are used to get an integral idea of the water quality.

3.1 Collection of Water Samples

The water samples were collected from three important stations during different seasons (Figure 1, Table 1). The first is the flow path of the Al-Diwaniyah River is Al-Saniyya, which was considered the control station as it has relatively clean water. One station is Al-Diwaniyah station, located in the centre of the governorate, with a high population density, where their domestic sewage influx is a possible source of pollution. The third station is Al-Hamza station, located in southern the study area. The samples were collected from the middle part of the river in August 2020 and November 2020, February2021, and May 2021.

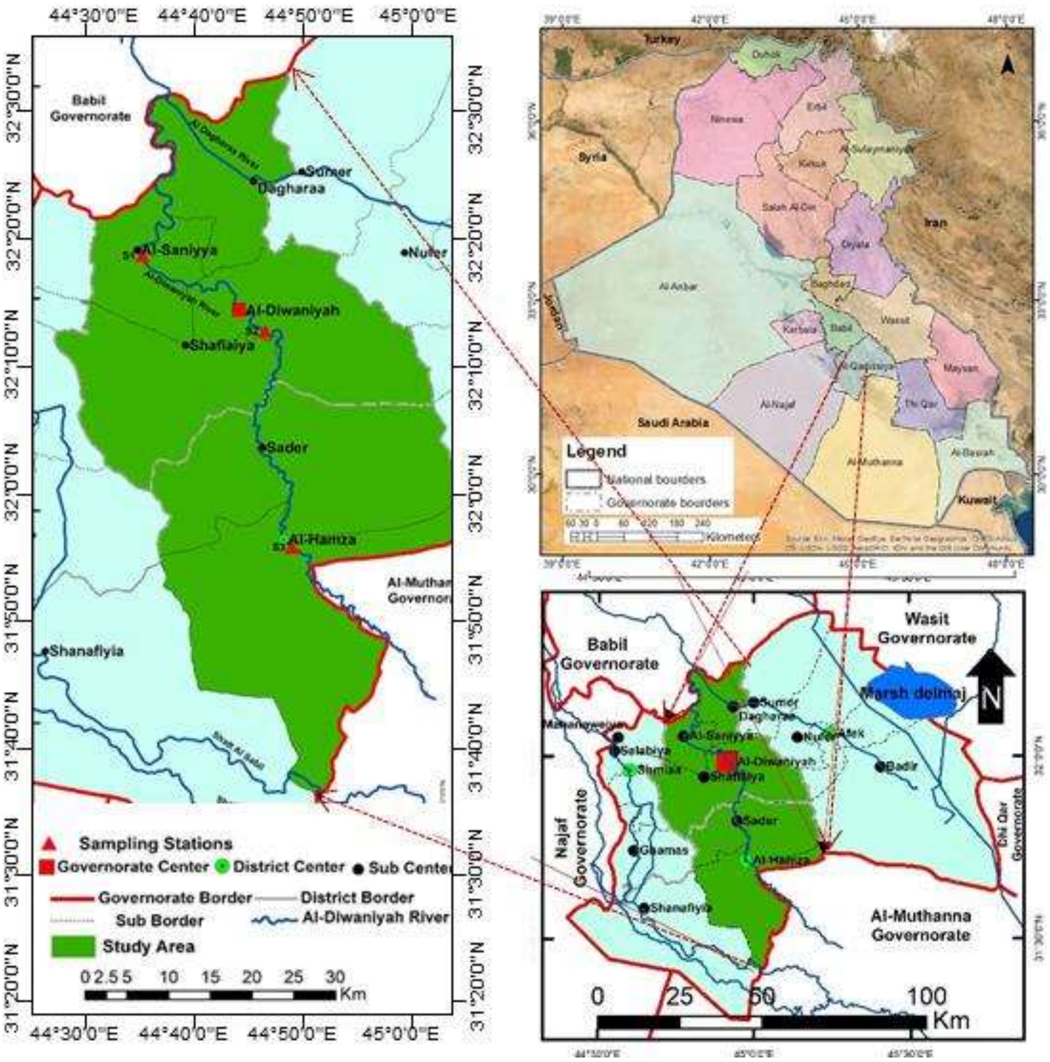

Figure 1: Location map of Al-Diwaniyah River and water sampling stations

Table 1: Geographic locations of sampling stations in the Al-Diwaniyah River

Stations name	Longitude	Latitude
Al-Saniyya	44˚46'31"	32˚03'16"
Al-Diwaniyah	44˚56'53"	31˚57'31"
Al-Hamza	44˚59'53"	31˚57'31"

