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Evaluation of the Environmental Integrity of the Al-Dujaila River by Using the Weight Water Quality Index

Rasha M. Salman[1], **Zahraa Zahraw Al-Janabi**[2, *]
[1]Department of Biology, College of Science, Wasit University, Iraq
[2]Environment Research Center, University of Technology, Iraq
[*]Corresponding Author: zahraa.z.farhan@uotechnology.edu.iq

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ABSTRACT

The water quality index (WQI) is a practical and comprehensive technique to evaluate water quality. It is often employed to assess water quality in simple terms and determine its suitability for various uses. The current study aimed to assess the temporal and spatial variation of the Al-Dujaila River. Three sites were selected for surveying from January to December 2021. The studied area starts after the AL-Kut dam and goes to the point where the river exits in the city of AL-Kut. Several physico-chemical parameters were addressed to calculate the IQ-WQI based on the Iraqi rivers maintaining limits; namely, dissolved oxygen (DO mg/ l), biological oxygen demand (BOD_5 mg/l), hydrogen ion (pH), phosphate (PO_4 mg/ l), nitrate (NO_3 mg/ l), chloride (Cl mg/ l), sulfate (SO_4^{-2} mg/ l), total dissolved solid (TDS mg/ l), and turbidity (Turb NTU). The concentrations of most parameters were within the standard limits, except for SO_4^{-2}, TDS, and Turb, where the highest concentrations reached 390mg/ l, 920mg/ l, and 70 NTU, respectively. The rating of the water quality index in these three sites falls under very poor water quality, where values of the IQ-WQI ranged between 83.41– 89.48 in the wet season, and in the dry season, the value was 85.24– 91.13. The shift of the index toward the worst conditions is related to the high concentration of TDS and SO4-2, where the standard limits for them are 500 and 200mg/ l according to the Iraqi rivers maintaining limits, respectively, which indicates pollution conditions of the river caused by the increased levels of salts. The principal component analysis (PCA) was used to visualize the data obtained to know how they interrelate in addition to extracting the most affecting parameters on water quality.

INTRODUCTION

One of the most significant irrigation projects on the Tigris River is the Kut Dam, which regulates water flow between Wasit, Maysan, and Dhi Qar Governorates. Moreover, several rivers and streams emerge on the right side of the dam, including the Al Gharaf and Dujaila Rivers and a group of streams critical for irrigating a large agricultural land **(Al-Barakat & Al-Saadi, 2023)**.

The importance of studying the chemical and physical characteristics of the Dujaila River lies in its significant impact on the success of economic projects, especially the agricultural projects related to the river's water. Therefore, this study analyzed some hydrological characteristics using the water quality index. Several indices have been applied to evaluate the health of aquatic life in order to estimate the suitability of water sources for different purposes of consumption (industrial operations, public water supplies, and irrigation). WQI uses data on water quality to assist environmental agencies in adapting their regulations; indices can also be used to compare sites and monitor changes over time and sites **(Kouadri *et al.*, 2021)**. The explanation of the water quality data for common public and non-specialists is difficult to understand. Hence, WQI has shown to be an easy way to provide policymakers and citizens with information on water quality **(Ahmed *et al.*, 2020)**. The primary aim of water quality indices is to give a single value for water quality by converting the data on the components and their concentrations in a sample into a unique number **(Uddin *et al.*, 2021)**. Hence, comparing different samples for their quality will be easy based on each sample's index value. WQIs condense selected variables into a single unitless score, allowing one to notice water changes over time or compare different water bodies **(Nowicki *et al.*, 2020)**.

The weighted arithmetic water quality index is one of the models used to assess the quality of water. It is based on the total of all the ratings and weights assigned to each parameter, with each parameter having a different weight. As a result, a weighted mean is assigned to each parameter based on an expert's opinion, depending on the environmental importance, recommended principles, and uses of the water body, and well the total of these weights equals one **(Chidiac *et al.*, 2023)**. The current study aimed to analyze the physical and chemical characteristics of the Dujaila River, temporally and spatially, based on the results of laboratory analyses, in addition to revealing the factors affecting water quality, whether natural or human factors. The significance of this study stems from its location within dry regions. The reliance on surface water, represented by the Dujaila River, is paramount due to its role as a key input for economic and social development. Therefore, the issue of water management in a region must be given a sufficient attention to ensure that it meets the various water requirements for now and in the future to develop the necessary plans.

MATERIALS AND METHODS

1- Study area

The study area is the Al-Dujaila River within the AL-Kut City. The river is 69.45km long with a width of 15m and a mean discharge of 42.15m3/ sec. Al-Dejila River provides the water share for 396 thousand acres **(Al-Dabbas & Maiws, 2016)**. The first site is located before the dam, around 450m; the second site is located at Al-Azza Bridge, and the distance between this site and the first is about 1500m; the third site is located after the river gets out of the A-Kut City (Fig. 1). Al-Dujaila River is one of the important sources for watering large areas of agricultural land **(Al-Barakat & Al-Saadi, 2023)**.

