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Applying Water Quality Index Technique to Estimate the Euphrates River Suitability for different uses in Samawa and Nasiriya, Southern Iraq

Marwa M. Hussein*, Moutaz A. Al- Dabbas
Geology Department, Collage of Science, University of Baghdad, Baghdad, Iraq

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Abstract

Water salinity assessment is fundamental to the management of water resources. The objective of this research is to calculate the water quality index of the Euphrates River by using mathematical methods. As well as to evaluate the water for various uses by estimating the inorganic pollution in the river water in two sites: Samawa and Nasiriya sites. Based on physiochemical characteristics such as pH, TDS, EC, and concentrations of the major ions of calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), sulphate (SO_4^{2-}) and Chloride (Cl^{-}), bicarbonate ions (HCO_3^{-}), and minor elements of nitrate (NO_3^{2-}) and total hardness (TH) were applied in this research for the period from the year 2005 to 2021. The results showed that the predominant ions are SO_4^{2-} and Ca^{2+} ions in Samawa, while in Nasiriya, the predominant ion are Mg^{2+} and SO_4^{2-} ions. According to international and Iraqi standards, the results indicated that water at these two sites along the Euphrates River are unsuitable for drinking. It is low alkalinity and very hard water. Although, the water at these two sites is moderate saline and very good for livestock uses and of doubtful water class, based on Todd's method of Na % for irrigation water.

Keywords: Water suitability; major ions; WQI; Samawa and Nasiriya sites; Euphrates River.

استخدام تقنية مؤشر جودة المياه لتقييم جودة مياه نـهر الفرات لاستخدامات مختلفة في السماوة والناصرية- جنوب العراق

مروة محمد حسين*, معتز عبد الستار الدباس
علم الارض ، كلية العلوم, جامعة بغداد, بغداد, العراق

الخلاصة

يعتبر تقييم ملوحة المياه أمرًا أساسيًا لإدارة موارد المياه. الهدف الرئيسي من هذا البحث هو حساب مؤشر جودة المياه (WQI) لنهر الفرات باستخدام الطرق الحسابية ، وتقدير كمية التلوث الكيميائي لمياه النهر لتقييم استخدامات المياه للشرب في محطتي قياس: السماوة والناصرية. بناءً على الخصائص الفيزيائية والكيميائية مثل الأس الهيدروجيني والملوحة مثل TDS و EC وتركيزات أيونات الكالسيوم الرئيسية (Ca^{2+}) والصوديوم (Na^{+}) والمغنيسيوم (Mg^{2+}) والبوتاسيوم (K^{+}) والكبريتات (SO_4^{2-}) والكلوريد (Cl^{-}) ، وأيونات البيكربونات (HCO_3^{-}) ، وعناصر ثانوية من النترات (NO_3^{2-}) والصلابة الكلية (TH) في هذا البحث للفترة من عام 2005 إلى 2021. وأظهرت النتائج أن الأيونات السائدة هي SO_4^{2-}وأيونات Ca^{2+} في السماوة ، بينما في الناصرية الأيونات السائدة هي Mg^{2+} وأيونات $SO4^{2-}$ ، وقد أشارت النتائج إلى أن المياه في هذين الموقعين على طول

*Email: Marwamuhammed90@yahoo.com

نهر الفرات غير صالحة للشرب وفقًا للمعايير الدولية والعراقية ، فهي ذات قلوية منخفضة وماء عسر للغاية. على الرغم من أن المياه في هذين الموقعين معتدلة الملوحة وجيدة جدًا للاستخدامات الحيوانية وفئة المياه المشكوك فيها ، بناءً على طريقة Todd لـ Na٪ لمياه الري.

