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Assessment of the Al-Abbasiyah River (Iraq) Water Quality for Drinking Purposes Using the Water Quality Index and GIS Software

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ABSTRACT
All kinds of life, including people, animals, plants, and other species, depend on the rich natural resources of water. However, this valuable resource is becoming increasingly threatened by the increasing population as well as the growing demand for quality water for domestic and economic purposes. Hence the requirement for ongoing river water quality monitoring and assessment. In this research, the water quality (WQ) of the Al-Abbasiyah River was assessed for drinking uses in the dry and wet seasons using the weighted arithmetic water quality index (WAWQI) and GIS software. Eighteen physical, chemical, and biological parameters were measured in 2022 (dry season) and 2023 (wet season) by collecting samples from eight locations along the river. These parameters are: Temperature, EC, pH, TDS, TSS, Turbidity, DO, BOD_5, alkalinity, NO_3^-, HCO_3^-, Cl^-, Mg^{+2}, Ca^{+2}, Na^+, K^+, TH, and SO_4^{-2}. The average of the measured water parameters showed that some of these parameters exceeded the standards limit of the WHO in all locations such as (Alk, TH, Ca^{+2}, Mg^{+2}, SO_4^{-2}) and at some locations such as (TDS, Turbidity, and HCO_3^-). During the dry season, the WA-WQI values varied between 70.33 in (L4) within the category of "poor" and 119.87 in (L7) within the category of "unsuitable", while in the wet season varied between 49.71 in (L5) within the category of "good", and 79.35 in (L2) within the category of "poor". Thus, the water of the Al-Abbasiyah River was unfit for drinking directly and must undergo treatment before use in both seasons.

Keywords: WQI, drinking uses, Al-Abbasiyah River, wet season, dry season, water quality, GIS.

INTRODUCTION

Water is a natural resource that all living species, including humans, require to survive and carry out their critical functions; but this valuable resource is becoming more and more endangered as human populations rise and demand for high-quality water for economic as well as domestic purposes grows. The use of water for domestic purposes, power generation, industrial production, and mining can lead to a decline in water quality (WQ) and quantity, affecting not only the aquatic ecosystem but also the availability of safe water for human consumption (UNEP/GEMS, 2006). The water quality needed to preserve ecosystem health depends on background natural conditions. The physical and chemical composition of a body of water can have a significant impact on the ecosystem services it provides and the biological diversity it supports, but some aquatic ecosystems are resilient enough to withstand large changes in water quality without suffering significant impacts on ecosystem composition and function (Stark et al., 2000).

In Iraq, there is a tremendous regional and temporal diversity in the availability of water. Undoubtedly, the expansion of economic activity and the growth of the population are factors in the rising need for water for usage in a variety of ways. Over the past twenty years, Iraq's water resources have been under a great deal of stress in terms of water quantity because of several causes, such as the construction of dams on the Euphrates and Tigris in the border nations, climatic changes, and, poor water use planning within Iraq as well as a decrease in annual precipitation rates (Rahi & Halihan, 2010). The amount and quality of supplies coming in from various sources will undoubtedly have an impact on the water quality. The distribution of priorities among the various uses of water requires comprehensive national planning and resource management. Due to these considerations, it is unsurprising that studying water quality is so crucial for maintaining environmental awareness and knowledge (Alobaidy et al., 2010). The chemical and physical features of a water sample are typically compared to criteria or recommendations for water quality to determine its quality. Guidelines and standards for drinking WQ have been established to make it possible to supply clean, safe water for human consumption, hence preserving human health. These are often predicated on the levels of toxicity to humans or aquatic species that have been scientifically determined to be acceptable (Al-Janabi et al., 2012). In addition, one of the simplest and best methods that give a clear assessment of water quality is the use of the water quality index (WQI) (Jafari et al., 2009).

The Water Quality Index (WQI) is regarded as one of the most effective tools for informing citizens and decision-makers about water quality. As a result, it is regarded as a significant indicator for evaluating and analyzing surface water quality with a high level of accuracy. The WQI is based on merging lots of data into a single value and then assessing it to the defined and applicable standards to streamline the verification and assessment process and keep it within a single value (Khudair, 2013). Horton (1965) used the index for the first time to show the chemical and physical alterations that occur in water that flows. Since then, other measurement techniques have been developed to produce the other WQIs. The NFS-WQI index was established in 1970 by Brown et al. The Canadian Council of Ministers of the Environment first released its water quality index (CCME-WQI) in 1990, whereas the Oregon Water Quality Index (OWQI) was first issued by the Environment Department of Oregon in 1970 (DEQ, 2003). Another method for calculating the WQI is the Weighted Arithmetic Water Quality Index (WA-WQI) method, which is superior to other methods because it factors in one primary mathematical equation for more quality parameters as well as can define the quality of surface and underground waters (Călmuc, et. al, 2018).

Additionally, in recent years many computer programs have been developed that are used in the field of water quality assessment and monitoring. One of these pieces of software is Geographic Information System (GIS). The entirety of geographical as well as temporal features related to water resource management requires the use of ArcGIS. These methods give users powerful analytical and visual tools for deciphering, characterizing, and simulating the workings of ecosystems. IDW (spatial interpolation technique in GIS) is commonly used for producing interpolation maps for polylines, particularly for rivers, due to their superior level of precision in WQ modeling (Madhloom & Alansari, 2018).

Since the first appearance of the WQI, many researchers in many countries have studied the quality of water using WQI approaches. Among the most recent research projects in this area that have been carried out around the world, is the study conducted by Marselina et al. (2022). They conducted water quality tests at Indonesia's Citarum River. They used three different approaches to determine the WQI. These approaches include CCME-WQI, OWQI, and NSF-WQ. The results were analyzed using the relationship between rainy and dry years and months. According to these results, the NSF-WQI estimation process was the most useful for figuring out the water quality of the Citarum River. The NSF-WQI method assessed the WQ of the Citarum River as Poor and Fair. Similarly, the WA-WQI was used by Godwin and Oborakpororo (2019) to assess the river's surface WQ near the Nigerian city of Warri. The WQI was calculated using a variety of physicochemical parameters. The WQI was calculated with values that varied greatly, from 110.12 to 821.5. Krishan et al. (2022) researched the Gomti River in India. Throughout 2013–2017, WQI and 12 parameters were utilized. The WQI in the research area ranged from 78.98 to 249.4. It is concluded that WQI is seriously contaminated and unsuitable for human consumption.

In Iraq, many researchers have used WQIs to assess surface water quality. Abbas & Hassan (2018) used the (CCME-WQI) to evaluate the Diwaniya River's WQ in 2015 and 2016. Nine parameters were chosen (temperature, NO_3, NO_2, TDS, alkalinity, PO_4, DO, pH, and turbidity). The WQI readings indicated that the WQ of the river ranged between (poor and marginal). Al-Ridah et al. (2020) studied WQ for drinking in the Al-Hillah River using the WA-WQI and the CCME-WQI. Turbidity, pH, Ca, Mg, TDS, Alk, Cl, TH, and EC are the variables that are measured. According to the WA-WQI method, the raw water quality for all stations varied from badly polluted to unsuitable for human use. By using the CCME-WQI method, the treated water was classified as "good" for consumption, whereas the river water received a Fair rating. Also, Chabuk et al. (2020) used GIS software as well as the WA-WQI for evaluating the water quality and creating prediction maps for the Tigris River. Twelve parameters have been tested at 14 locations along the river, including Cl, BOD_5, Na, TH, EC, SO_4, HCO_3, K, TDS, Mg, NO_3, and Ca. The findings demonstrated that the WQI readings at sites S_1 to S_7 assessed the water quality as "poor" while classifying the WQ at sites S_8 to S_{11} as good.