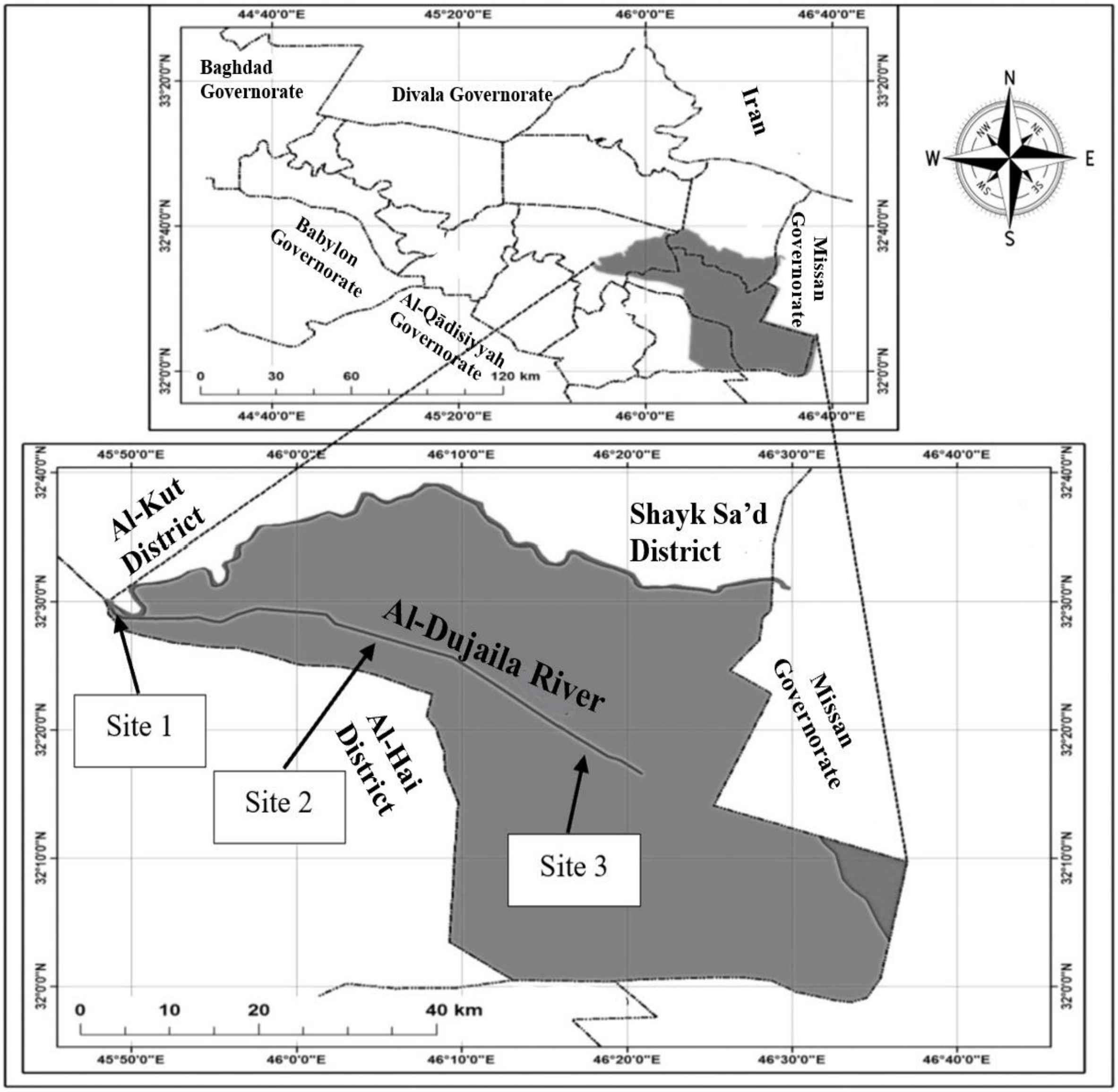


Fig. 1. Study sites

2- Sampling

The water samples were collected in a clean polyethene bottle during 2021. Ten parameters were chosen to evaluate the environmental status of the river. W.T. and pH were measured by using pH meter (WTW, Germany), DO by titration (4500-OC-Azide modification), BOD_5 (5210 B, 5-Day BOD Test/ Incubator/ JRAD), PO_4 (Spectrophotometer UV-1200), NO_3 and SO_4^{-2} (Multiparameter/ photolab S12), Cl (Titration), T.D.S (2540-C/ Oven/ solids dried at 180 ºC), and Turb (Turbidity meter/

Lovibond, Germany); all these parameters were analyzed according to the guidelines of **APHA (2017)**.

Nine parameters were chosen to calculate the water quality index. The dataset was split into two seasons (dry and wet) according to the two main seasons in Iraq based on the percent of humidity RH% (Table 1), where RH above 50% is considered a wet season, while less than 50 RH% is considered a dry season **(Aljanabi *et al.*, 2022)**. Therefore, January, February, November, December were considered as the wet season, while March, April, May, Jun, July, August, September, and October were the dry season.

Table 1. Percent of humidity (RH%) for the studied sites

RH %								
Wet	Jan-21	Feb-21	Nov-21	Dec-21				
	55	59	60	69				
Dry								
	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21
	41	31	25	22	21	24	27	34

3- Application of the Iqai water quality index (IQ-WQI)

The IQ-WQI was applied to discover the water quality of the Al-Dujaila River for different usages based on Iraqi Rriver maintaining criteria **(Law25, 1967)**. Nine parameters were chosen to run the index. The index was calculated as shown in equations 1- 4 according to the method of **Aljanabi *et al.* (2023a)**, and the rating is presented in Table (2).

$SI_i = final\ wight \times\ Q_i$……… Eq. 1

$Qi = \frac{C_i - C_{ideal}}{s_i - C_{ideal}} \times 100$ for pH and DO…. Eq. 2 (Cideal for DO= 14.6; Cideal for pH=7; Wi= final wight)

$Qi = \frac{C_i}{s_i} \times 100$ for other parameters……. Eq. 3

$IraqiWQI = \sum SI_i / Wi$………. Eq……. 4

Where, SIi= the sub-index of the ith parameter; Qi= quality rating based on the concentration of the ith parameter; Ci= the observed value of the nth parameter, and Si= the standard value of the nth parameter.

