Hydrochemical Assessment of Tigris River for Irrigation Purposes within Baghdad Province, Iraq

Aqeel Khaleel Ibraheem[1] and Osama S. Majeed[2]

[1]*Babylon Education Directorate, Ministry of Education, Iraq*
[2]*Directorate of Third Karkh, Ministry of Education, Baghdad, Iraq*

KEYWORDS

Kelly’s index, Na%, Sodium Hazard, Piper diagram, USSL diagram, Wilcox diagram

ABSTRACT

The aims of this study are (1) to determine whether Tigris River water is suitable for irrigation using specific irrigation indices. (2) Analysis of thirteen hydrochemical parameters, including pH, EC, TDS, , , , , , , , , TA and as total hardness. Also, seven irrigation water quality indices were used: Magnesium Hazard (MH), Kelly's Index (KI), Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Soluble Sodium Percentage (SSP), Potential Salinity (PS), and Sodium Hazard (SH), supported by the most specific irrigation diagrams (Piper, USSL and Wilcox). Samples were taken monthly from twelve different sites along the river for two consecutive years (2021-2022). The results revealed that the water is suitable for irrigation chemically according to SAR, Na%, SSP, KI, and MH, except for PS due to high levels of sulfate and chloride ions. Furthermore, the USSL diagram indicated Irrigation water quality, that 100% of water samples taken from the Tigris fell into the appropriate class within 2021. While in 2022, 83.33% of samples were within the appropriate class (C3-S1). According to the Wilcox diagram, 91.66% and 83.33% among the water samples within a good class (low sodium and moderate salinity) for two consecutive years

1. Introduction

Tigris River has great importance for Iraqi agriculture. It is the main river that supplies agricultural areas with water needed for irrigated uses. Most farming and agricultural areas within the Baghdad region depend on water withdrawal through irrigation canals [1]. In Iraq, numerous irrigation projects were constructed along the river, depending on pumping or gravity flow [2, 3, 4]. It is well known that irrigation is essential to the agricultural production in the southern and central parts of Iraq. Within these regions, the majority of the population depends on water supplies from projects for irrigation the crops, watering the livestock and for domestic use [5].

High salinity water is poisonous to plants and poses a salinity hazard. High total salinity soils are referred to as saline soils. Increasing the soil's salinity levels by irrigating with saline water causes a decrease in water absorption by growing plants. A high salt content raises the osmotic pressure of soil water and prevents the roots from taking water. This results in a physiological drought condition. Even though the field appears to have plenty of moisture, the plants may wilt because the roots do not absorb enough water to replace water lost from transpiration [6, 7, 8, 9].

Numerous water quality indices can be used to evaluate the quality of irrigation water that are widely utilized globally. These include: Salinity Hazard (SH), Sodium Percentage (Na%), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Kelly’s Index (KI), and Potential Salinity (PS) [10]. As well as, Numerous diagrammatic and graphical methods can be applied to depict the hydrochemical properties of water destined for irrigation usage [11, 12, 13]. The widely-used United States Salinity Laboratory (USSL) water quality classification system for agricultural production applications, which draws solely on electrical conductivity (EC) and sodium adsorption ratio (SAR). A significant factor in assessing whether water is suitable for irrigation is its sodium percentage. Soil is classified as either alkaline or saline depending on whether the sodium ions are linked to the carbonate or chloride ions. These soil types eventually become unsuitable for irrigation [14].

2. Methodology

Study Area

The examined region lies in Baghdad central Iraq at 33°10′N 44°10′E and 33°30′ N44°35′E. The river separates Baghdad into two sections: "Karkh" was the western section and "Rasafa" was the eastern one [15, 16]. Many agricultural areas within Baghdad zone feeds the water from the left and right sides of the Tigris River [3].

Study Sites Description

As can be seen in Figure 1, samples were taken along the river at twelve different sites. First site located in Al-Tarmiyah District northern Baghdad City and the last site locate in Al-Rasheed District southern Baghdad City, covers an area of about Baghdad City as explained below in Table 1.

TABLE 1. Explain the location of the study sites within Baghdad City.