Finally, by reviewing many studies that dealt with assessing the quality of surface water in Iraq, it was concluded that there is a lack of studies on the WQ of the Al-Abbasiyah River. The Al-Abbasiyah River is one of the branches of the Euphrates River in central Iraq as well as is considered an important source of drinking and irrigation water for many cities and villages located on both sides of it in the provinces of Babylon, Najaf, and Qadisiyah. Therefore, this study aimed to evaluate the WQ of the Al-Abbasiyah River for drinking purposes in the dry and rainy seasons by using the WA-WQI and creating spatial distribution maps along the river using GIS software.

Study aims

The Al-Abbasiyah River feeds large agricultural areas within the Governorates of Najaf and Qadisiyah, and it is the most important source to supply water for drinking uses for many cities, towns, and villages that lie on both sides of the river. The major aims of the current study were as follows:

1. Select suitable locations along the Al-Abbasiyah River to measure suitable physical-chemical parameters for one year (2022–2023) and the four seasons.
2. Assess water quality for the Al-Abbasiyah River for drinking uses using the WQI for dry and wet seasons.
3. Create estimation maps for the results of the WA-WQI for the wet and dry seasons along the total length of the river.

MATERIALS AND METHODS

Study area

AL-Abbasiyah is a subdistrict in the Najaf governorate of Iraq, located south of the country's capital and regarded as one of the central Euphrates region's most significant areas. The Euphrates River is located to its east (Al-Janabi & Berktay, 2021).

The Al-Abbasiyah River is one of the branches of the Euphrates River, where the Euphrates River branches off in the south of Babylon Governorate to the Al-Abbasiyah River and the Al-Kufa River, about (2 km) from Al-Kifil City and enters

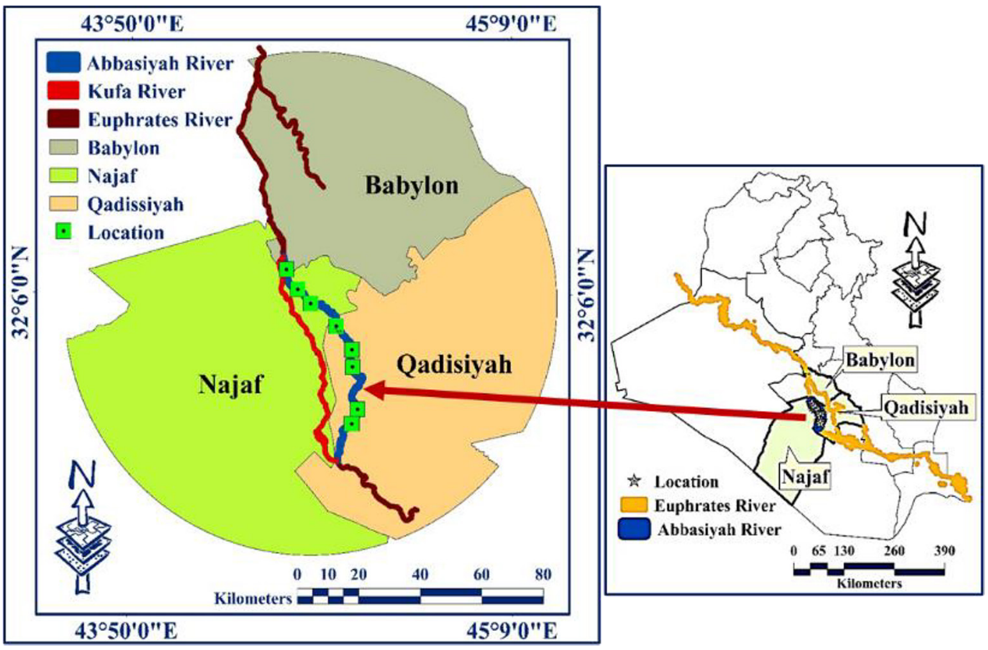

Figure 1. The mainstream of the Al-Abbasiyah River

Al-Abbasiyah City after 8 km from the branching point. The length of the Al-Abbasiyah River is about 80 km and it passes through Najaf Governorate (28 km inside Najaf Governorate), where it is called the Al-Abbasiyah River. Then, through Al-Qadisiyah Governorate (the remaining length of the river), where it is called the Al-Shamiyah River and meets at the end of the Al-Kufa River again to form together the main Euphrates River at a distance of about (8 km) north of Al-Shanafiyah city in Al-Qadisiyah Governorate. In this study, the river will be named along its length as the Al-Abbasiyah River (Figure 1) (Iraqi Ministry of Water Resources, 2022a).

The river passes through several cities (Al-Abbasiyah, Al-Mhannawiyah, Al-Salahiyah, Al-Shamiyah, and Ghammas), as these cities depend entirely on the Al-Abbasiyah River and its branches to meet their requirements for drinking water, in addition to irrigating its surrounding agricultural lands. The large agricultural lands on both sides of the river are always characterized by the cultivation of several important crops. Otherwise, on the riverbanks, much sewage, regarding the inhabitants, is drained by a sewer into the river as shown in Figure 2. Therefore, draining wastewater into a river directly affects the contamination of the river environment (Iraqi Ministry of Water Resources, 2022a).

The Al-Abbasiyah River receives about 40% of the water from the Euphrates River and the rest (60%) goes to the Al-Kufa River. The annual average capacity discharge for the Al-Abbasiyah River is 140.3 m^3/s. The highest value of discharge is in summer, usually in the months of rice cultivation, in June, July, August, and September with an average monthly range of (150–200 m^3/s). For the rest of the months of the year, the drainage values of the river are few to medium with an average monthly range of (25–95 m^3/s). The

Figure 2. Drainage wastewater and waste into the river

Figure 3. Al-Abbasiyah Barrage, Najaf Governorate

average monthly discharge of the Al-Abbasiyah River was recorded as (about 30 m^3/s) due to the water scarcity crisis in Iraq during recent years (Iraqi Ministry of Water Resources, 2022b).

Al-Abbasiyah Barrage controls the discharges of the Al-Abbasiyah River (Figure 3), where the barrage is located 8 km south of the branching area of the river. The Abbasiyah barrage was built in 1986 by a Chinese company, with a maximum design discharge of (1100 m^3/s) with seven radial gates powered by electricity. In addition to Al-Abbasiyah Barrage, Al-Shamiyah Barrage was built on the river, where Al-Shamiyah Barrage is located 3 km north of Al-Shamiyah City (Iraqi Ministry of Water Resources, 2022b).

Methodology of the study

Figure 4 shows the stages of implementing the study plan from the beginning, through the