Table 2. Water quality rating **(Aljanabi *et al*., 2023)**

WQI value	**Rating**	
0-25	Excellent	Blue
26-50	Good	Green
51-75	poor	Yellow
76-100	very poor	Orange
Above 100	unsuitable	Red

4- Data analysis

The data of the current study were handled by Jeffreys's amazing statistics program statistical analysis (JASP) based on R programming language. Additionally, the principal component analysis (PCA), and Pearson's correlation were calculated. PCA is a statistical feature extraction approach that creates fewer independent variables from a mixture of the original parameters. PCA is used to identify the most relevant indicators in water samples, and it allows the presentation of gathered information and how it interacts **(Teixeira de Souza *et al*., 2021)**.

RESULTS

1- Water quality properties

Descriptive data of the water quality parameters for the current study are illustrated in Table (3), which shows the mean values and the standard deviation for all studied parameters. The data were visualized by raincloud plots, as shown in Figs. (2- 4), where 'rain' stands for the raw data, and the 'cloud' stands for the data distribution. Effective data visualisation combine the distribution of the data, individual data points, and summary statistics, such as median, mean (horizontal bars), standard error (boxplot) and appropriate confidence intervals in an appealing and flexible format with a minimal redundancy **(Allen *et al*., 2021)**.

Dissolved oxygen in Dujaila River ranged between 9.4- 1.3mg/ l (Fig. 2a), with an average value of 7.6mg/ l. DO is an important indicator for the health of any aquatic ecosystem; a high value (above 5mg/ l) indicates good conditions for the ecosystem, and vice versa **(Zhang *et al.*, 2023)**. In general, the availability of DO is controlled by many factors like water temperature, salinity (when they increased, the DO decreased), atmospheric pressure, and water current (when they increased, the DO increased) **(Lorenzo-González *et al.*, 2023)**, as exhibited in Table (2). The high value of DO was observed in the wet season at all sites, influenced by the decrease of water temperature (Fig. 2b).

Table 3. Descriptive analysis of physical and chemical parameters of Al-Dujaila River

	Site 1				**Site 2**				**Site 3**			
	Wet		Dry		Wet		Dry		Wet		Dry	
	mean	Sd	mean	Sd	mean	Sd	mean	Sd	mean	Sd	mean	Sd
W.T. (C°)	14.17	5.55	18.6	4.2	14.47	6.01	19.0	4.4	14.17	5.2	18.9	4.3
DO (mg/l)	8.42	1.31	7.45	0.64	7.55	1.21	6.98	0.62	8.41	1.30	7.60	0.69
BOD_5 (mg/l)	2.87	0.55	3.44	0.60	2.89	0.83	3.38	0.32	3.28	0.83	3.57	0.64
pH	7.77	0.23	7.6	0.13	7.92	0.27	7.90	0.42	8.03	0.26	7.85	0.27
PO_4 (mg/l)	0.32	0.06	0.29	0.04	0.33	0.05	0.31	0.04	0.36	0.02	0.29	0.07
NO_3 (mg/l)	5.60	1.47	5.55	1.54	5.38	1.66	5.81	1.58	6.60	0.57	6.33	1.23
Cl (mg/l)	139.16	11.43	128.50	10.73	138.65	13.46	128.78	8.94	137.85	8.53	130.64	10.39
SO_4^{-2} (mg/l)	279.00	38.97	252.13	57.41	286.75	47.97	263.00	59.67	301.75	53.59	257.75	60.78
T.D.S (mg/l)	889.50	148.04	775.25	104.49	920.00	186.01	782.50	89.66	915.00	143.00	786.25	124.14
Turb (NTU)	21.48	12.57	29.01	17.89	20.28	11.53	31.66	19.81	24.00	14.63	30.88	18.56

Biological oxygen demand ranged between 0.55 and 3.9mg/ l (Fig. 2c), with a mean value of 2.94mg/ l in wet and 3.46mg/ l in dry seasons. BOD_5 is an indicator of the presence of organic pollution in water using the microorganism action. The high mean value was observed in the dry season due to the increased temperature, which facilitated the degradation of organic compounds **(Prambudy *et al.*, 2019)**.

A high value of hydrogen ions (8.4) was recorded during the wet season at site 2 (Fig. 2d), and a low value (7.4) was detected in the dry season at site 3. pH can determine the safety of the aquatic system entirely. Many Iraqi researchers proved that the Iraqi's waters are alkaline to sub-alkaline **(Prambudy *et al.*, 2019; Mohammed *et al.*, 2021; Saod *et al.*, 2021)**. From Table (3), it was noticed that pH value in the dry season is less from the wet season; this is due to the decomposition of some phytoplankton and aquatic plants and the production of carbon dioxide and organic materials, and the increase in the pH in the wet season may be due to the rise in the water level due to rainfall and low temperatures, and this subsequently leads to an increase in the basal increase **(Abbas & Sharaq, 2022)**. Therefore, it can be assessed that Dujaila River has a high regulatory capacity.