1. Introduction

Water quality is vital for all beings and life continuation [1]. Increasing surface water pollution due to wastewater and farm waste will affect surface water suitability worldwide [2]. Many scientists have substituted the traditional procedure for describing water quality by using specific water body characteristics (with mathematical formulas), which can be used to describe water quality [3 and 4]. The new procedure is the Water Quality Index (WQI), which uses a mathematical formula to reduce a large amount of data to a single number in an objective and reproducible manner. WQI can describe, in one word or number, the elusive entity known as water quality which therefore represents the integrated effect of the concentration and the importance of the relevant parameter in water use [3 and 4]. WQI is a single value indicator of the water quality determined through summarising multiple parameters of water test results in a simple term for management and decision-makers. Several indices have been developed to summarise water quality data in an expressible and easily understood format. As a synthetic indicator, WQI provides overall summaries of water quality and potential trends on a simple and scientific basis [3 and 4]. These indexes use various numbers of water quality parameters. For example, [5] proposed a WQI formula that used seven water quality parameters (TDS, total hardness, pH, DO, biochemical oxygen demand (BOD), nitrate (NO_3), and phosphate) to evaluate water quality in the Tigris and Euphrates rivers in Iraq. Terrado et al. [6] presented a detailed review and classification of WQI methods. The National Water Quality Standards (NWQS) defined six classes (I, IIA, IIB, III, IV, and V) for river water classification based on the descending order of water quality, i.e., Class I being the “best” and Class V being the “worst” water quality [7]. In this study, [8] classification is chosen because it is realistic, simple and easy. The problem of salinity in the Euphrates River is evident after the Hindiya Barrage, and it tends to reduce the river’s discharge, which reaches low rates, as it contributed to the rising of the pollutants concentration and salts [9]. This situation is damaging economic practices in the Euphrates basin in general and to biodiversity in particular [10 and 11]. This problem caused the suffering of more than four Million people in the Muthanna, Diwaniyah and Dhi Qar governorates [12].

The current study aims to calculate the WQI for Euphrates water by knowing the physical and chemical properties and estimating the amount of chemical pollution of the river water in two sites: Samawa and Nasiriya; (Figure 1).

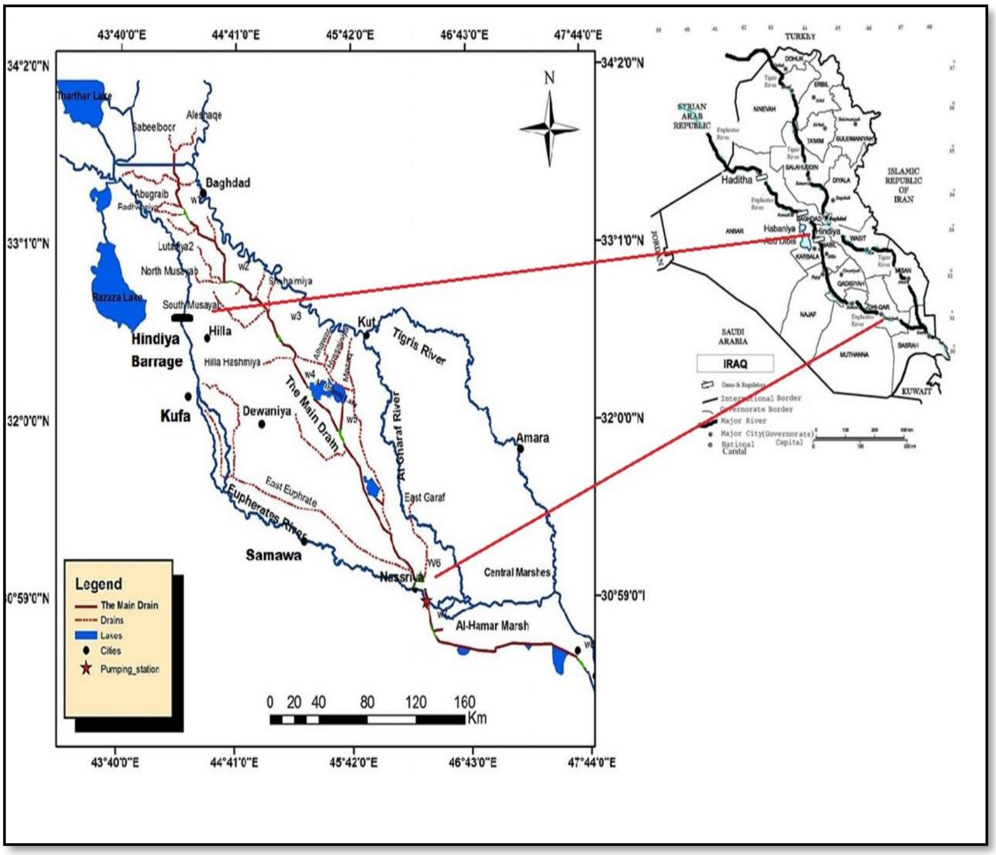

Figure 1: The study area of the Euphrates River reaches from Samawa to Nasiriya [16].