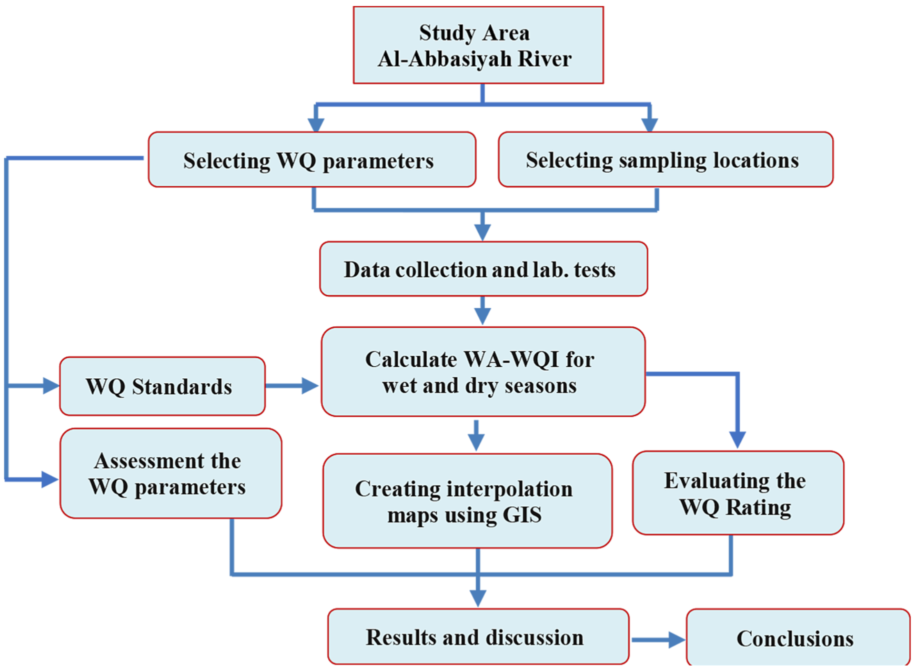

Figure 4. Methodology of the study

Table 1. Sampling Locations along the Al-Abbasiyah River

Location	The coordinates		Distance from the river upstream	Description
	X	Y		
L1	32°10’20.2”N	44°22’27.3”E	4 km	It is located 4 km before the Al-Abbasiyah Dam, about 6 km south of the city of Al-Kifil, within the borders of the Babylon Governorate
L2	32°06’54.0”N	44°24’46.0”E	12 km	It is located 4 km before the city of Abbasiyah and 4 km after the Al-Abbasiyah Dam, within the borders of Najaf Governorate
L3	32°04’28.7”N	44°27’24.5”E	19 km	It is located directly after the city of Abbasiyah within the borders of Najaf Governorate
L4	32°00’35.0”N	44°32’44.0”E	34 km	It is 4 km before the Al-Shamiyah dam and is located directly after the city of Salahiyah, within the borders of the Al-Qadisiyah Governorate
L5	31°56’33.8”N	44°35’59.7”E	45 km	It is 6 km after the Al-Shamiyah dam. It is located directly after the city of Al-Shamiyah within the borders of the Al-Qadisiyah Governorate
L6	31°53’35.4”N	44°36’08.1”E	51 km	(First agricultural location) It is located within a large agricultural area within the borders of the Al-Qadisiyah Governorate
L7	31°46’16.7”N	44°37’11.3”E	69 km	(Second agricultural location) It is located at the end of a large agricultural area and before the city of Ghammas about 3 km, within the borders of Al-Qadisiyah Governorate
L8	31°43’48.0”N	44°36’00.4”E	75 km	It is located directly after the city of Ghammas within the borders of the Al-Qadisiyah Governorate

collection and analysis of samples, the application of the necessary programs and equations, and the most important results that have been reached.

Sampling locations

The choice of sampling locations is considered one of the main objectives of this study. Therefore, eight locations were set for sampling along the river (about 80 km) considering the nature of the area in each location as well as the different factors and activities that affect the WQ of the river. The locations were set at the beginning and end of each residential city or a large agricultural area along the river as shown in Table 1.

Sample collection

After determining eight locations along the river, samples were taken from the raw river water at each location two times throughout the study duration. The samples were collected over the summer (dry season) of 2022 and in the winter (wet season) of 2023.

At each location, samples were taken at different depths from the center and sides of the river and then mixed to obtain one sample from the mixture with a volume of 10 liters to represent the actual picture of the WQ in that site. The samples were placed in a well-sealed plastic bottle with a volume of (1.5 liters) for each (0.5 liters) for dissolved oxygen and BOD tests to preserve the sample until it was analyzed. The samples were tested in the private laboratory in Al-Diwaniya City and the laboratory of Babylon Water Directorate.

Water is a complex substance that can be described by various parameters. These parameters provide information about the chemical, physical, and biological properties of water. Eighteen parameters were tested for all samples taken from the river throughout the study period, which are as follows temperature, hydrogen ions (pH), potassium (K^+), electrical conductivity (EC), total suspended solids (TSS), chloride (Cl^-), magnesium (Mg^{+2}), sodium (Na+), total alkalinity (Alk), total hardness (TH), bicarbonate (HCO_3^-), calcium (Ca^{+2}), turbidity (Turb), dissolved oxygen (DO), nitrates (NO_3^-), sulfates (SO_4^{-2}), Biochemical oxygen demand (BOD_5), and total dissolved solids (TDS).

The collected water samples from eight locations (along the Al-Abbasiyah River) during the four seasons were analyzed in the laboratory except for the water temperature which was measured directly in the river. For the selected parameters, these tests were conducted in the laboratory using standard chemical processes or using modern electronic devices. The "standard methods for the examination of water and wastewater" (APHA, 2017) were employed for all analyses. The results of laboratory tests of collected samples during each season can be found in Table 2 and Table 3.

Table 2. Results of laboratory tests for samples in summer

Site	Temp	pH	EC	TDS	Turb	DO	BOD_5	HCO_3	ALK
L1	35	7.19	1455	945.8	6.13	5.2	0.6	106	114
L2	36	7.32	1500	975	11.7	5.1	1.0	100	112
L3	36	7.40	1588	1032.2	4.89	4.7	0.5	90	110
L4	37	7.54	1682	1093.3	4.76	5.9	0.7	94	102
L5	37	7.60	1638	1064.7	5.14	6.5	1.1	94	102
L6	37	7.66	1673	1087.5	9.49	5.9	0.4	104	104
L7	38	7.72	1722	1119.3	14	5.2	1.9	100	108
L8	38	7.73	1798	1168.7	9.29	5.3	0.5	102	118
Site	TH	Ca	Mg	Cl	NO_3	SO_4	TSS	Na	k
L1	572	120.0	66.4	180.3	4.144	222.8	7.60	130.32	12
L2	532	121.6	55.6	162.7	3.599	225.8	10.46	133.90	12
L3	520	116.8	55.6	178.4	3.104	216.9	4.82	148.20	13
L4	576	118.4	68.3	194.0	3.44	226.4	4.60	154.16	14
L5	560	116.8	65.4	209.7	1.664	232.0	5.40	164.89	13
L6	536	118.4	58.6	197.9	2.37	220.5	8.86	166.08	14
L7	560	121.6	62.5	215.6	1.438	225.8	13.8	187.54	16
L8	544	123.2	57.6	211.7	1.542	209.6	9.60	187.96	15

Table 3. Results of laboratory tests for samples in winter

Site	Temp	pH	EC	TDS	Turb	DO	BOD_5	HCO_3	ALK
L1	12	7.82	1471	956.2	4.27	9.7	1.8	150	150
L2	12	7.81	1468	954.2	8.63	9.4	1.7	152	152
L3	12	7.9	1546	1004.9	3.74	9.3	1.9	151	151
L4	12	7.91	1476	959.4	3.13	9.5	2.1	140	140
L5	13	7.82	1469	954.9	2.63	10.2	1.7	146	146
L6	13	8.00	1486	965.9	2.82	9.4	1.1	114	150
L7	13	7.78	1476	959.4	3.74	9.0	2.0	132	152
L8	13	7.77	1482	963.3	7.62	9.0	1.6	152	152
Site	TH	Ca	Mg	Cl	NO_3	SO_4	TSS	Na	k
L1	536	120.0	57.6	217.6	6.213	386.9	5.2	114.28	7.5
L2	620	116.8	80.0	196.0	6.245	374.8	10.8	113.80	7.6
L3	544	126.4	55.6	213.6	6.507	330.5	3.8	119.85	7.9
L4	608	112.0	80.0	203.8	6.288	538.7	4.4	115.25	7.7
L5	516	120.0	52.7	199.9	5.488	362.7	4.8	112.34	6.4
L6	632	115.2	73.1	209.7	5.708	359.0	3.2	114.52	6.2
L7	568	110.4	71.2	197.9	6.717	294.3	3.6	113.8	6.0
L8	528	104.0	65.4	213.6	6.805	342.6	8.2	112.10	5.9

Water quality index (WQI)

WQI is a number that evaluates the water quality of any water body by aggregating several characteristics. The WQI methods express the condition of the water quality in a single number while also greatly reducing the amount of data (Kachroud et al., 2019).