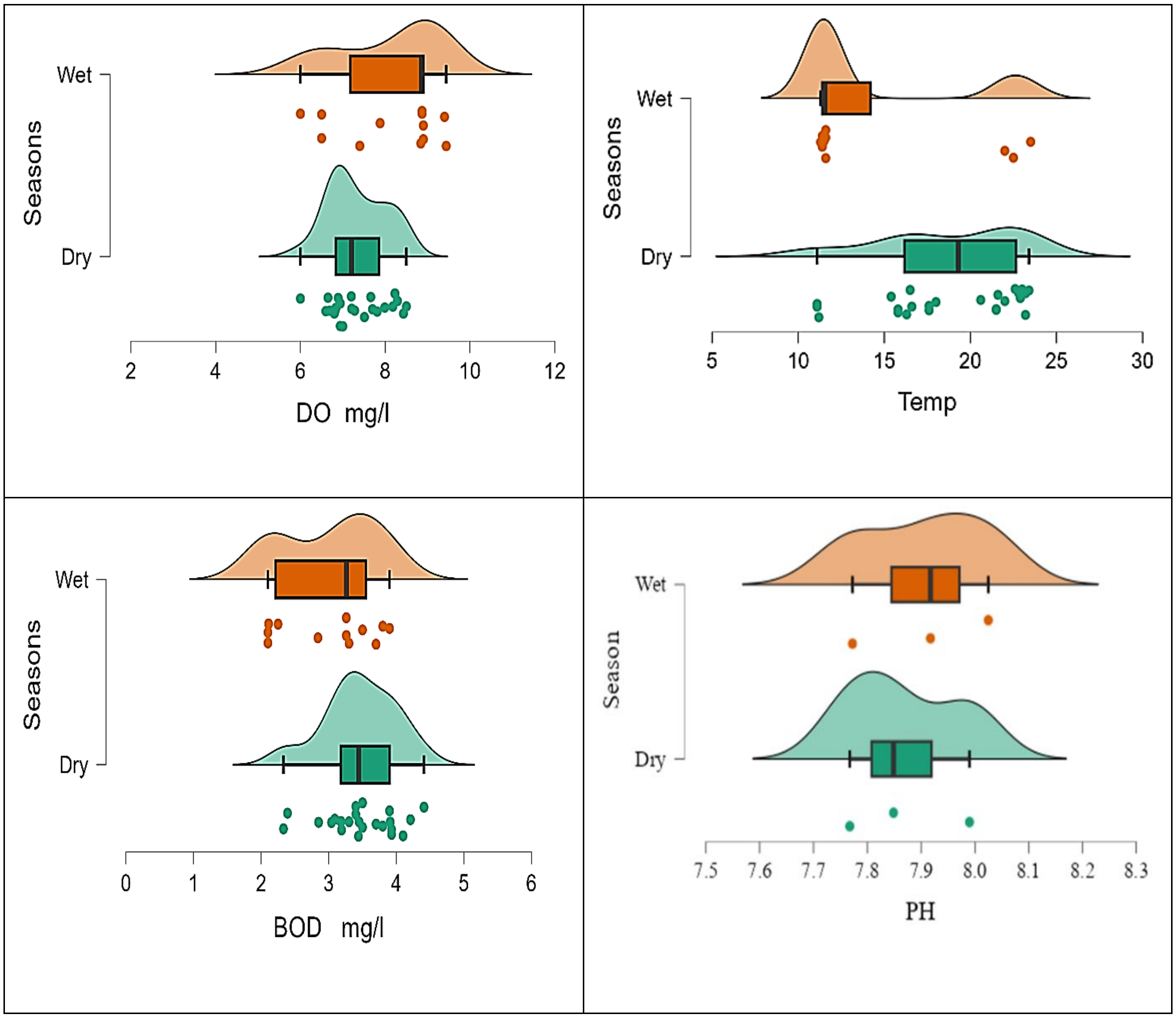


Fig. 2. The concentration of water quality parameters: **(a)** Dissolved oxygen, **(b)** Water temperature, **(c)** Biological oxygen demand$_5$, and **(d)** pH

The nutrient mean concentration raneged between 0.29 & 0.36mg/ l and 5.38-6.33mg/ l for PO_4 (Fig. 3a) and NO_3 (Fig, 3b), respectively. According to the standard values of Iraqi rivers as per **Law 25 (1967)**, the concentrations of PO4 and NO3 are within the acceptable limits. However, the concentration of $SO4^{2-}$(Fig. 3c) exceeded the limit during the study period, with the lowest concentration being 230mg/ l, recorded at site 1 and the highest concentration being 390mg/ l, recorded at site 2. The chloride concentration in this study was within the limits at all sites for the entire study, where the low mean value of 128.5mg/ l was recorded a site 1 during the dry season, and the high value of 193.16mg/ l was registered for site 1 during the wet season (Fig. 3d). The main sources of water pollution with chloride are irrigation water drains and domestic and industrial wastes **(Hong *et al.*, 2023)**.