Sites	Name	Latitude	Longitude	Description the locations
Site 1	Al-Karkh	33°36'36.7"N	44°19'42.6"E	In Al-Tarmiyah, 45 Km northern Baghdad.
Site 2	Al-Rusafa	33°27'02.9"N	44°22'20.8"E	Northern Baghdad, 5 Km from Baghdad Island.
Site 3	Sharq Digila	33°25'01.3"N	44°20'54.5"E	Eastern part of the river, closely Sab'abkar area.
Site 4	Al-Sadir	33°24'48.5"N	44°26'38.1"E	Located on the eastern part of the river.
Site 5	Kadhimiya	33°21'31.2"N	44°21'01.2"E	In At Taifiya, western part of the river.
Site 6	Al-Karama	33°21'26.2"N	44°21'28.1"E	Located on the eastern part of the river.
Site 7	Al-Wathba	33°21'04.8"N	44°22'23.6"E	Eastern side of the river, central Baghdad.
Site 8	Al-Baladiat	33°20'37.3"N	44°29'33.0"E	Located on the eastern part of the river.
Site 9	Al-Qadisya	33°17'37.9"N	44°21'41.6"E	Located on the western part of the river.
Site 10	Al-Dawraa	33°15'41.5"N	44°22'56.7"E	Southern Baghdad, western side of the river.
Site 11	Al-Wahda	33°17'44.6"N	44°26'39.5"E	Southern Baghdad, eastern part of the river.
Site 12	Al-Rasheed	33°17'10.1"N	44°27'16.9"E	In Al-Za'franiya, eastern side of the river.