The water quality index methodology's goal is to classify water resources according to their characteristics, identify potential uses for them, as well as practice responsible management of them (Boyacioglu, 2007).

In the current research, the WA-WQI method was used. The WA-WQI method is favored over alternative WQI calculation methods due to its ability to assess both surface and groundwater quality using a single core mathematical equation for all relevant quality factors (Călmuc et al., 2018). Many physicochemical parameters can be used to calculate WQI by this method.

This method involves multiplying various water quality parameters by a weighting factor. The simple arithmetic mean is then used to aggregate them. The recommended standard (S_i) for each parameter has an inverse relationship with the weight (W_i) for that parameter. The formula used to compute Wi values is described as below (Tyagi et al., 2013):

$$W_i = \frac{1}{S_i} \tag{1}$$

where: S_i – the permissible standard value for the ith parameter. The quality subindex (q_i) of each parameter in water bodies is then determined using Equation 2 and compared to higher standard limits as follows:

$$q_i = \frac{X_i - X_o}{S_i - X_o} \times 100 \tag{2}$$

where: q_i – the subindex of WQ for each variable;
X_i – the measurement of each variable's value;
X_o – the measured value in pure water for each variable. For all parameters, ($X_o = 0$), while for DO and pH parameters the X_o is 14.6 and 7, respectively. According to Tyagi et al. (2013), the final WA-WQI value is determined as follows:

$$\mathrm{WA-WQI} = \frac{\sum_{i=1}^{i=n} Wi \times qi}{\sum_{i=1}^{i=n} Wi} \tag{3}$$

Table 4. The WQ Rating that based on WA-WQI values (Paun et al., 2016)

WA-WQI value	WQR	Symbol
0–25	Excellent	EWQ
25–50	Good	GWQ
50–75	Poor	PWQ
75–100	Very poor	VPWQ
More than 100	Unsuitable uses for human	UUHWQ

Table 5. Allowable water quality limits (S_i) of parameters for drinking uses according to Iraqi standards (2009), and WHO standards (2017)

No.	Parameter	Unit	Iraqi standards	WHO standards
1	Temperature	°C	….	25
2	pH	…..	6.5–8.5	6.5–8.5
3	EC	µS/cm	2000	2000
4	TDS	mg/l	1000	1000
5	Turbidity	NTU	5	5
6	DO	mg/l	5	5
7	BOD5	mg/l	Nil	5
8	HCO_3	mg/l	….	125
9	Total alkalinity	mg/l	200	120
10	TH	mg/l	500	500
11	Ca	mg/l	150	75
12	Mg	mg/l	100	50
13	Cl	mg/l	350	250
14	NO_3	mg/l	50	50
15	SO_4	mg/l	400	250
16	TSS	mg/l	…	20
17	Na	mg/l	200	200
18	K	mg/l	10	12

Table 4 shows the WQ Rating based on WA-WQI. Table 5 presents the permissible standards (S_i) for drinking uses for the selected parameters in this study according to the WHO (2017), and Iraqi standards for drinking water (2009). The standards of the WHO for 2017 were adopted in this study.

Geographic information systems (GIS)

The GIS is comprehensive software created for generating, collecting, storing, processing, controlling, and displaying any kind of geographical information. Such systems are regarded as crucial resources for the geoinformatics scientific field. GIS employs basic concepts from geography, cartography, and geodesy to enable users to create queries, present data in maps, analyze spatial data and display the outcomes of every part of the selected features on raster maps (Kolios et al., 2017). Additionally, GIS software can perform a broad variety of operations and procedures; one of the most important procedures used in this research is spatial interpolation.

Spatial interpolation is a method for estimating unidentified data at specific points utilizing identified points data (Kolios et al., 2017). From several points of data, interpolation makes predictions about the values of cells in the raster. It can be used to forecast unknown values for any point based on known points. There are several methods of spatial interpolation in GIS software. One of the most popular of these methods is the Inverse Distance Weighting (IDW) method, which has unrivaled benefits for modeling the water quality of rivers due to it has high accuracy compared with other methods. This method is also commonly applied by many researchers (e.g., Chabuk et al., 2020 and 2022).

RESULTS AND DISCUSSION.

Water quality parameters (WQP)

Testing of water quality parameters is an important part of environmental assessment and monitoring. The most important factors that affect the WQ whether it is chemical, physical, or biological factors, not only impact aquatic life but also the surrounding ecosystem. Therefore, in this study, eighteen parameters were tested, and they will be discussed as shown below.

Temperature (Temp)

Water temperature can significantly affect aquatic life and WQ. Temperature can affect dissolved oxygen levels, chemical reactions, and the growth and reproduction of aquatic organisms

(EPA, 2023). The lowest temperature value was 12 °C in the wet season and the highest value was 38 °C in the dry season (Figure 5a). The average temperature along the river was 24.6 °C, which was within the WHO standard limit (2017) (25 °C). This large difference in water temperature between different seasons of the year was due to the great extremism between air temperatures between summer and winter in Iraq.

Hydrogen ions (pH)

The pH of water is a measure of its acidity or alkalinity. It is ranging from 0 to 14, where 7 is considered neutral. The pH can affect the chemical reactions and biological processes that occur in water. For example, acidic water can cause corrosion in pipes and harm aquatic life, while alkaline water can cause scaling on surfaces and affect water quality (APHA, AWWA, WEF, 2017). The pH values of the river water ranged between 7.19 at (L1) in the dry season and 8.0 at (L6) in the rainy season (Figure 5b). The annual mean of the pH for all locations along the river in both seasons was 7.68. This value was within the standards range of WHO (2017), between (6.5 and 8.5).

Electrical conductivity

Conductivity (EC) is the measure of a solution's ability to conduct electricity. It can provide information about the total dissolved solids and ionic content of water. High conductivity levels can indicate the presence of dissolved minerals and salts, and it is measured in micro-Siemens per centimeter (µS/cm) (APHA, AWWA, WEF, 2017). EC values increased gradually with the length of the river, where the electrical conductivity and salinity of river water in Iraq generally increase gradually as the water flows downstream (Ewaid et al., 2020). The lowest value of EC was 1455 µS/cm in (L1) in the dry season and the highest value was 1798 µS/cm in (L8) in the same season (Figure 5c). Along the river during the study period, the average value of EC was 1558 µS/cm, which was within the WHO standard limit (2000 µS/cm).

Total dissolved solids (TDS)

TDS measures the sum of all organic and inorganic compounds found in a given volume of water. The minimum value of TDS was 945.7 mg/L in (L1) in the dry season and the maximum value was 1168.7 mg/L in (L8) in the same season as shown