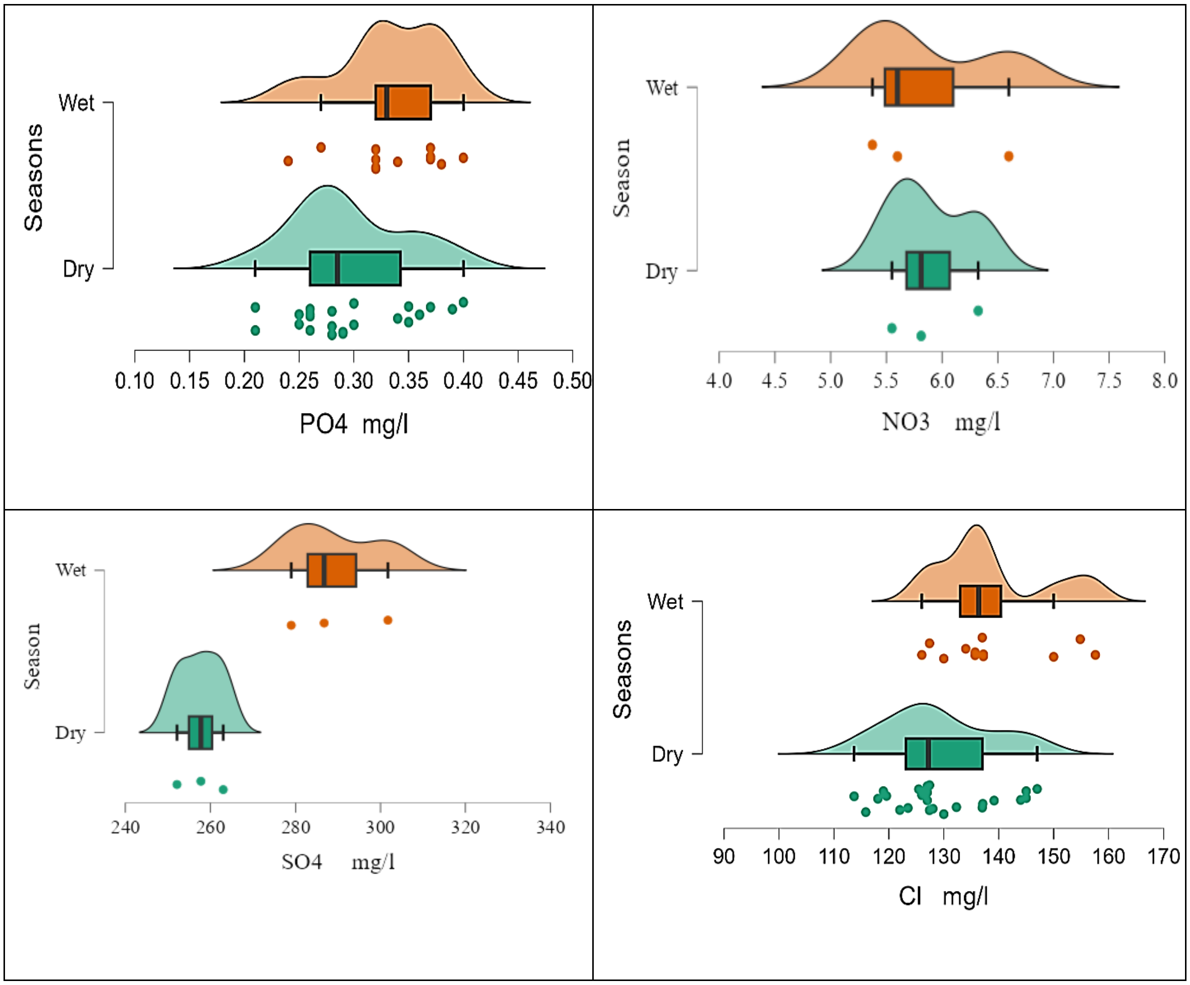


Fig. 3. The concentration of water quality parameters: **(a)** Phosphate, **(b)** Nitrate, **(c)** Sulphate, and **(d)** Chloride

The results of the current study showed apparent changes in the total dissolved solid, where the highest value of 920mg/ l was recorded in the wet season at site 2, and the lowest value was 775.25mg/ l at site 2 during the dry season (Fig. 4a). In general, the values in the wet season were higher than in the dry season at all sites, which may be related to the increase of rainfall and water level that led to the washing of the soil around the river bank, and eventually increased the ion concentration in water **(Duong *et al.*, 2019)**.

Turbidity results showed that the highest value was 70 NTU at site 2 during the dry season, and the lowest value was 8.7 NTU, where turbidity can be called a measure of how the water's color appears **(Zhu *et al.*, 2020)**. Table (3) illustrates the mean value of turbidity at all sites for both seasons; it can be seen that the mean values of turbidity in the dry season were higher than in the wet season (Fig. 4b). In technical terms, turbidity can be defined as a measurement of the amount of light that travels through water and is brought about by light-scattering suspended solid particles **(Sembel *et al.*, 2021)**. Turbidity of the water layer was also caused by the presence of suspended and dissolved particles, including organic matter, muck, microbes, clay, colloids, and floating items that did not settle right away. Turbidity affects fish respiration, photosynthesis, and productivity **(Risjani *et al.*, 2020)**.

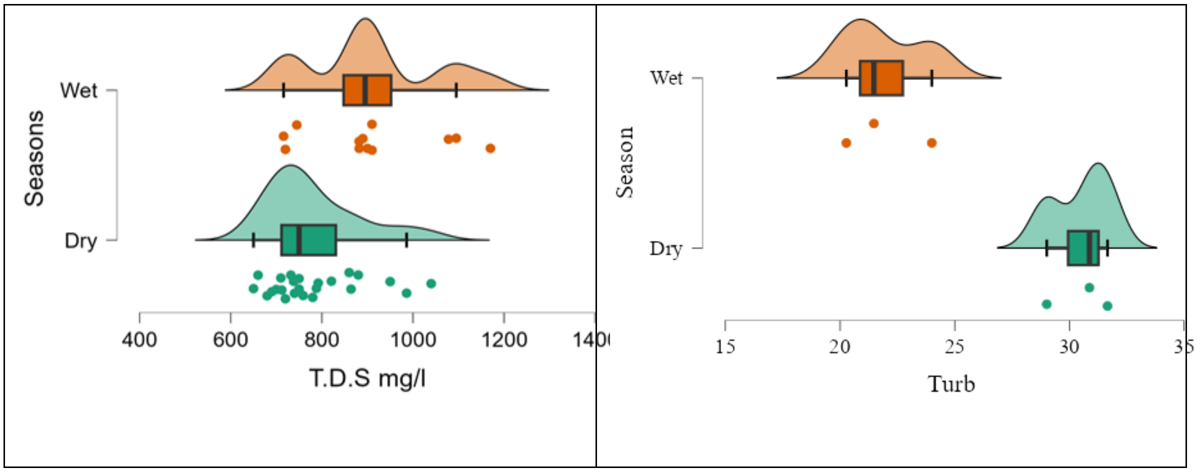


Fig. 4. The concentration of water quality parameters: **(a)** Total dissolved solid and **(b)** Turbidity

2- Iraqi water quality index (IQ-WQI)

Table (4) shows an example of index calculation. As seen from column four, the summation of final weight equals 1, indicating the correct calculation.