3.2 Chemical Analysis of Water Samples

The chemical analysis of the water samples was carried out using the standard methods recommended by the American Public Health Association[22]. Electrical conductivity (EC) and pH values were measured in the field using a Horiba U-10 device. For each season, a 1 litre of water sample was collected in clean polyethene bottles from each station. All samples were stored at 4 C° until they were analysed. The major cations, anions and heavy metals were analysed by Atomic Absorption Spectrophotometer (Model AA-7000, Company SHIMADZU) at the U- Science Laboratory in Al-Diwaniyah District, Al-Qadisiyah Governorate, Iraq. The analytical accuracy of results is computed according to the equation of ionic balance error[23]:

$$\text{Ionic balance error } \% = \frac{(\sum \text{Cation} - \sum \text{Anions})}{(\sum \text{Cations} + \sum \text{Anions})} \times 100 \quad (1)$$

All the concentrations are converted into meq/l. If the percentage of ionic balance error is less than 5%, it means an acceptable result [24, 25].

3.3 Model of water quality index (WQI)

The weights of the chemical variables according to their relative influence on water quality for drinking purposes are required for computing the WQI [26-29]. The assigned weights are used to calculate the relative weights according to equation 2 as listed in Table 2 [30, 31].

$$\text{Wi} = \text{wi} / \sum_{i=1}^{n} \text{wi} \quad (2)$$

Where wi and Wi are the weight and relative weight factors of the i variable, respectively and n is the number of tested variables.

The ratio of variable concentration in water samples (Ci) to the standard of the variable (Si) assigned as quality rating index (qi) of i^{th} variable [32] and computed according to equation (3):

$$q_i = \frac{C_i}{S_i} \times 100 \quad (3)$$

The sub-index of each variable (SIi) is computed by multiplying of quality rating index (qi) by the relative weight (Wi) of each variable as given in equation (4):

$$SI_i = W_i \times q_i \quad (4)$$

The summation of SIi of all chemical variables represents the value of WQI as in equation (5):

$$WQI = \sum_{i=1}^{n} SI_i \quad (5)$$

Table 2: Standards, weights (Wi) and percentage weights (Wi) of chemical elements [23, 29-31].

Variable	WHO standards	Weight (wi)	Percentage weight (Wi)
pH	8.2	4	0.12
EC	1000	5	0.15
Na+	200	4	0.12
Ca+2	75	3	0.09
Mg+2	50	3	0.09
K+	12	2	0.06
SO4-2	200	4	0.12
Cl-	250	3	0.09
NO3-	50	5	0.15
HCO3-	120	1	0.03
Sum=		$\sum$ wi =34	$\sum$ Wi =1

3.4 Assessment of Heavy Metals Risk

Equations 6-9 were used to calculate the composite HPI in the study area [33, 34]:

$$HPI = \sum_{i=1}^{n} HPI^i \quad (6)$$

Where HPIi is the pollution index of i^{th} metal calculated as:

$$HPI^i = W_i . Q_i \quad (7)$$

Where ωi and Wi are the weight factor and relative weightage factor of i^{th} metal respectively as shown in Table 3.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (8)$$

The proportionality constant is considered as 1 for all the parameters. A sub-index Qi for ith parameter is calculated as:

$$Q_i = \frac{|M_i - I_i|}{(S_i - I_i)} \times 100 \quad (9)$$

Where Mi is the measured concentration of the ith metal, Si is the maximum permissible concentration of the ith metal and Ii is the highest desirable concentration of the ith metals [33].

Table 3: WHO Standards, weights and relative weights of heavy metals in water [35].

Parameter	WHO Standards	Weight (wi)	Relative weight (Wi)
Pb	0.05	5	0.17
Mn	0.5	3	0.10
Ni	0.02	4	0.13
Cr	0.05	4	0.13
Zn	0.02	2	0.07
Cu	0.05	3	0.10
As	0.01	4	0.13
Cd	0.01	5	0.17
Sum=		30	1.00

4. Results and discussion

The chemical parameters of tested water samples are listed in Table 4 and compared to the WHO standards. The ionic balance errors are calculated after converting the concentrations to the meq/l. the results of calculated errors are between 3.96 and 4.97 %, indicating that all the samples are within the acceptable error limits (Table 5), and the lab test of the samples is assumed to be accepted.