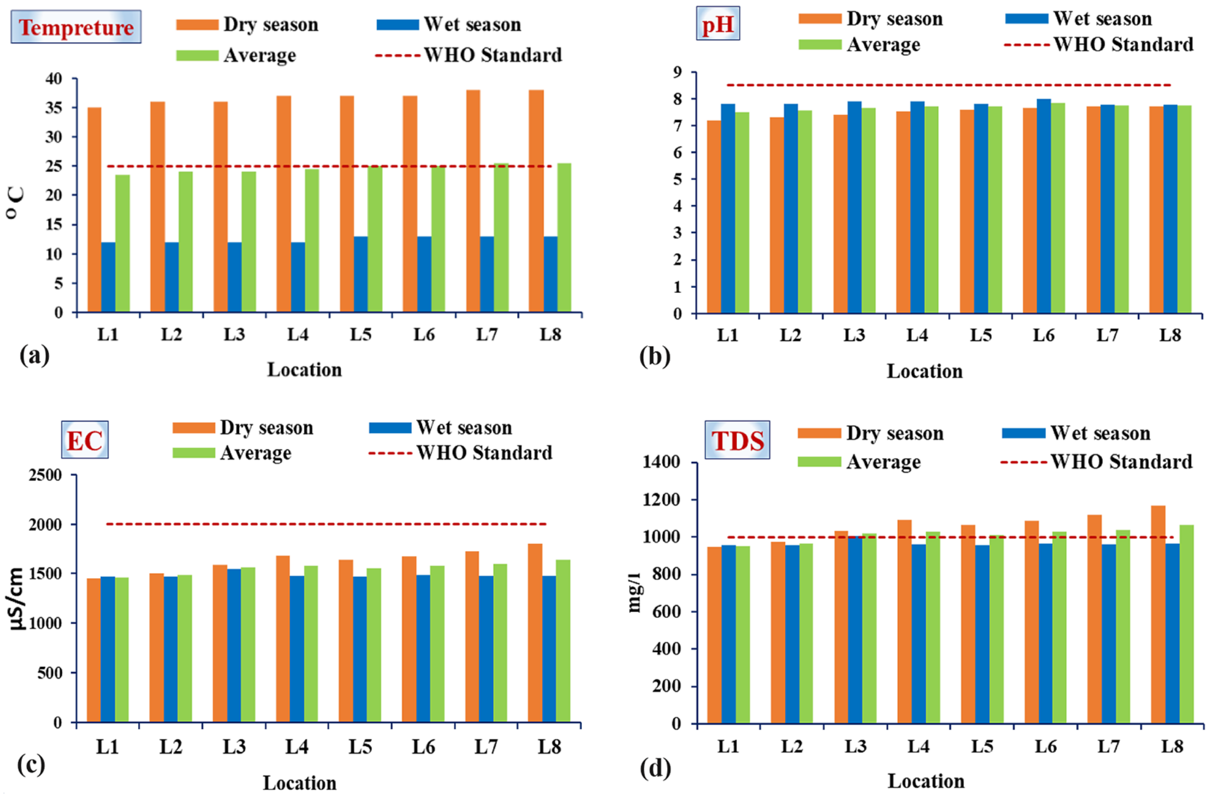

Figure 5. Concentration values of selected parameters measured from locations along the Al-Abbasiyah River for (a) temp., (b) pH, (c) EC, (d) TDS

in Figure 5d. The annual average of TDS along the river during both seasons was 1012.8 mg/L, which was very slightly above the WHO allowable limit (1000 mg/L). Higher TDS levels can be hazardous to aquatic life due to salt increases or changes in water composition. Soil erosion, agricultural runoff, pollution from domestic garbage, and other human activities may all contribute to the high TDS levels found in river water (Ewaid et al., 2020).

Total suspended solid (TSS)

TSS refers to the total amount of suspended particles, for instance, sediment, organic matter, and other solids in water. High TSS levels can affect WQ and clarity as well as harm aquatic life by reducing the amount of light that penetrates the water (EPA, 2023). The minimum value of TSS was 3.2 mg/L at (L6) in the rainy season and the maximum value was 13.8 mg/L at (L7) in the dry season. In both seasons, the annual mean of TSS was 6.8 mg/L, and this value was accepted according to the WHO standard limit in 2017 (20 mg/L). The decrease in the TSS values may be due to the decrease in the discharge of the Al-Abbasiyah barrage throughout the study period, which leads to a decrease in the river water velocity and an increase in sedimentation rates. Figure 6a shows the change in TSS values at all locations during the study period.

Turbidity

Turbidity is the measure of the cloudiness or haziness of water due to the existence of suspended particles. High turbidity levels can affect water quality and clarity. Turbidity can be influenced by the presence of sediment, organic matter, and other suspended particles; it is measured by nephelometric turbidity units (NTU) (EPA, 2023). The lowest value of turbidity was 2.63 NTU at (L5) in the winter season and the maximum value was 14 NTU at (L7) in the summer season (Figure 6b). The average value of turbidity for drinking water along the river during these seasons was 6.37 NTU, which exceeded the acceptable limit of WHO (2017) (5 NTU).

Dissolved oxygen (DO)

DO is the amount of oxygen present in water that is available for aquatic life. DO is important for respiration and other metabolic processes in aquatic organisms. DO levels can be influenced by temperature, water flow, and the existence of organic solids (EPA, 2023). In this study, the values of DO in the wet season were higher than it in the dry season. This was because of the decrease in temperatures in the wet season, where the oxygen's ability to dissolve in water decreases at high temperatures. Dissolved oxygen levels drop during the dry season because more organic matter is added to the water (mostly in the form of leaf litter), and its decomposition causes more oxygen to be used up and the stream to become stagnant (Izonfuo and Bariweni, 2001). The lowest value of DO was 4.7 mg/L in (L3) in the dry season, while the highest value was 10.2 mg/L in (L5) in the wet season (Figure 6c). The annual mean of DO throughout the study duration was 7.5 mg/L, which was within the WHO standard limit (2017), which recommends that DO values > 5 mg/L.

Biochemical oxygen demand (BOD_5)

BOD_5 is the quantity of oxygen utilized by microorganisms during the decomposition of organic matter in water. It is a measure of the number of organic pollutants in water. High BOD_5 levels can lead to hypoxia and the death of aquatic organisms (APHA, AWWA, WEF, 2017). Figure 6d shows the BOD_5 values of the river water ranged between 0.4 mg/L at (L6) in the dry season and 2.1 mg/L at (L4) in the rainy season. The annual average of the BOD_5 for all locations along the river was 1.3 mg/L, which was within the standard limit of the WHO (2017).

Bicarbonate (HCO_3^-)

Bicarbonate is an important component of alkalinity in water. It can affect the pH of the water and the solubility of metals. Bicarbonate can also serve as a source of carbon for aquatic organisms (USGS, 2019). The HCO_3^- values in the summer were lower than their values in the winter. The minimum value of HCO_3 was 90 mg/L at (L3) in the summer season and the maximum value was 152 mg/L at (L2) and (L8) in the winter season. The mean yearly concentration of HCO_3 for the river was 120 mg/L, which is within the recommendations of the WHO (2017). Figure 6e shows the change in HCO_3^- values at all locations during the study period.

Total alkalinity (Alk.)

Total alkalinity is the measure of a solution's ability to neutralize the acid. Bicarbonate, carbonate, and hydroxide ions are considered the major parameters that affect the alkalinity of water bodies. Alkalinity can affect the pH of the water and the solubility of metals (APHA, AWWA,