Table 4. Example xalculation of IQ-WQI.

Iraqi water quality index (IWQI)								
Parameter	**Mean rating returned by respondents**	**Temporary weight**	**Final weight**	**Observed value**	**Iraqi rivers maintaining limit**	**Qi=[Ci/Si]*100**	**SIi=RW*Qi**	**IWQI=∑SIi/Final weight**
DO	4.170	5.000	0.348	8.87	5.00	59.688	20.761	**78.88**
BOD	3.880	1.075	0.075	3.26	5.000	65.200	4.875	
pH	3.880	1.075	0.075	7.64	(6.5-8.5)	128.000	9.570	
PO_4	3.700	1.127	0.078	0.32	0.40	80.000	6.272	
NO_3^-	3.650	1.142	0.079	4.5	15.00	30.000	2.384	
Cl^-	3.460	1.205	0.084	137.2	200.00	68.600	5.751	
SO_4^{-2}	3.260	1.279	0.089	270	200.00	135.000	12.013	
TDS	3.760	1.109	0.0772	882	500.00*	176.400	13.609	
Turb.	3.060	1.363	0.095	19.2	50.00	38.400	3.640	
sum		**14.37**	**1.000**					

* only TDS standards were according to **Moran (2018)**.

The results of IQ-WQI for the freshwater at different sites and during various seasons for the current study are shown in Table (4), where nine parameters were used to calculate the index. All sites fall under very poor water quality. The values of the IQ-WQI ranged between 83.41– 89.48 in the wet season and 85.24– 91.13 in the dry season. This increase represented by the presence of pollutants from the agricultural drainage system and sewage effluent that's found along the AL-Dujailah River **(Al-Dabbas & Maiws, 2016)**. From Fig. (5), it can be noticed that, site 2 has the highest values in both seasons comparable to sites 1 and 3, and this may be returned to the effect of the city since site 2 is located in the middle of the Al-Kut City, reflecting the impact of the urban activity on the water quality of the river **(Al-Barakat & Al-Saadi, 2023)**. On the other hand, statistical analysis shows no significant differences between seasons. Still, it can be seen from Fig. (5) that there is a slight difference between the index values of wet and dry seasons, as the index values in the dry season were higher at all sites compared to sites during the wet season. This variation may be ascribed to the decrease of water level during the dry months since the increasing water temperature increases evaporation and eventually causes an accumulation of salts in water **(America *et al.*, 2020)**. The parameters exceeding the Iraqi rivers maintenance system **(Law25, 1967)** in both the dry and wet seasons were SO_4^{-2} and TDS concentrations **(Moran, 2018)**, consistently remaining beyond the limits, while turbidity exceeded the limit only in 3 months of the dry season. Hence, it is obvious that pollution caused by salinity in the Al-Dujaila River has resulted in water quality falling into the 'very poor' category.

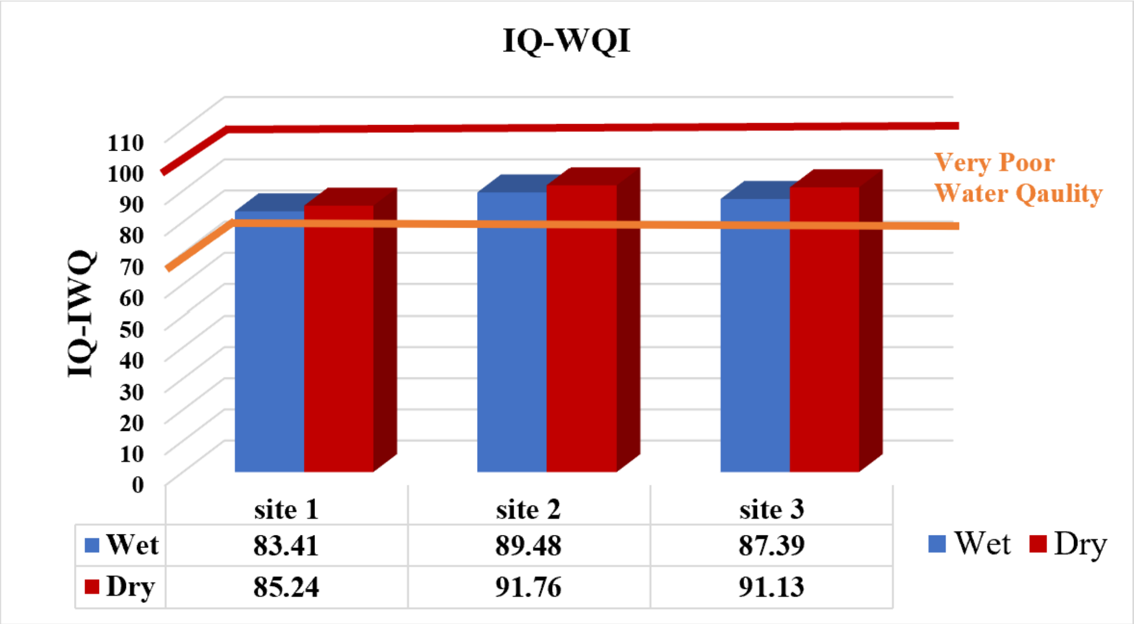


Fig. 5. The result of IQ-WQI

3- Principal component analysis (PCA) factor loadings

PCA was computed for the nine parameters from 3 sites on the AL-Dujailah River to determine the most critical parameters affecting water quality by determining the eigenvalues that give the highest degree of factor significance. Significant eigenvalues are those that are greater than 1.0 (Table 5). There are three classes of PC; weak (0.30-0.50), moderate (0.50- 0.75), and strong (> 0.75) **(Teixeira de Souza *et al.*, 2021)**.