Table 4: Chemical parameters of Al-Diwaniyah River water

Station	**Season**	**Ph**	**EC (µS/cm)**	**Elements concentration (mg/L)**							
				Na^+	Ca^{+2}	Mg^{+2}	K^+	SO_4^{-2}	Cl^-	NO_3^-	HCO_3^-
Al-Saniyya	Summer	8.07	991	89.5	39.50	34.59	7.87	182	97	10.35	108
	Fall	7.81	1017	88.9	41.30	39.30	6.33	196	105	10.92	102
	Winter	7.3	808	85.2	32.01	31.01	5.96	112	112	13.30	99
	Spring	8.23	1040	114.9	31.62	30.62	5.04	156	109	14.50	116
Al-Diwaniyah	Summer	7.68	1034	105.2	36.50	36.49	7.96	198	105	12.35	93
	Fall	7.75	1049	89.3	35.86	32.85	3.69	194	112	12.92	104
	Winter	7.44	923	96.3	32.50	32.49	4.50	180	99	14.30	138
	Spring	7.99	1094	115.7	36.53	35.53	5.40	161	115	11.50	134
Al-Hamza	Summer	7.33	1076	92.7	33.30	33.30	3.87	190	115	12.35	109

	Fall	7.03	1141	87.8	37.76	39.76	3.87	204	115	10.32	132
	Winter	7.05	841	100.1	31.50	32.50	4.05	143	98	13.90	117
	Spring	7.69	1205	126.9	36.89	36.89	5.58	227	115	13.50	124
Average		7.61	1018.2	99.37	35.43	34.60	5.34	178.58	108.08	12.51	114.66
Standard deviation (S.D)		0.38	115.25	13.47	3.24	3.02	1.48	30.99	7.06	1.47	14.70
Coefficient of variance (C.V)		5.09	11.31	13.55	9.16	8.74	27.75	17.35	6.53	11.78	12.82
WHO (PL)		6.5-8.5	400	<20	75	<30	10-12	10-50	200	<25	-
WHO (MCL)		< 9.5	1250	<200	200	150	-	<200	600	<50	-

PL = Permissible limit, MCL = Maximum contaminant level.

Table 5: Chemical concentration in (meq/l) and percentage of balance errors of major ions of Al-Diwaniyah River water

Station	**Season**	**Elements concentration (meq/L)**								**% of balance error**
		Na^+	Ca^{+2}	Mg^{+2}	K^+	SO_4^{-2}	CL^-	NO_3^-	HCO_3^-	
Al-Saniyya	Summer	3.893	1.971	2.838	0.201	3.789	2.736	0.167	1.770	2.54
	Autumn	3.867	2.061	3.233	0.162	4.081	2.962	0.176	1.672	2.37
	Winter	3.706	1.597	2.551	0.152	2.332	3.160	0.215	1.623	4.42
	Spring	4.998	1.578	2.519	0.129	3.248	3.075	0.234	1.901	4.33
Al-Diwaniyah	Summer	4.576	1.821	3.002	0.204	4.122	2.962	0.199	1.524	4.32
	Autumn	3.885	1.790	2.703	0.094	4.039	3.160	0.208	1.705	-3.64
	Winter	4.189	1.622	2.673	0.115	3.748	2.793	0.231	2.262	-2.46
	Spring	5.033	1.823	2.923	0.138	3.352	3.244	0.185	2.196	4.97
Al-Hamza	Summer	4.032	1.662	2.739	0.099	3.956	3.244	0.199	1.787	-3.69
	Autumn	3.819	1.884	3.271	0.099	4.247	3.244	0.166	2.163	-3.96
	Winter	4.354	1.572	2.673	0.104	2.977	2.765	0.224	1.918	4.94
	Spring	5.520	1.841	3.035	0.143	4.726	3.244	0.218	2.032	1.53

4.1 Values of pH and EC

The chemical analysis results of the Al-Diwaniyah River water are given in Table 4. The average pH value of the river water is 7.61, ranging from 7.03 to 8.23, suggesting that the river water tends to be slightly alkaline. The alkaline properties might be due to the dominance of the bicarbonate contents in the river water. There is a minor discrepancy in the station's measurements according to the seasons regarding pH values, as the highest value was recorded in spring in Al-Saniyya station with a value of 8.23. In contrast, Al-Hamza station recorded the lowest pH value in the Fall (7.03). There is a gradual decrease in pH values towards the southern parts of the river flow. Towards the south, the mean pH value in Al-Saniyya station is the highest (7.85), but it decreased to 7.71 in Al-Diwaniyah station. In contrast, the Al-Hamza station recorded the lowest average value in the study season at 7.27. The variations in the average pH values decreased the value of the coefficient of variation (CV) of 5.09.

The average EC value in the river water is 1018.25µS/cm, with a moderate spatial variation between 808 and 1205 µS/cm. As for the temporal variation, it is noted that the EC value decreases in winter with a value of 808, 923 and 841 µS/cm in Al-Saniyya, Al-Diwaniyah and Al-Hamza and stations, respectively. In contrast, the EC values increased in spring as the highest levels were recorded as 1040, 1094 and1205 µS/cm in Al-Saniyya, Al-Diwaniyah and Al-Hamza and stations, respectively. The pattern of EC values increased along the river flow direction, where a relatively high value of CV equal to 11.31 was recorded in the tested samples, indicating a high variation in the standard deviation compared to the mean value of CV.