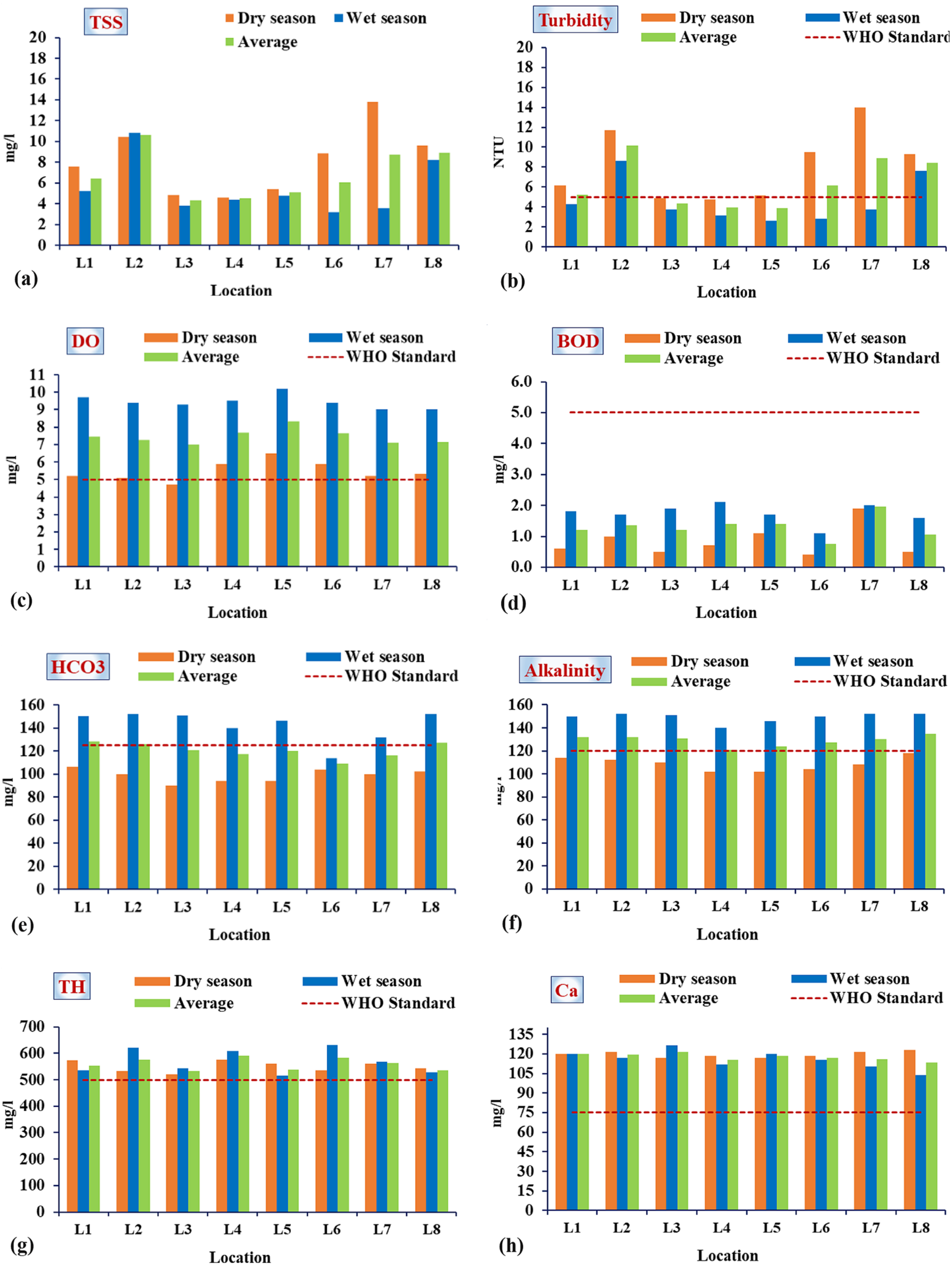

Figure 6. Concentration values of selected parameters measured from locations along the Al-Abbasiyah River for (a) TSS, (b) turbidity, (c) DO, (d) BOD_5, (e) HCO_3, (f) alkalinity, (g): TH., (h) Ca

WEF, 2017). The values of alkalinity in the summer were lower than their values in the winter. The minimum reading of Alkalinity (102 mg/L) was measured at (L4) and (L5) in the summer season and the maximum reading was 152 mg/L at (L2), (L7), and (L8) in the winter season. The average reading of alkalinity along the river in both seasons was 128.9 mg/L, as shown in Figure 6f. This value was higher than the WHO permissible limit (5 mg/L).

Total hardness

Total hardness (TH) is a measure of how much calcium and magnesium ions are present in a given volume of water. Hard water can cause scaling on surfaces as well as affect the WQ for domestic and industrial uses (WHO, 2011). The average reading of the TH for all locations in the river was 560 mg/L, and this value was above the upper limit of the WHO (2017) (500 mg/L). The TH values of the river water ranged between 520 mg/L at (L3) in the dry season and 620 mg/L at (L2) in the rainy season (Figure 6g).

Calcium

A frequent divalent cation in water is calcium (Ca^{+2}). It is crucial for keeping healthy bones and teeth and is essential for the health of humans. However, high levels of calcium in water can contribute to water hardness, which can cause scaling and reduced soap effectiveness (WHO, 2011). For calcium ions, there is no significant change between the values within the seasons and the locations of the river. However, all Ca values were upper than the WHO standard limit (2017) (75 mg/L). Figure 6h shows the Ca values ranged between 104 mg/L at (L8) in the wet season and 126.4 mg/L at (L3) in the same season. The seasonal average value of the Ca for all locations was 117.6 mg/L.

Magnesium

Magnesium is a common ion found in water that has a significant impact on health as well as the growth of plants and animals. It is also involved in several biochemical processes within the body, such as muscle and nerve function. However, high levels of magnesium in drinking water may cause water hardness, which can lead to scaling and reduced soap effectiveness (WHO, 2011). The Mg values of the river ranged between 55.63 mg/L at (L2), and (L3) in the dry season and 80.03 mg/L at (L2), and (L4) in the rainy season (Figure 7a). The annual mean of Mg at all locations along the river during the study period was 64.1 mg/L. According to the WHO standard limit (2017)(50 mg/L), the average value was unaccepted.

Chlorine

Chlorine (Cl^-) is a common ion found in water; it can have both positive and negative effects on water quality. Chlorine is important for maintaining electrolyte balance in the body, but high levels of chlorine in water may be a sign of contamination from sewage or agricultural runoff (EPA, 2023). The seasonal average value of the Cl^- at all locations along the river was 200.16 mg/L, which was accepted according to the WHO standard limit (2017)(250 mg/L). Figure 7b illustrates the Cl^- values of the river water ranged between 162.68 mg/L at (L2) in the dry season and 217.56 mg/L at (L1) in the wet season. The chlorine in natural water comes from the leaching of chlorine-containing rocks and sediments that come in touch with the water. Agricultural and domestic wastewaters that are dumped into surface waters are also a source of Cl^- (Metcalf and Eddy, 2004).

Nitrate

Nitrate (NO_3^-) is a common form of nitrogen found in water, and it is often a result of agricultural practices and wastewater discharge. High levels of nitrate in water lead to eutrophication, which can cause algal blooms and harm aquatic life. Nitrate can also be converted into nitrite, which can be harmful to human health, particularly in infants (WHO, 2011). The NO_3 levels were lower in the summer than they were in the winter. In the summer, NO_3 levels were as low as 1.438 mg/L at (L7) and as high as 6.805 mg/L at (L8) in the winter. Figure 7c demonstrates the average value of NO_3 in the river during the study seasons which was 4.45 mg/L, and it was within the WHO (2017) allowable standard limit of NO_3 (50 mg/L).

Sulfate

Sulfate (SO_4^{-2}) is a common ion found in water, and it can affect the taste and odor of water.

High levels of sulfate in water can also cause scaling as well as corrosion of pipes and infrastructure (EPA, 2023). Figure 7d illustrates the SO_4 values of the river water ranged between 209.6 mg/L at location 8 in the dry season and 539 mg/L at location 4 in the rainy season. For all locations, the average reading of SO_4 throughout all seasons was 298.0 mg/L, which was more than the standard limit of the WHO (2017) (250 mg/L).

Sodium

Sodium (Na^+) is a common ion found in water, and it can affect the taste and effect of water on health. High levels of sodium in water can be a concern for people with hypertension or cardiovascular disease, as it can increase blood pressure (WHO, 2011). The Na values ranged between 112.1 mg/L at (L8) in the winter and 187.96 mg/L at the same location (L8) in the summer. The seasonal average reading of the Na at the selected locations along the river was 136.8 mg/L, and this reading was within the acceptable limit of the WHO (2017) (200 mg/L). Figure 7e illustrates the variation in Na values at all locations over the study period.