Two components were extracted from the PCA, which facilitates the identification of pollution sources using water quality data. Fig. (6) illustrates this study's component loadings of the most significant parameters. The green color represents the positive loading, and the red color indicates negative loading, and the more the line gets thicker, the more the PC becomes close to 1.

The eigenvalue of the first PC1 was 5.918 and loaded heavily on turbidity, DO, SO_4^{-2}, TDS, PO_4, Cl, and BOD_5. A strong positive loadings ($P< 0.05$) of DO (r= 0.910), SO_4^{-2} (r= 0.839) TDS (r= 0.811) was observed. Moreover, moderate positive loading of Cl (r= 0.713) and BOD_5 (0.681) were observed, with strong negative loadings ($P< 0.05$) of turbidity (r=-0.949), and moderate positive loading of PO_4 (r= -723), as shown in Table (5). these parameters are considered the most important factor with the strongest impact.

Most parameters (TDS, PO_4, SO_4^{-2}, and Cl) show pollution by salinity **(Chabuk *et al.*, 2020)**, as the Al-Dujaila River is considered one of the essential sources for agricultural activities. In addition, this river's water source comes from the Tigris River, where many researchers agree in their studies that the Tigris River from the north of Baghdad to Basra has been experiencing serious problems with salinity and drainage **(Aljanabi *et al.*, 2023b).**

The eigenvalue of the second PC2 was accounted for 1.879, with a strong positive loading of NO_3 (r= 0.978) and pH (0.925), while Cl (r= 0.679), and BOD_5 (r=0.703) have moderate positive loading (Table 4). This component refers to the discharge of industrial and agricultural activities **(Akhtar *et al.*, 2021)**.

Table 5. Principal component analysis (PCA) of water quality parameters for the study

Component loadings			
	PC1	**PC2**	**Uniqueness**
Turb	-0.949		0.050
DO	0.910		0.168
SO_4^{-2}	0.839		0.293
T.D.S	0.811		0.014
PO4	-0.723		0.425

Component loadings

	PC1	PC2	Uniqueness
Cl	0.713	0.679	0.031
BOD	0.681	0.703	0.043
NO_3		0.978	0.043
pH		0.925	0.138

Note. Applied rotation method is varimax.

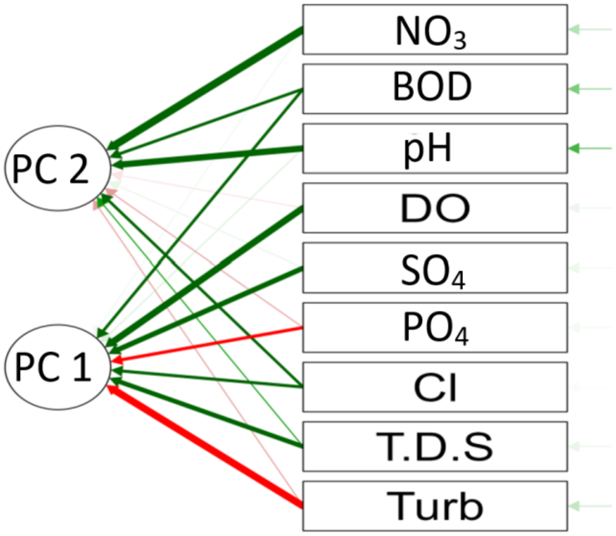
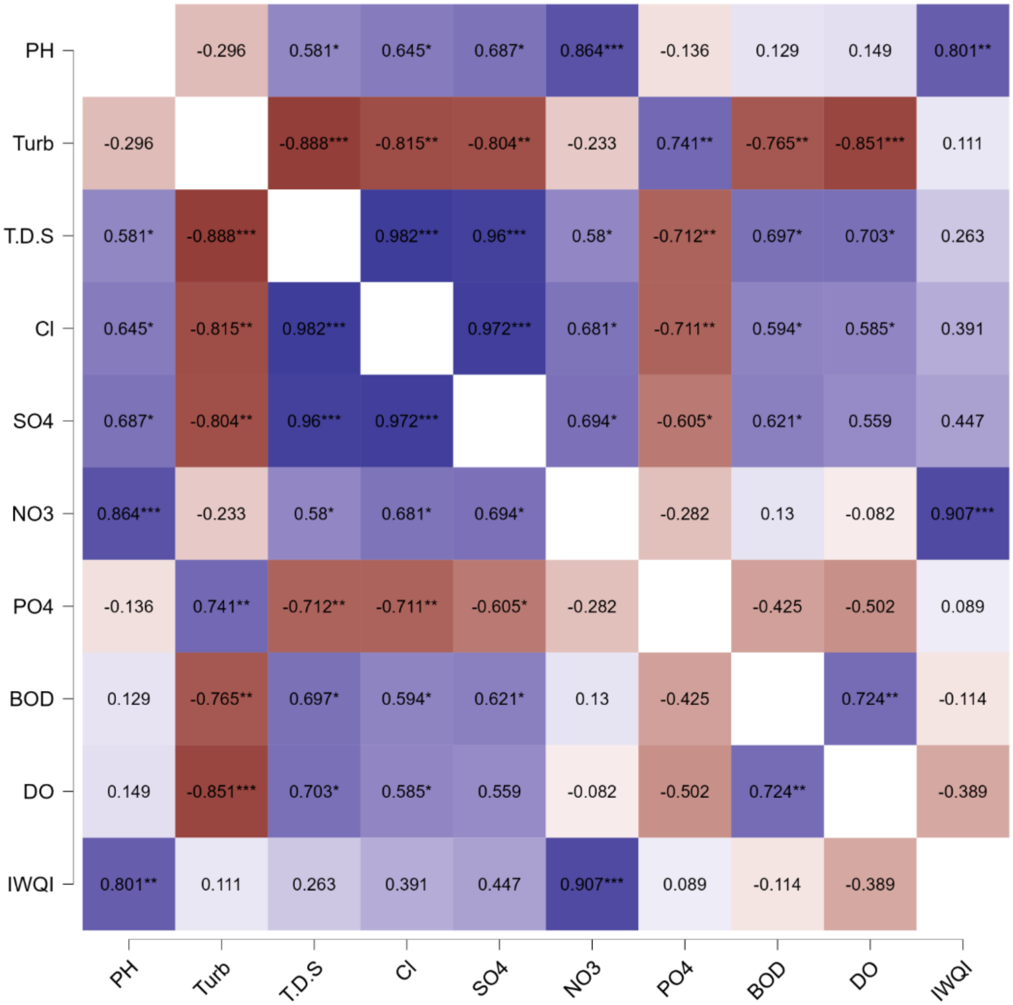