4.2 Major Ions

Generally, the lowest concentrations of major ions were recorded at the Al-Saniyya station through the four seasons, but the highest concentrations at the Al-Hamza station in all four seasons. The CV was used to measure the spread of the data relative to the average of the data; based on that the CV values of the major ions that are range between 6.53 and 27.75, indicating the standard deviation of the chloride (Cl^-) is only 6.53%. In comparison, the standard deviation of potassium (K^+) is 27.75% (Table 4). The concentration of Na ion, which represents the highest concentration of cations ranges from 85.2 mg/l in the Al-Saniyya station in the winter to 126.9 mg/l in Al-Hamza station in spring, with an average value of 99.37 mg/l. On the other hand, the concentration of K ion represents the lowest levels of cations; it ranges from 3.69 mg/L to 7.96 mg/l in the Fall and summer, respectively. These values were detected in the Al-Diwaniyah station, with an average of 5.34 mg/l. The cation, according to their contents in the river water, were ordered in the following trend Na> Mg> Ca> K.

As for the anions (SO_4, HCO_3, Cl and NO_3), it was found that the SO_4 ion concentration had the highest levels among anions at all stations. It varies between 112 mg/L in winter at the Al-Saniyya station and 227 mg/L in spring at the Al-Hamza station, with an average value of 178.58 mg/L. The concentration of NO_3 ion is the lowest among the anions, as the values varied between 10.32 mg/L at Al-Hamza station in the Fall and 14.5 mg/L in spring at Al-Saniyya station, with an average value of 12.51 mg/L. Hence, the results demonstrate that the distribution pattern of the anions in the river water in descending order is SO_4> HCO_3> Cl > NO_3.

4.3 Water Quality Index (WQI)

The WQI model states five categories of water quality for drinking purposes are assigned as follows: If WQI < 50, excellent water quality; 50- 100, good; 100- 200, poor water quality; 200 - 300, very poor and when WQI > 300 is unsuitable water [36]. The results of computed WQI values range from 57.53 to 75.71 and the water of Al-Diwaniyah River represents a good water for drinking (Table 6 and Figure 2).

Table 6: Description of WQI results of the Al-Diwaniyah River

Station	Season	WQI	Description of WQ
Al-Saniyya	Summer	67.15	Good
	Fall	68.58	Good
	Winter	57.53	Good
	Spring	66.90	Good
Al-Diwaniyah	Summer	69.68	Good
	Fall	66.65	Good
	Winter	64.61	Good
	Spring	69.12	Good
Al-Hamza	Summer	66.32	Good
	Fall	69.07	Good
	Winter	59.80	Good
	Spring	75.71	Good

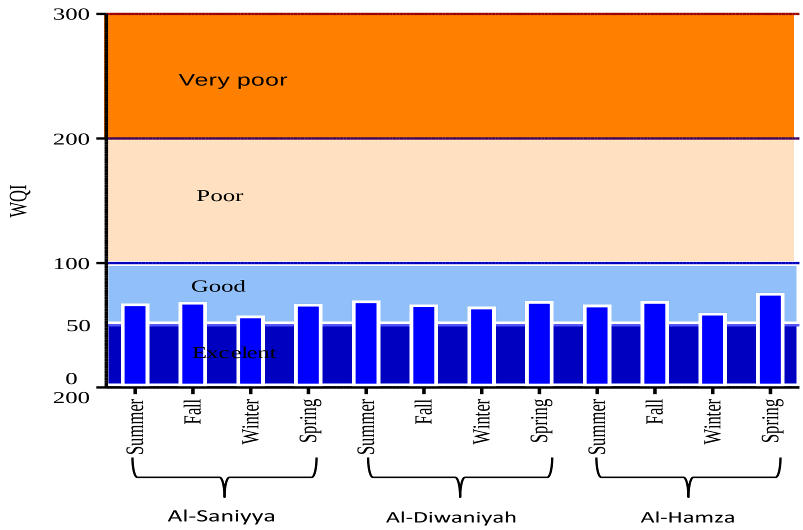

Figure 2: Temporal and spatial variation of the WQI at three sites of Al-Diwaniyah River