Potassium)

Potassium (K^+) is a less common ion found in water compared to sodium, but it is still important for the body's health. Potassium plays a role in

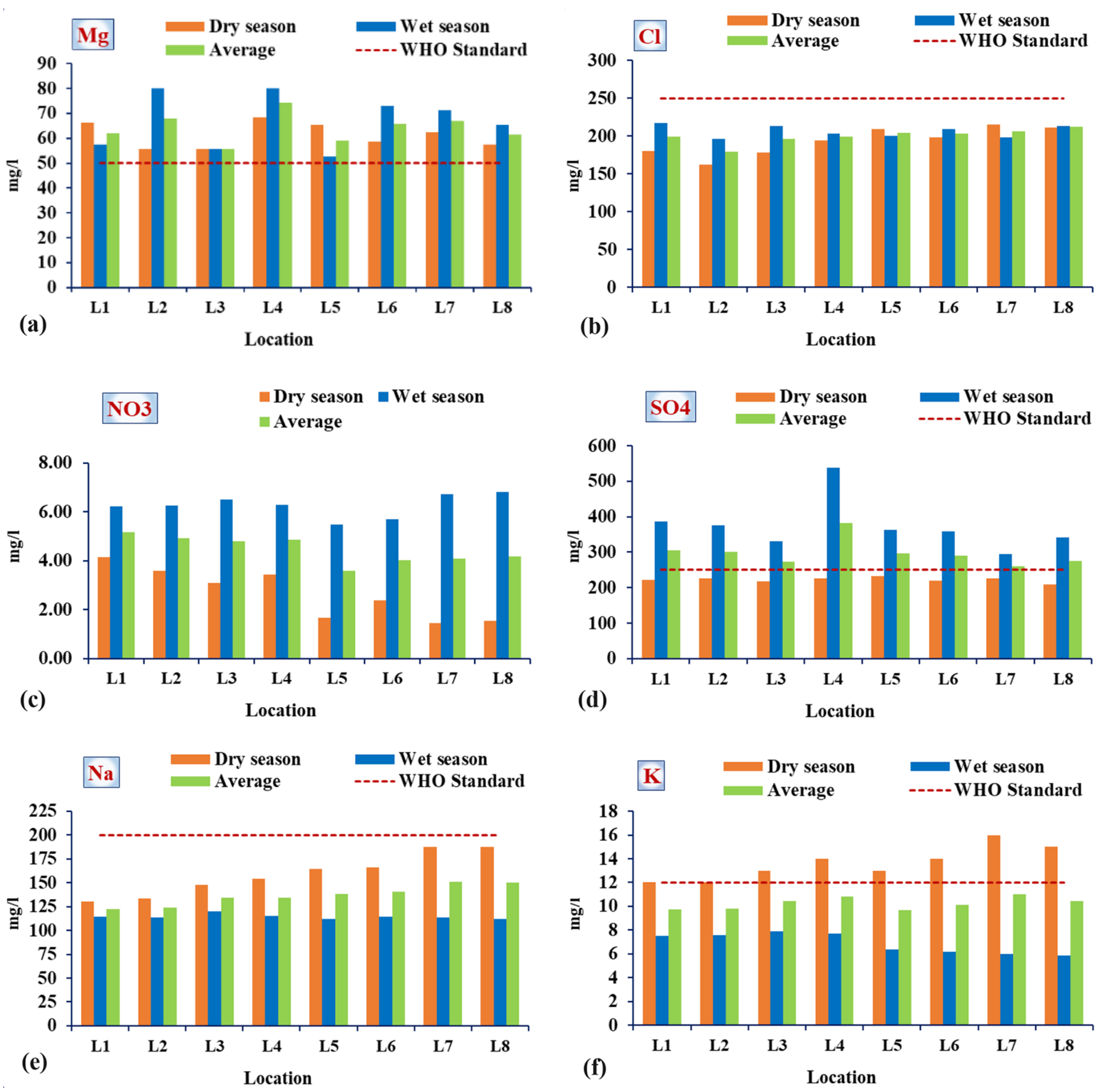

Figure 7. Concentration values of selected parameters measured from locations along the Al-Abbasiyah River for (a) Mg, (b) Cl, (c) NO_3, (d) SO_4, (e) Na, (f) K

several biological processes, such as muscle and nerve function, and it can also help regulate blood pressure (WHO, 2011). In the summer, the K values were higher than their values in the winter. The minimum value of K was 5.9 mg/L at (L8) in the winter and the maximum value was 16 mg/L at (L7) in the summer. The annual mean of K along the river in both seasons was 10.3 mg/L, which was slightly above the WHO standard limit (2017) (12 mg/L). Figure 7f shows the change in K values at all locations during the study period.

Water quality index (WQI)

The water quality indices aim to obtain a single value that represents the required value of the surface water quality at any location from which the sample was taken. In this study, WA-WQI was used to calculate the WQ of the Al-Abbasiyah River for drinking use by using the water samples taken in dry and wet seasons from eight locations along the river. The World Health Organization standards (2017) for drinking purposes were used to find the weight of each parameter (w_i) using Equation 1. This method also included finding the sub-index for each parameter (q_i) using Equation 2. The final value of the WQI was found in Equation 3. The water quality rating is given for each WQI value according to Table 4. The results of WA-WQI for dry and wet seasons are shown in Figure 8 and Table 6.

In the dry season, the WA-WQI values for the Al-Abbasiyah River ranged between 70.33 at (L4) and 119.87 at (L7). Therefore, the classification of river water quality for drinking uses was "poor" in locations (L1), (L-3), (L4), and (L-5), "very poor" in locations (L2), (L6), and (L8), and "unsuitable uses for human" in location (L7). In the wet season, the WA-WQI values ranged between 49.71 in location 5 and 79.35 in location 2. Therefore, the classification of river water quality for drinking uses was "good" in location (L5) and "poor" in locations (L1), (L3), (L4), (L6), (L7), and (L8) and "very poor" in location (L2).

By observing the values of the WQI for both seasons, it was evident that the WQ of the river in the wet season was slightly better than it was in the dry season. The decrease in the discharge of

Table 6. The results of WA-WQI for dry and wet seasons

Location	Dry season		Wet season		Average	WQR
	WA-WQI	WQR	WA-WQI	WQR		
L-1	73.266	PWQ	58.982	PWQ	66.124	PWQ
L-2	99.333	VPWQ	79.351	VPWQ	89.342	VPWQ
L-3	70.403	PWQ	58.631	PWQ	64.517	PWQ
L-4	70.325	PWQ	57.528	PWQ	63.927	PWQ
L-5	72.044	PWQ	49.707	GWQ	60.876	PWQ
L-6	90.159	VPWQ	51.269	PWQ	70.714	PWQ
L-7	119.873	UUHWQ	57.621	PWQ	88.747	VPWQ
L-8	92.829	VPWQ	72.756	PWQ	82.792	VPWQ
Average	86.029	VPWQ	60.731	PWQ	73.380	PWQ

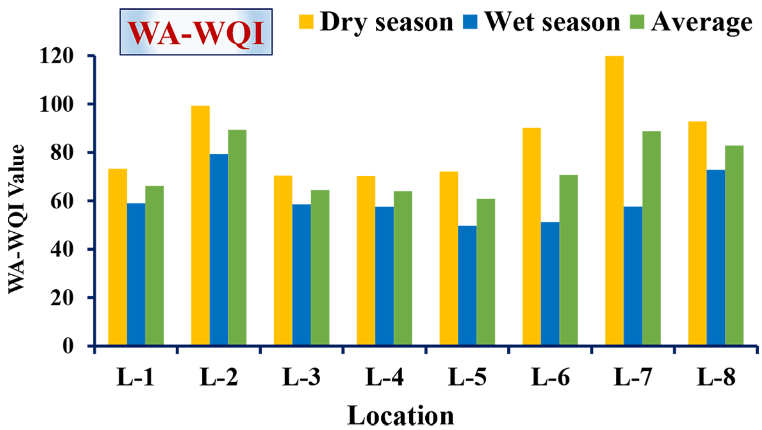

Figure 8. The results of WA-WQI for wet and dry seasons

the river water as well as the increased evaporation rates brought on by the hot weather in the dry season is the most crucial reason for the decrease in the WQ of the river in the dry season (Al-Mansouri, 2017). However, the river water in both seasons was polluted, so this water is unsuitable for direct use for drinking in all seasons and must undergo treatment before use. This decline in river water quality can be attributed to improper waste disposal, large amounts of agricultural and urban runoff, sewage, excessive use of inorganic fertilizers, as well as improper operation and maintenance of the sewage system (Rabee et al., 2011).