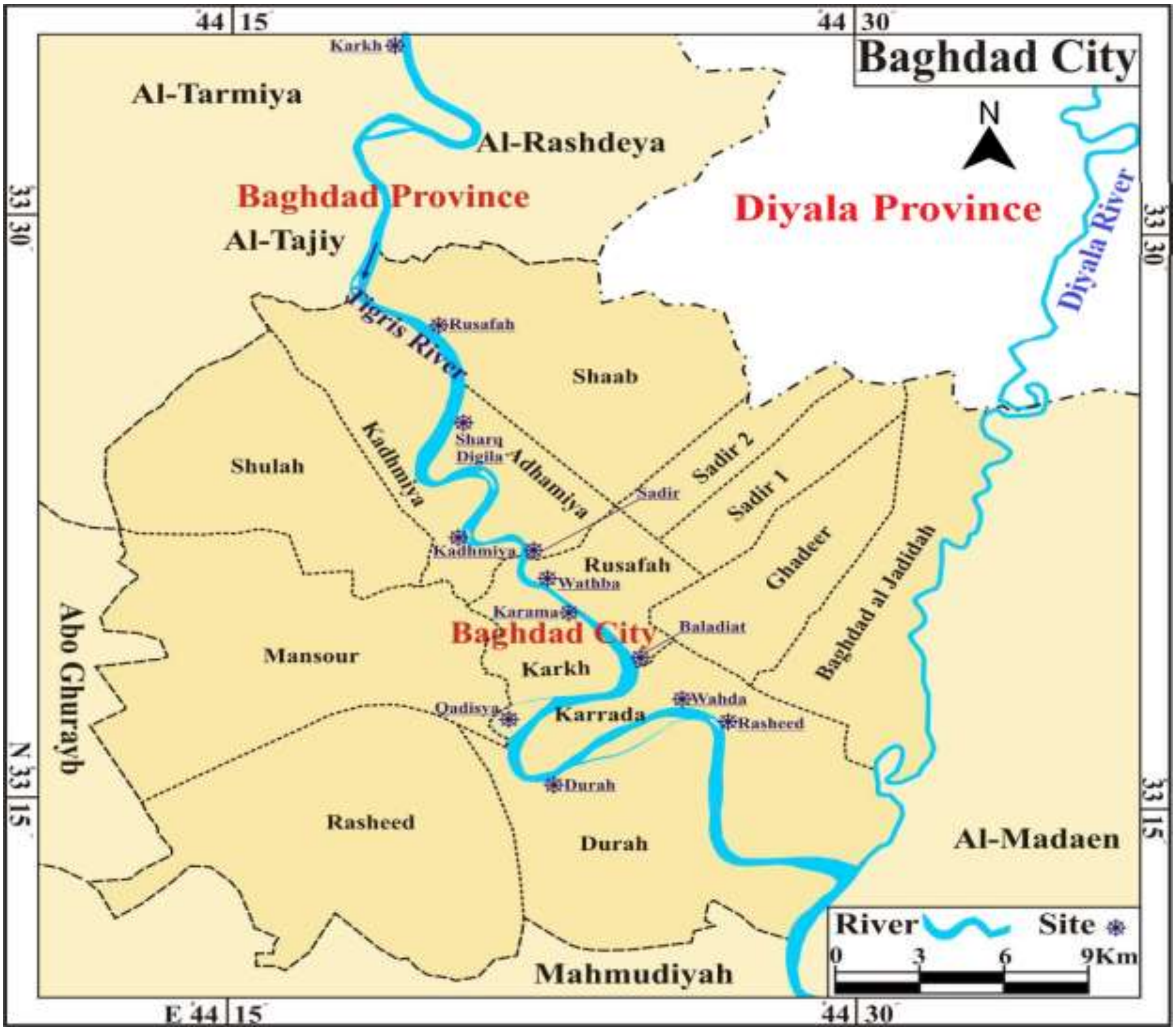


FIGURE 1. Map of river state within Baghdad City. The scale is 1/300000.

Data for Calculation

The data applied in this research are provided by the Mayoralty of Baghdad (Amanat Baghdad). Includes thirteen typical physicochemical water parameters based on both availability and importance (Table 5). Also, water samples were taken from various specialized stations along the river via clean polyethylene bottles.

Sample Measurements

Some parameters were analyzed directly at the study site, such as TDS, EC, and pH, using digital instruments. Whereas other parameters were analyzed in laboratory according to standard methods [17, 18].

Irrigation Indices

The most widely used indices to evaluate the water quality for irrigation purposes are sodium adsorption ratio (SAR), sodium percentage (Na%), salinity hazard (SH), magnesium ratio (MR), Kelly's index (KI), potential salinity (PS) and salinity hazard (SH) were calculated using the standard equations (Table 2). Piper diagram, Wilcox diagram and US salinity laboratory diagram (USSL) also were used to assess the quality of the river water for irrigation purposes. The concentration is expressed in milliequivalents per liter (meq/L).

TABLE 2. Irrigation water quality indices (All concentrations are in meq/L).

Index	Formula	Range	Quality	References
SAR	$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}/2}}$	< 10	Excellent	[12, 19, 20]
		10 - 18	Good	
		18 - 26	Doubtful	
		> 26	Unsuitable	
MH	$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	<50 >50	Suitable Unsuitable	[21, 22]
Na%	$Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$	< 20	Excellent	[13, 23, 24]
		20-40	Good	
		40-60	Acceptable	
		60-80	Doubtful	
		> 80	Unsuitable	
SSP	$SSP = \frac{(Na^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+})} X\ 100$	< 60	Safe	[25, 26, 27].
		> 60	Unsafe	
KI	$KR = \frac{Na^{+}}{Ca^{+} + Mg^{+}}$	< 1	Suitable	[28, 29, 30].
		>1	Unsuitable	
PS	$PS = Cl^{-} + \frac{1}{2} SO_4^{-2}$	< 3	Excellent	[31, 32]
		3-5	Acceptable	
		> 5	hazardous	
SH	Calculated depending on electrical conductivity values (µS/cm).	0-250	Excellent	[12, 32]
		250-750	Good	
		750-2250	Doubtful	
		> 2250	Unsuitable	

Chloride Concentration (Cl^{-})

According to Zaman et al. [8], irrigation water quality based on chloride concentration is divided into four levels; less than 70 mostly harmless, 70 to140 slight to moderate damage, 141 to 350 minors to significant damage, more than 350 mg L^{-1} lead to serious problems.

Total Hardness (TH)

Total hardness was determined by EDTA titrimetric method, expressed in milligram per liter of calcium carbonate [17, 33]. Measured according to standard methods and divided into four groups; less than 75 soft water; 75-150 a little hard water; 150 to 300 hard water; more than 300 mg L^{-1} very hard water [17, 34, 35, 36].

Piper Diagram

The Piper plot displays the three primary chemical compositions of a ternary diagram, which are used to demonstrate the chemistry of the water sample. Cations can be seen in the graph on the left, while anions can be seen in the graph on the right and the combined location of cations and anions is shown by a diamond-shaped area. This graph not only helps to identify the type of water but also to understand the geochemical processes that affect its composition [11].