4.4 Concentrations of Heavy Metals

The average of heavy metals in the river water are 0.0006 and 0.0661 mg/l for Cd and Pb, respectively (Table 7). All heavy metals dissolved in the river water are of low concentration, and several of them were not detected in some seasons, especially Ni, Cd, Zn and Cu except for Pb. The low concentrations of heavy metals can be attributed to the limitation of human and industrial activities in the study area. Industrial activity is restricted by the waste of the textile and the rubber factories. The heavy metals in the river water tend to adsorb to the suspended particles leading to precipitation in the river bed; due to that, they have low solubility. Moreover, river water alkalinity decreases heavy metals' solubility and increases the adsorption process [37, 38]. The relatively high concentration of Pb (0.0011- 0.3670 mg/L) in the river water, especially in Al-Hamza station, may be due to the increase in gasoline use and agricultural drainage water. Textile factory dumps untreated pollutants directly into the river, so they are considered possible sources of the metal [39-41]. Despite the strong adsorption of the Pb on the sediment particles [42], their high levels in Al-Diwaniyah River may indicate that it was more than most of the other heavy metals and exceeded the WHO and Iraqi standards during the summer, Fall and spring seasons with values of 0.367, 0.128 and 0.105 respectively. Chromium and Zn slightly exceeded these standards. The water current and discharge velocity play an important role in the variation of heavy metal concentrations. The increase of discharges contributes to a dilution of metal levels, while an increase in current velocity leads to a water column turbulence. It contributes to increase the heavy metal contents in water due to the mixing process with the bottom sediments [43]. Heavy metals dissolved in the river water are characterised by a non-uniform random variation during the whole year, with a spatial variation of their levels tending to increase in Al-Diwaniyah station. The reason can be attributed to the relative increase in anthropogenic activities and the presence of textile and rubber factories in Al-Diwaniyah. The variation in the levels of heavy metals has ordered as the following pattern Pb > Mn > Ni > Cr > Zn > Cu > As > Cd.

Table 7: Seasonal concentrations of heavy metals (mg/l) in the Al-Diwaniyah River water

Station	Season	Pb	Mn	Ni	Cr	Zn	Cu	As	Cd
Al-Saniyya	Summer	0.0011	0.036				0.035	0.001	
	Fall	0.096	0.017	0.082	0.061			0.0076	
	Winter	0.023	0.023			0.0007		0.0021	
	Spring		0.0071	0.0491			0.0101	0.0024	
Al-Diwaniyah	Summer	0.013	n.d.	0.008			0.0012	0.001	0.003
	Fall				0.092	0.065		0.0085	0.002
	Winter	0.014	0.046		0.0306	0.0001		0.0035	0.0013
	Spring	0.105	0.056			0.0188	0.0128	0.0026	
Al-Hamza	Summer	0.367	0.014	0.0105			0.0044	0.0017	
	Fall	0.128				0.016	0.001	0.0076	0.001
	Winter	0.047	0.0517			0.0009	0.0083	0.0047	0.0004
	Spring		0.0216	0.0398				0.0029	
WHO[44]		0.05	0.1-0.5	0.02-0.07	0.05	0.02-3.0	0.05-2.0	0.05	0.01
Iraqi Standards [45]		0.05	0.1	0.1	0.05	0.05	0.05	0.05	0.005

4.5 Composite heavy metal pollution index (HPI)

The composite heavy metal pollution index (HPI) of river water was classified according to the classification of [46, 47] (Table 8). The results obtained are listed in Table 9.

The HPI values in Table 9 and Figure 3 indicate that most of the river water is classified as a clean from heavy metals except for two samples. The first one was collected during Fall from Al-Saniyya station, which was identified as light polluted with an HPI value of 1.12. The second sample was collected during summer from Al-Hamza station with a value of 1.35. The reason for the relatively high content in these stations is due to either source come from industrial and agriculture activities or attributed to decreased river flow.

Table 8: Description of HPI classes of water quality based on heavy metal concentrations.

Classification	HPI
Clean	Less than 1
Light polluted	1.01-2.0
Polluted	2.01- 3.0
Heavy polluted	3.01 – 5.0
Seriously polluted	Greater than 5.0

Table 9 : Summary of HPI results and heavy metals risk of the Al-Diwaniyah River

Station	Season	HPI	Risk level
Al-Saniyya	Summer	0.09	Clean
	Fall	1.12	Light polluted
	Winter	0.11	Clean
	Spring	0.37	Clean
Al-Diwaniyah	Summer	0.16	Clean
	Fall	0.61	Clean
	Winter	0.20	Clean
	Spring	0.49	Clean
Al-Hamza	Summer	1.35	Light polluted
	Fall	0.61	Clean
	Winter	0.26	Clean
	Spring	0.52	Clean