2. Material and Methods

The study sites are located on the Euphrates River course within the coordinates between 31°19′00″N 45°17′00″E and 31°03′14″N 46°16′00″E Samawa and Nasiriya, respectively (Figure 1). The physiochemical parameters of the Euphrates River such as TDS, EC, pH and TH, the main ions Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, and minor elements nutrient as NO_3^{2-} were analysed in the laboratory of the National Centre for Water Resources Management, Ministry of Water Resources [13]. The physical parameters are measured by a field electrode meter. Moreover, the obtained data analysed and tested independence, stationariness, and homogeneity. These data were used to develop connections between water discharge (m^3/sec) and total dissolved solids (mg/l) and main ions (mg/l) such as major cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) and anions (Cl, SO_4^{2-}, HCO_3^-) in the Euphrates River water. The hydrochemical analysis of water was done following the international methods of analyses, according to APHA, 1999 methods of hydrochemical analyses [14 and 15]. The plots reveal an inverse relationship between the rise in water salinity and the decrease in discharge.

To get an entire idea about the water quality of the river in Samawa and Nasiriya sites from 2005 to 2021 and to compare the range and average of these parameters with many classifications for identifying the suitability of the Euphrates River for different uses (drinking, livestock and irrigation water), the WQI [14] was determined using mathematical methods (Table 1).

Calculation WQI includes three steps. The first is to calculate a specific weight assigned to the chemical parameter that plays an essential role in water quality for drinking purposes. For example, the Nitrate parameter plays a major role in groundwater quality more than other parameters such as sulphate, pH, TDS, Mg, and Na, assigned lesser weight than NO_3^- parameter because they are not harmful to water quality for drinking purposes. Second step includes calculating the relative weight (Wr) as the following equation:

$$Wr = wi / \sum_{n=1}^{n} wi \quad \text{------------(1)}$$

Where:
Wr: is the relative weight,
Wi: is the weight of each parameter,
n: is the number of parameters.
The values of Wr of each parameter are given in Table (1).

The third step includes calculating the quality rating scale (qi) for each parameter assigned by dividing its concentration in each sample by its respective standard according to the guidelines laid down. WHO and the Iraqi standard are illustrated in Table (1)
In order to find the quality rating, the result multiplied by 100

$$qi = (Ci / Si) *100 \quad \text{-------(2)}$$

Where :
qi : is the quality rating,
Ci: the concentration of each parameter in each water sample.
Si : is the Iraqi standard for drinking purpose.
Finally, to compute WQI, the sub-index Sli should be determined first for each chemical parameter in order to be used later for determining the WQI as the following equation:

$$Sli = Wr * qi \quad \text{-------------(3)}$$

$$WQI = \sum Sli \quad \text{-------------(4)}$$

Sli : is the sub-index of the parameter.
Wr: is the relative weight based on the concentration of each parameter, n: is the number of parameters.

Table 1: International and Iraqi standards, weight and relative weight for each parameter [14].

Chemical parameter (mg/l)	Si Iraqi standard (2009)	WHO Standard (2008)	Weight (wi)	Relative weight (Wr)
pH	6.5-8.5	7-8	4	0.1212
TDS	1000	1000	4	0.1212
TH	500	100-500	2	0.0606
Ca^{2+}	100	75-200	2	0.0606
Mg^{2+}	50	30-150	2	0.0606
Na^{+}	200	200	2	0.0606
k^{+}		12	2	0.0606
Cl^{-}	250	250	3	0.0909
SO_4^{2-}	250	250	4	0.1212
HCO_3^{-}	-	200	3	0.0909
NO_3^{-}	50	50	5	0.1515
Total			∑wi= 33	∑ = 0.99

3. Discussing the Results

The range and average of the results of the analysis are given in Table 2.

Table 2. The average ranges for each component of the study area for years from 2005 to 2021.