Prediction maps using ArcGIS software

Spatial distribution maps of the Al-Abbasiyah River's water quality for drinking uses were generated based on the WA-WQI values in the dry season of 2022 and the wet season of 2023 by using the GIS software. The producing maps provide a representation of the river's water quality based on the WA-WQI values that were calculated using the measured parameters of water samples taken from eight sites along the river during this study.

In addition, to estimate the value of WA-WQI at all other points along the river, the spatial interpolation techniques provided by ArcGIS 10.5 had to be used. The inverse distance weighting (IDW) method, as one of the most accurate spatial interpolation methods, was used to predict the WA-WQI value in all river locations based on the calculated WA-WQI value for the eight selected locations (L1 to L8).

Figure 9 shows the spatial distribution maps of the Al-Abbasiyah River's water quality for drinking uses in the dry and wet seasons during the study period. The importance of these maps is that they give a quick impression of the mechanism of changing the river's quality and the length of the river associated with each WQ classification, clearly for the decision-makers and the public. In these figures, the WA-WQI values in the dry seasons were within the categories of (70–75), (75–100), and (> 100) and rated (respectively) as "PWQ", "VPWQ", and "UUHWQ". In the wet season, based on the WA-WQI values, the river was classified into three categories (49.7–50), (50–75), and (75–79.4) with a rating of "GWQ", "PWQ", and "VPWQ", respectively.

CONCLUSIONS

The Al-Abbasiyah River is one of the branches of the Euphrates River in central Iraq and is considered an important source of drinking and irrigation water for many cities and villages located

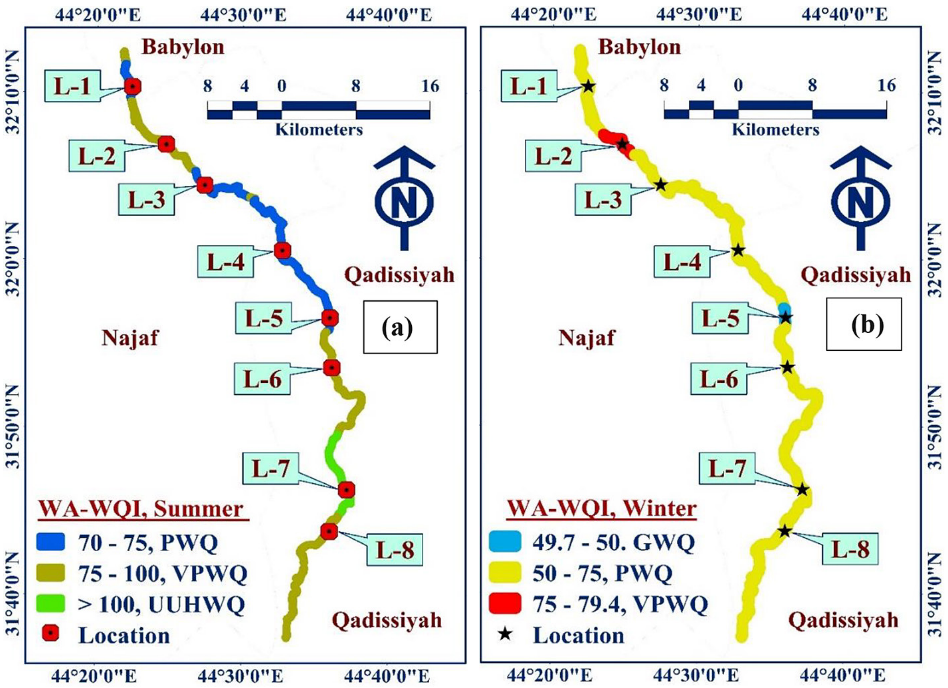

Figure 9. Maps of WA-WQI values along the Al-Abbasiyah River that resulted using the IDW method for the (a) dry season; (b) wet season

on both sides of it in the governorates of Babylon, Najaf, and Qadisiyah. Therefore, this research aimed to evaluate the Al-Abbasiyah River's water quality for drinking purposes in the wet and dry seasons using the water quality parameters and WA-WQI as well as creating spatial distribution maps along the river using GIS software.

In the current research, eighteen chemical, physical, and biological parameters were measured in the wet season of 2023 and the dry season of 2022 by taking samples of river water from eight locations along river length. The measured parameters are temperature, pH, EC, TDS, TSS, Turbidity, DO, BOD_5, alkalinity, TH, Cl^-, NO_3^-, Mg^{+2}, HCO_3^-, Ca^{+2}, K^+, Na^+, and SO_4^{-2}.

The results showed that all parameters in the wet season were within the WHO standards for drinking water except (HCO_3^-, Alk, SO_4^{-2}, Mg^{+2}, Ca^{+2}, and TH), which exceeded the WHO standards in all locations along the river, as well as (Turb.) which also exceeded the WHO standards in (L2) and (L8) only. In the dry season, most of the water quality parameters were within the WHO standards except (K^+, Temp, TH, Ca^{+2}, and Mg^{+2}), which exceeded the WHO standards in all locations along the river, as well as Turb and TDS, they exceeded the WHO standards at locations (L1), (L2), (L6), (L7), (L8) and (from L3 to L8), respectively.

For WA-WQI, the results of the dry season demonstrated that the WQ of the Al-Abbasiyah River was "PWQ" in locations (L1), (L3), (L4), and (L-5) within the category of (50–75), and it was rated as "VPWQ" in (L2), (L6), and (L8) within the category of (75–100), and rated as "UUHWQ" at (L7) within the category (> 100). The values of the wet season demonstrated that the water quality was rated as "GWQ" in (L5) within the category of (25–50), "PWQ" in locations (L1), (L3), (L4), (L6), (L7), and (L8) within the category of (50–75), and it was rated as "VPWQ" in (L2) within the category of (75–100). The average value of WA-WQI in the dry seasons was 86.029 and the water of the river was rated as "VPWQ", while in the wet season, the average value was 60.731 and rated as "Poor". In both seasons, the water of the total length of the Al-Abbasiyah River was classified as "PWQ" based on the WA-WQI value (73.380) located within the category of (50–75).

The main reason for changes in values of WQ parameters in the Al-Abbasiyah River is due to many factors, including differences in temperatures between summer and winter, night and day, and sewage discharge directly into the river in some cities where the river passes through them. In addition, the disposal of fertilizers and animal waste from the farms existing on both banks of the river into the river stream led to rising concentrations for some parameters in the river.

Moreover, in this study, an interpolation tool in the GIS software (IDW technique) was used for mapping the WA-WQI results calculated for the dry and wet seasons. This will help find sampling sites or places along the river that are more likely to be affected by pollution. These maps demonstrated that the water of the river was rated as "PWQ", "VPWQ", and "UUHWQ" in the dry season and as "GWQ", "PWQ", and "VPWQ" in the wet season.

It is concluded from the foregoing that the WQ of the Al-Abbasiyah River in the wet season was slightly better than in the dry season due to the decrease in river water discharge and the increase in evaporation rates with the high temperatures in the dry season. However, the river water in both seasons was polluted, so this water is unsuitable for direct drinking use and must undergo treatment before use. This decline in river water quality can be attributed to improper waste disposal, large amounts of agricultural and urban runoff, sewage, and excessive use of inorganic fertilizers.

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