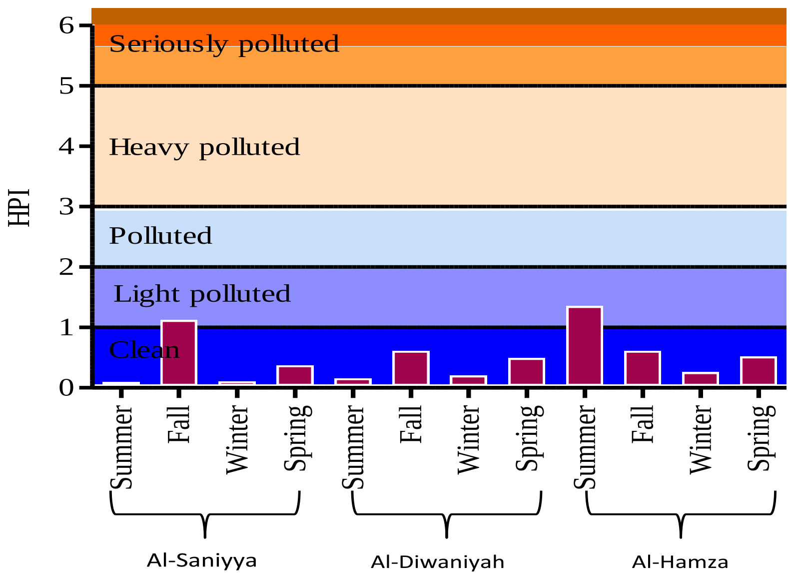

Figure 3 : Temporal and spatial variation of HPI at three sites of Al-Diwaniyah River

5. Conclusions

The current study represents a detailed analysis of major ions and heavy metals in Al-Diwaniyah River water as its importance for supplying drinking water for many cities along the river banks.

The water chemistry was compared with WHO standards. The values of WQI as a comprehensive index in the water quality assessment for drinking purpose ranges between 57.53 and 75.71. The water quality of the studied samples was classified as good based on the major cations and anions during all seasons. This doesn’t mean safe water; probably, other types of pollutants may have occurred. The composite HPI shows the heavy metal contents in the river water are safe for drinking purposes, except for two samples; these are Al-Saniyya during Fall and Al-Diwaniyah during Summer. They have been slightly polluted by heavy metals with HPI values of 1.12 and 1.35, respectively. The decreasing river water level during the summer and fall seasons is considered one of the reasons for concentration heavy elements. The study area wetness significantly declined agricultural and industrial activities during the last years; decreasing pollutants is accordingly expected. The river water is suitable for drinking and different domestic purposes and no chemical risk to human public health. Consequently, the surrounding urban along the river banks need continuous monitoring according to the clean environmental roles to prevent the rising pollution levels in the future. The anthropogenic wastes along the river banks must be verified periodically to assess the pollution state.

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References
[1] M. Vega, R. Pardo, E. Barrado, and L. Debán, "Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis," *Water research*, vol. 32, pp. 3581-3592, 1998.
[2] K. Usharani, K. Umarani, P. Ayyasamy, K. Shanthi, and P. Lakshmanaperumalsamy, "Physico-chemical and bacteriological characteristics of Noyyal River and ground water quality of Perur, India," *Journal of Applied Sciences and Environmental Management*, vol. 14, 2010.
[3] Y. A. Shekha, "Evaluation of water quality for Greater Zab River by principal component analysis/factor analysis," *Iraqi Journal of Science*, vol. 57, pp. 2650-2663, 2016.
[4] P. S. NAJAF, A. Alkarkhi, M. Kadir, and G. D. Najafpour, "Evaluation of spatial and temporal variation in river water quality," 2008.
[5] T. Ouyang, Z. Zhu, and Y. Kuang, "River water quality and pollution sources in the Pearl River Delta, China," *Journal of Environmental Monitoring*, vol. 7, pp. 664-669, 2005.
[6] M. Rode and U. Suhr, "Uncertainties in selected river water quality data," *Hydrology and Earth System Sciences*, vol. 11, pp. 863-874, 2007.
[7] D. M. Joshi, A. Kumar, and N. Agrawal, "Studies on physicochemical parameters to assess the water quality of river Ganga for drinking purpose in Haridwar district," *Rasayan journal of chemistry*, vol. 2, pp. 195-203, 2009.
[8] M. Singh, A. Gupta, and K. Beeteswari, "Physico-chemical properties of water samples from Manipur river system, India," *Journal of Applied Sciences and Environmental Management*, vol. 14, 2010.
[9] R. K. Verma, S. Murthy, R. K. Tiwary, and S. Verma, "Development of simplified WQIs for assessment of spatial and temporal variations of surface water quality in upper Damodar river basin, eastern India," *Applied Water Science*, vol. 9, p. 21, 2019.
[10] C. G. Cude, "Oregon water quality index a tool for evaluating water quality management effectiveness 1," *JAWRA Journal of the American Water Resources Association*, vol. 37, pp. 125-137, 2001.
[11] Ş. Şener, E. Şener, and A. Davraz, "Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey)," *Science of the Total Environment*, vol. 584, pp. 131-144, 2017.