Components for the period 2005 to 2021		Samawa site		Nasiriya site	
		Range	Average	Range	Average
Physical properties	pH	7.03-8.8	7.74	6.5-8.5	7.79
	TH	610-1740	937.5	808-2080	996
	TDS ppm	1495-3900	2434.2	1545-5805	2773.5
	EC ds/m	2.05-7.88	3.78	1.13-8.92	4.12
Major cations	Ca^{2+} mg/l	70-274	153.1	16-300	144.9
	Mg^{2+} mg/l	64.8-254	140.5	36-312	149.5
	Na^{+} mg/l	182-1065	478.1	168-1329	541
	K^{+} mg/l	6-17.8	11.5	5.5-21	12.1
Major anions	Cl^{-} mg/l	238-1832	692.8	107-1853	747.62
	SO_4^{2-} mg/l	518.4-1363	845.81	297.6-1968	910.25
	CO_3^{-} mg/l	3-18	10.06	3-26	12.8
	HCO_3^{-} mg/l	109.8-226	170.03	109.8-226	168.5
Minor Ions	NO_3^{2-} mg/l	0.2-27.3	8.5	1-30	8.27

3.1 Accuracy

The results' accuracy of the analysed sample of the water may be reflected by the reaction error test results (U) [3, 4 and 15]. The results of accuracy of surface water in the Samawa and Nasiriya for the period (2005-2021) are certain according to [16]; (Table 4).

Table 3. The accuracy method depends on [16].

U	A	Class or type
U ≤ 5 %	A ≥ 95 %	Certain
10 % ≥ U > 5 %	90 % ≤ A < 95 %	Probable certain
U > 10 %	A < 90	Uncertain

Determination of accuracy is as a following:

$r \sum Cation = r K + r Na + r Mg + r Ca$

$r \sum Anion = r HCO_3 + r SO_4 + r Cl + r NO_3$

$| \Delta = |r \sum Cation - \sum Anion$

$S = r \sum Cation + \sum Anion$

$U\% = (\Delta/S) * 100$

$A = 100 - U$

Where: U = (uncertainty) or reaction error, A = Accuracy

Table 4: Accuracy of chemical analysis of the Euphrates Rivers water samples for the study area for (2005– 2021).

	Samawa site	Nasiriya site
epm Ca^{2+}	7.5	6.9
epm Mg^{2+}	11.5	11.4
epm Na^{+}	20.7	22.3
epmK^{+}	0.29	0.31
epm SO_4^{-}	17.6	18.3
epm Cl^{-}	19.5	19.1
epm HCO_3^{-}	2.78	2.68
epm NO_3^{-}	0.33	0.11
Sum of cation	40.1	40.9
Sum of anion	40.4	40.6
Δ	0.33	0.32
S	80.5	81.6
U	0.41	1.79
A	99.5	98.5
Class or type	Certain	Certain

3.2 Water quality index

According to [14], the WQI of the Euphrates river in Samawa and Nasiriya sites for 2005 to 2021 are 180.7 and 194.8, respectively[14].

After comparing the WQI in the present study with the Iraqi Standard (2009), Samawa and Nasiriya's water quality is poor for drinking (Table 6).

Table 5: The value of Sli and WQI for each parameter in the study area.

Parameters	Samawa	Nasiriya
	Sli= Wr * qi	Sli= Wr * qi
TDS	29.7	33.4
PH	17.45	19.21
TH	11.38	12.12
Ca^{2+}	8.68	8.81
Mg^{2+}	16.84	18.10
Na^{+}	14.73	16.27
K^{+}	5.74	6.19
Cl^{-}	24.71	26.7
SO_4^{2-}	41.17	43.65
HCO_3^{-}	7.73	7.77
NO_3	2.58	2.44
WQI=∑Sli	180.755	194.81

Table 6: Water quality classification according to the WQI values [14].

WQI value	class	Water quality	Water quality classification
≤50	I	Excellent	
50-100	II	Good water	
100- 200	III	Poor water	Samawa and Nasiriya
200- 300	IV	Very poor water	
≥ 300	V	unsuitable water	

3.3 physical properties

3.3.1 *Calcium Ion Ca^{2+}*

The Calcium ion is one of the most common cations in water [20]. Calcium Annual average values of the Euphrates River for the period (2005-2021) range between 70 and 274 ppm with a mean value of 153.1ppm in Samawa station while ranging between 16 and 300 ppm with a mean value of 144.9 ppm in Nasiriya station. The Ca^{2+} concentration along the Euphrates River in the Samawa site is dominated (Table 2).