Fig. 6. Component loading of water quality parameters during the period of the study

1- Correlation matrix (Pearson)

This study could get a complete sense of the dataset, and subsequently evaluating the relationship between the environmental parameters. It can identify the parameters with greater significance (0.05 significance level). The correlation coefficient (r) ranges from +1 to −1. When r is close to +1, the association is considered strongly positively correlated. The relationship is demarcated as anticorrelated when the r-value is close to –1 (negative correlation). If the value of r tends to be zero, the reading is considered less correlated and uncorrelated **(Pobi *et al.*, 2019)**.

According to the Pearson coefficient, only those variables in the dataset with correlations of r = 0.6 are significant **(Sakaa *et al.*, 2020)**. Fig. (7) shows the correlation between physical and chemical parameters. The blue box shows a positive relationship; the red box shows a negative correlation, and the darker blue or red shows a strong correlation; only a few parameters exhibited statistically significant correlations, within physical and chemical parameters. There is a positive and significant correlation between water NO_3 and pH (r = +0.864), PO_4 and turbidity (r= +0.741). Moreover, TDS has strong positive and significant correlation with Cl and SO_4^{-2} (r= +0.982), (r= +0.96), respectively. Additionally, Cl also has a strong and positive correlation with each of SO_4^{-2} and NO_3 (r= + 0.972) (r=+ 0.681) respectively, and there is a positive correlation between NO_3 and SO_4^{-2} (0.694). All these parameter correlated with each other since they all represented the summation of ion and cation of salinity, indicating the increase in agricultural and domestic runoffs along the river nowadays **(Chabuk *et al.*, 2020)**. On the other hand, TDS has a strong and negative correlation with turbidity (r= - 0.888) since turbidity is related or caused by total suspended solid rather than total dissolved solid **(Adjovu *et al.*, 2023)**. Moreover, turbidity has a negative correlation with DO and BOD_5 (r=- 0.851) (r= - 0.765), where DO and BOD_5 are affected by salts more than debris in water **(Xu, 2022)**.



	PH	Turb	T.D.S	Cl	SO4	NO3	PO4	BOD	DO	IWQI
PH		-0.296	0.581*	0.645*	0.687*	0.864***	-0.136	0.129	0.149	0.801**
Turb	-0.296		-0.888***	-0.815**	-0.804**	-0.233	0.741**	-0.765**	-0.851***	0.111
T.D.S	0.581*	-0.888***		0.982***	0.96***	0.58*	-0.712**	0.697*	0.703*	0.263
Cl	0.645*	-0.815**	0.982***		0.972***	0.681*	-0.711**	0.594*	0.585*	0.391
SO4	0.687*	-0.804**	0.96***	0.972***		0.694*	-0.605*	0.621*	0.559	0.447
NO3	0.864***	-0.233	0.58*	0.681*	0.694*		-0.282	0.13	-0.082	0.907***
PO4	-0.136	0.741**	-0.712**	-0.711**	-0.605*	-0.282		-0.425	-0.502	0.089
BOD	0.129	-0.765**	0.697*	0.594*	0.621*	0.13	-0.425		0.724**	-0.114
DO	0.149	-0.851***	0.703*	0.585*	0.559	-0.082	-0.502	0.724**		-0.389
IWQI	0.801**	0.111	0.263	0.391	0.447	0.907***	0.089	-0.114	-0.389	

Fig. 7. Pearson's correlation heatmap for the data of the study

CONCLUSION

It is widely acknowledged that natural and man-made activities contribute to rising water pollution levels in Iraq's surface waters of rivers, and negatively affecting aquatic life and public health. Therefore, the main objective of this study was to assess the natural status of the Al-Dujaila River in Al-kut City using the water quality index. WQI is an easy method that provides a single number for water's chemical and physical characteristics, also known as variables, in order to effectively and sufficiently represent water quality. It was concluded that the deterioration in the river's water quality at all sites during the study period was traced back to the increased levels of salinity, with TDS and SO_4^{-2} being responsible for shifting the index value toward 'poor water quality' category. Thus, strategies are needed to minimize environmental impacts and manage the ecological-economic impact since the river is considered a vital water source for irrigation. In addition, further studies should be undertaken to examine the water quality's impact on the environment and aquatic organisms.

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