[12] M. Bora and D. C. Goswami, "Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India," *Applied Water Science*, vol. 7, pp. 3125-3135, 2017.
[13] H. Dominguez Franco, M. Custodio, R. Peñaloza, and H. De la Cruz, "Application of Multivariate Statistical Methods and Water Quality Index for the Evaluation of Surface Water Quality in the Cunas River Basin, Peru," *Asian Journal of Water, Environment and Pollution*, vol. 18, pp. 19-27, 2021.
[14] R. Prusty and T. Biswal, "Assessment of Pollution Load in Terms of Water Quality Index and Modelling of Taladanda Canal and Mahanadi River in Paradip Area, Odisha, India," *Asian Journal of Water, Environment and Pollution*, vol. 17, pp. 59-72, 2020.
[15] Z. Zhao, G. Liu, Q. Liu, C. Huang, and H. Li, "Studies on the spatiotemporal variability of river water quality and its relationships with soil and precipitation: a case study of the Mun River Basin in Thailand," *International journal of environmental research and public health*, vol. 15, p. 2466, 2018.
[16] M. Salam, M. Kabir, L. Yee, and M. Khan, "Water quality assessment of perak river, Malaysia," *Pollution*, vol. 5, pp. 637-648, 2019.
[17] J. Xiao, L. Wang, L. Deng, and Z. Jin, "Characteristics, sources, water quality and health risk assessment of trace elements in river water and well water in the Chinese Loess Plateau," *Science of the Total Environment*, vol. 650, pp. 2004-2012, 2019.
[18] L. H. Alazawii, M. R. Nashaat, and F. S. Muftin, "Assessing the effects of Al-Rasheed electrical power plant on the quality of Tigris River, Southern of Baghdad by Canadian Water Quality Index (CCME WQI)," *Iraqi Journal of Science*, pp. 1162-1168, 2018.
[19] M. o. W. Resources, "*Directorate of Al- Qadisiyah Water Resources, (Unpublished data)," ed. Baghdad, Iraq: Unpublished data*, 2020.
[20] A. M. B. a. A. S. Nasira, "Geological map of Al-Najaf quadrangle sheet NH-38-2 of scale 1: 250 000.”," ed. Baghdad, Iraq: General Commission for Geological Survey and Mining, 1996.
[21] APHA. American Public Health Association), Standard methods for the examination of water and wastewater [Online].
[22] D. Karunanidhi, P. Aravinthasamy, T. Subramani, and G. Muthusankar, "Revealing drinking water quality issues and possible health risks based on water quality index (WQI) method in the Shanmuganadhi River basin of South India," *Environmental Geochemistry and Health*, vol. 43, pp. 931-948, 2021.
[23] D. K. Todd and L. W. Mays, *Groundwater hydrology: John Wiley & Sons*, 2004.
[24] W. D. Weight, *Manual of applied field hydrogeology: McGraw-Hill Education*, 2001.
[25] S. Krishna Kumar, R. Bharani, N. Magesh, P. S. Godson, and N. Chandrasekar, "Hydrogeochemistry and groundwater quality appraisal of part of south Chennai coastal aquifers, Tamil Nadu, India using WQI and fuzzy logic method," *Applied Water Science*, vol. 4, pp. 341-350, 2014.
[26] H. B. Ghalib, "Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq," *Applied Water Science*, vol. 7, pp. 3447-3467, 2017.
[27] A. Abbasnia, M. Radfard, A. H. Mahvi, R. Nabizadeh, M. Yousefi, H. Soleimani, et al., "Groundwater quality assessment for irrigation purposes based on irrigation water quality index and its zoning with GIS in the villages of Chabahar, Sistan and Baluchistan, Iran," *Data in brief*, vol. 19, pp. 623-631, 2018.
[28] A. A. F. Beg, S. M. Awadh, M. B. Thamer, and A. H. Al-Sulttani, "Assessment of Groundwater Quality for Drinking Purposes Using Water Quality Index, and Identifying the Affecting Mechanism in Rashdiya, Central Iraq," *The Iraqi Geological Journal*, pp. 20-32, 2021.
[29] M. Vasanthavigar, K. Srinivasamoorthy, K. Vijayaragavan, R. Rajiv Ganthi, S. Chidambaram, P. Anandhan, et al., "Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India," Environmental monitoring and assessment, vol. 171, pp. 595-609, 2010.
[30] M. A. H. Bhuiyan, M. Bodrud-Doza, A. Islam, M. Rakib, M. S. Rahman, and A. Ramanathan, "Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis," *Environmental Earth Sciences*, vol. 75, pp. 1-23, 2016.