3.3.2 *Magnesium Ion Mg^{2+}*

The Mg^{2+} concentration varies from 64.8 to 254 ppm with a mean value of 140.5 ppm and 36 to 312 ppm with a mean value of 149.5 ppm in Samawa and Nasiriya sites, respectively. The Mg^{2+} concentration along the Euphrates River in the Nasiriya site is dominated (Table 2).

3.3.3 *Sodium Ion Na^{+}*

Na^{+} concentrations vary from 182 to 1065 ppm with a mean value of 478.1 ppm and between 168 and 1329 ppm with a mean value of 541 ppm in both stations Samawa and Nasiriya sites, respectively. In general, sodium ions are responsible for the deterioration of water quality, the result of the increase in the presence of sodium salts in the feeding areas through agricultural areas, the evaporation, and the releasing of untreated wastewater from different anthropogenic sources directly into the river (Table 2).

3.3.4 *Potassium Ion K^{+}*

The range and average potassium ion in the Euphrates River for the period (2005-2021) are 6-17.8 ppm with a mean value of 11.5 ppm and 5.5-21 ppm with a mean value of 12.1 ppm in the Samawa and Nasiriya sites, respectively; (Table 2).

3.3.5 *Chloride Ion Cl^{-}*

The range and average chloride ions (Cl^{-}) concentration of the Euphrates River in Samawa was 238-1832 ppm with a mean value of 692.8 ppm, and the concentration of chloride ions in Nasiriya was 107-1853 ppm with a mean value of 747.62 ppm; (Table 2).

3.3.6 *Sulfates Ions SO_4^{2-}*

The range and average of sulfates ion (SO_4^{2-}) concentration of the Euphrates River in Samawa and Nasiriya sites (2005– 2021) are 518.4-1363 ppm with a mean of 845.81 and 297.6-1968 ppm with a mean of 910.25 ppm respectively (Table 2).

3.3.7 *Bicarbonate Ion (HCO_3^{-}), (CO_3^{2-})*

The range and average of the (CO_3^{-}), (HCO_3^{-}) concentration of the Euphrates River in Samawa are 3-18 ppm with a mean value of 10.06 ppm and 109.8-226 ppm with a mean of 170.03 ppm, while in Nasiriya, the range and average concentration of CO_3 and HCO_3 3-26 ppm with mean 12.8 ppm and 109.8-226 ppm with mean 168.5 ppm respectively; (Table 2).

3.3.8 *Minor elements: Nitrate (NO_3^-)*

The nitrate ion concentrations of the river water in the study area for the period (2005-2021) are 0.2-27.3 ppm with a mean value of 8.5 ppm and 1-30 ppm with a mean of 8.27 ppm in the Samawa and Nasiriya sites, respectively [23]; (Table 2).

4. *Suitability of Euphrates river water for different uses*

4.1 *Water assessment for drinking*

Drinking water standards (WHO, 2008) [18] and Iraqi Standard (2009) [17] are used as a basis for the water quality evaluation of the present study. The average study area for the period (2005- 2021) are compared with the Iraqi quality standard IQS (2009) and World Health Organization Standard WHO (2008) to determine its suitability as drinking water in the study area; (Table 9). Generally, the surface water in Samawa and Nasiriya sites is unsuitable for drinking and not within the standard quality criteria for most physiochemical parameters; (Table 7).

Table 7: Classifications of drinking water quality according to [17, 18] in Samawa and Nasiriya sites for (2005– 2021).

Components	Iraqi Standard 2009 [17] (ppm)	WHO Standard 2008 [18] (ppm)
pH	6.5-8.5	7-8
EC	1500	1530
TDS	1000	1000
TH	500	100-500
Ca^{2+}	100	75-200
Mg^{2+}	50	30-150
Na^+	200	200
K^+	-	12
Cl^-	350	250
SO_4^{2-}	400	250
HCO_3^-	-	-
NO_3^-	50	50

4.2 *Evaluation of water quality for livestock purposes*

According to [24], all surface water samples in the study area are very good for livestock drinking, as illustrated in Table 8.

Table 8. Classification of livestock water [24] for Samawa and Nasiriya sites for (2005- 2021).

Elements	Very Good water (ppm)	Good Water (ppm)	Permi (ppm)	Can be used (ppm)	threshold
Na^+ (mg/l)	800	1500	2000	2500	4000
Ca^{2+}(mg/l)	350	700	800	900	1000
Mg^{2+}(mg/l)	150	350	500	600	700
Cl^-(mg/l)	900	2000	3000	4000	6000
SO_4^{2-}(mg/l)	1000	2500	3000	4000	6000
TDS (ppm)	3000	5000	7000	10000	15000
TH	1500	3200	4000	4700	54000

4.3 *Evaluation of water quality for irrigation purposes*
FAO [25] and [22] classifications are used as a basis for the water quality evaluation of irrigation water.

4.3.1 *Salinity*
The surface water for both studied sites at the Euphrates river is moderate saline type according to salinity by FAO classification; (Table 9).

Table 9: Classification of irrigation water according to salinity [25].

Water class	EC ds/m	TDS (mg/l)	Type of water
Non- Saline	< 0.7	< 500	Drinking and irrigation water
Slightly Saline	0.7-2	500-1500	Irrigation water
Moderate Saline	2-10	1500-7000	Primary drainage water and groundwater
Highly Saline	10-25	7000-15000	Secondary drainage water and groundwater
Very highly Saline	25-45	15000-35000	Very Saline groundwater
Brine	> 45	> 35000	Sea water

4.3.2 *Percent Sodium, Na%*
It approximates the sodium hazard of irrigation water; it expresses sodium out of the total cations. Na% is calculated by the following formula [26]:

$$\text{Na\%} = \frac{(Na+K)}{(Ca+Mg+Na+K)} * 100$$

The River water samples indicate (doubtful) irrigation water class for both Samawa and Nasiriya sites, Na% is 61.04 and 64.4 respectively by [22] classification; (Table 10).

Table 10: Classification of irrigation water based on Na % depending on [22].

Water class	Na%	Ec µ/cm
Excellent	<20	< 250
Good	20-40	250-750
Permissible	40-60	750-2000
doubtful	60-80	2000-3000
Unsuitable	>80	> 3000

4.3.3 *Sodium Adsorption Ratio (SAR)*
The SAR was computed by using the expression developed by [22] as:
$SAR = rNa / [r(Ca+Mg)/2]^{0.5}$
Based on Todd classification, all of the River water samples for excellent water class of both stations, in which SAR < 10.0, SAR (6.5 and 6.8) in Samawa and Nasiriya sites respectively; (Table 11).

Table 11: Classification of irrigation water based on SAR values depends on [22].

SAR	Water class	SAR in study area	
<10	Excellent	Samawa site	Nasiriya site
10-18	Good	6.5	6.8
18-26	Fair	Excellent water class	Excellent water class
>26	poor		

5. Conclusions

- The WQI is affected by climate change (Temperature) that increases over the years from 1980 to 2021. Because decreased rainfall over these years will decrease discharge and increase TDS and all major cations and anions, the average annual temperature values in Samawa and Nasiriya sites were 23.6 C^o and 33.4 C^o, respectively.
- The water quality index in the study area, according to [14], is 180.7 in Samawa and 194.8 in Nasiriya. Therefore, the Euphrates water classification in both stations of the study area was poor water for drinking.
- The pH values of all water samples in the study area are generally low alkalinity, ranging between (7.03 and 808), with an average of 7.74 in Samawa and in Nasiriya ranging from (6.5 to 8.5), with an average of 7.79.
- The average value of TDS in Samawa is 2434.2 ppm, whereas in Nasiriya, the average is 2773.5 ppm. Therefore the classification of Euphrates River water according to [20] is considered (brackish water) and, depending on [21], considered (salty water).
- The results show that the predominant cation is Ca^{2+} ion in Samawa, while Mg^{+2} is predominant in Nasiriya, and anions are SO_4^{2-} in both sites.
- All samples in the river are very hard. The average (TH) values concentration of the river water samples (2005– 2021) in the Samawa site is 937.5 ppm, while in Nasiriya station is 996 ppm.
- After comparing the results in the present study with the standards of different uses [14, 20,21, 17, 18, 24, and 25], water in both sites is unsuitable for drinking, very good for livestock use, moderate saline, brackish water and salt water.
- According to [22], based on sodium, Na% in the classification of irrigation water, the results reflect that the river water samples indicate doubtful irrigation water class for both Samawa and Nasiriya sites, Na% is (61.04) in Samawa while in Nasiriya Na% was (64.4).

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