[31] W. H. Organization, "*Guidelines for drinking-water quality: first addendum to the fourth edition*," 2017.
[32] A. Chaturvedi, S. Bhattacharjee, A. K. Singh, and V. Kumar, "A new approach for indexing groundwater heavy metal pollution," *Ecological Indicators*, vol. 87, pp. 323-331, 2018.
[33] A. K. Tiwari, M. De Maio, P. K. Singh, and M. K. Mahato, "Evaluation of surface water quality by using GIS and a heavy metal pollution index (HPI) model in a coal mining area, India," *Bulletin of environmental contamination and toxicology*, vol. 95, pp. 304-310, 2015.
[34] M. A. H. Bhuiyan, M. Bodrud-Doza, A. T. Islam, M. Rakib, M. S. Rahman, and A. J. E. E. S. Ramanathan, "Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis," vol. 75, p. 1020, 2016.
[35] S. Jehan, I. Ullah, S. Khan, S. Muhammad, S. A. Khattak, and T. Khan, "Evaluation of the Swat River, Northern Pakistan, water quality using multivariate statistical techniques and water quality index (WQI) model," *Environmental Science and Pollution Research*, vol. 27, pp. 38545-38558, 2020.
[36] S. A. Al-Asadi, "A study of pH values in the Shatt Al-Arab River (southern Iraq)," *International Journal of Marine Science*, vol. 6, 2016.
[37] S. A. Al-Asadi, W. S. Al-Qurnawi, A. B. Al Hawash, H. B. Ghalib, and N.-H. A. Alkhlifa, "Water quality and impacting factors on heavy metals levels in Shatt Al-Arab River, Basra, Iraq," *Applied Water Science*, vol. 10, pp. 1-15, 2020.
[38] A. S. Ahmed, M. B. Hossain, S. O. F. Babu, M. M. Rahman, and M. S. I. Sarker, "Human health risk assessment of heavy metals in water from the subtropical river, Gomti, Bangladesh," *Environmental Nanotechnology, Monitoring & Management*, vol. 15, p. 100416, 2021.
[39] M. H. Abdo, H. Ahmed, M. Helal, M. Fekry, and A. Abdelhamid, "Water Quality Index and Environmental Assessment of Rosetta Branch Aquatic System, Nile River, Egypt," *Egyptian Journal of Chemistry*, vol. 65, pp. 1-2, 2022.
[40] A. Bozdağ, "Quality and health risk assessment of water resources in Sızma-Lâdik (Konya) inactive mining area, Turkey," *Environmental Earth Sciences*, vol. 80, pp. 1-18, 2021.
[41] A. T. Hejabi, H. Basavarajappa, A. Karbassi, and S. Monavari, "Heavy metal pollution in water and sediments in the Kabini River, Karnataka, India," *Environmental Monitoring and Assessment*, vol. 182, pp. 1-13, 2011.
[42] S. A. Al-Asadi, A. B. Al Hawash, N.-H. A. Alkhlifa, and H. B. Ghalib, "Factors affecting the levels of toxic metals in the Shatt Al-Arab River, Southern Iraq," *Earth Systems and Environment*, pp. 1-13, 2019.
[43] G. WHO, Guidelines for drinking-water quality, 4th ed + 1st add ed. vol. 216, 2017.
[44] S. N. H. Al-Hussaini, A. H. M. J. Al-Obaidy, and A. A. M. Al-Mashhady, "Environmental assessment of heavy metal pollution of Diyala River within Baghdad City," *applied water science*, vol. 8, pp. 1-6, 2018.
[45] Z. Zhaoyong, J. Abuduwaili, and J. Fengqing, "Heavy metal contamination, sources, and pollution assessment of surface water in the Tianshan Mountains of China," *Environmental monitoring and assessment*, vol. 187, pp. 1-13, 2015.
[46] X.-R. Zhao, T. Nasier, Y.-Y. Cheng, J.-Y. Zhan, and J.-H. Yang, "Environmental geochemical baseline of heavy metals in soils of the Ili river basin and pollution evaluation," *Huan Jing ke Xue= Huanjing Kexue*, vol. 35, pp. 2392-2400, 2014.
[47] C. I. Addey, N. O. Ayoola, A. A. Omobolaji, and O. E. Tolulope, "Heavy metals pollution index of surface water from Commodore channel, Lagos, Nigeria," *African Journal of Environmental Science and Technology*, vol. 12, pp. 191-197, 2018.