The Piper diagram is a trilinear chart that was created by Arthur M. Piper [11] to help visualize the chemistry of water by showing the concentrations of major cations and anions. This graph aids in both classifying the type of water and comprehending the geochemical processes influencing its composition.

USSL or Salinity Diagram

The USSL graph indicates whether the water quality is suitable for irrigation, based on the level of risk for both SAR and EC [37]. Richard's classification for irrigation purposes is represented in Tables 3 and 4.

TABLE 3. Richard's classification, 1954 for irrigation water [12]

Quality	SAR (meq/L)	Level	EC (μS/cm)	Level
Excellent for irrigation	Less than 10	S1	Less than 250	C1
Good for irrigation	10 to 18	S2	250 to 750	C2
Permissible for irrigation	18 to 26	S3	750 to 2.500	C3
Unsuitable for irrigation	More than 26	S4	More than 2.500	C4

Table 4. Water classification according to Richard classification [12].

Rank	Quality	Rank	Quality
C1-S1	Excellent	C3-S1	Appropriate
C1-S2	Good	C3-S2	Acceptable
C1-S3	Appropriate	C3-S3	Acceptable
C1-S4	Poor	C3-S3	Appropriate
C2-S1	Good	C4-S1	Poor
C2-S2	Good	C4-S2	Poor
C2-S3	Acceptable	C4-S3	Poor
C2-S4	Poor	C4-S4	Very Poor

Wilcox Diagram

An important diagram is usually employed to assess whether water is suitable for irrigation [13]. The databases for electrical conductivity and sodium percent were used to determine the diagram's structure.

3. Result and Discussion

Hydrochemical Assessment

The results of hydrochemical assessment of 13 parameters includes; electrical conductivity (EC), hydrogen ion concentration (pH), total dissolved solids (TDS), potassium (K^{+}), magnesium (Mg^{2+}), sodium (Na^{+}), calcium (Ca^{2+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), nitrate (NO_3^{-}), total hardness as $CaCO_3$ and total alkalinity (TA) as ($HCO_3^{-} + CO_3^{2-}$) for all sites are given in Table 5 for 2021-2022.

The total amount of dissolved salts in river water is known as the electrical conductivity [35, 36]. When elevated, it decreases the intake of water and nutrients from the soil while increasing the osmotic pressure of the soil solution [38]. The EC data of the Tigris River is presented in Table 5. The average values varied between 788.5-1073.0 µS/cm and 694.4-901.1 µS/cm during 2021 and 2022, respectively. Indicate that all samples fall within the doubtful quality of irrigation water (class 3) in 2021. Whereas 16% of all samples were within good quality (class 2) whereas the rest were of doubtful quality for irrigation purposes (class 3) in 2022 as explained by Richards' classification [12].

The average concentration of cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} fluctuated between (63.4-118.9 mg L^{-1}) and (57.8-91.58 mg L^{-1}); (26-36.3 mg L^{-1}) and (25.6-30.3 mg L^{-1}); (37.8-61.95 mg L^{-1}) and (29.1-50.1 mg L^{-1}); (2.54-3.72 mg L^{-1}) and (1.75-2.93 mg L^{-1}) in 2021 and 2022, respectively (Table 10). Also, the average anions concentration SO_4^{2-}, PO_4^{3-}, NO_3^{-} ranged between (171.6-296.5 mg L^{-1}) and (151-234 mg L^{-1}); (0.01-0.18 mg L^{-1}) and (0.04-0.18 mg L^{-1}); (0.6-1.7 mg L^{-1}) and (0.4-1.72 mg L^{-1}) in 2021 and 2022, respectively (Table 5).

The average values of chloride ions fluctuated between 54-88.5 mg L^{-1} and 41.58-71.6 mg L^{-1} in 2021 and 2022, respectively. In 2021 the majority of water samples (91.7%) were within slight effect 70-140 mg L^{-1} except site 1 was within safe effect. While in 2022 majority of water samples (91.7%) were within safe effect of 70-140 mg L^{-1} except site 1 was within slight effect. As well as, the average values of pH, TDS, TH, and TA in water ranged between (7.7-8.1) and (7.8-8.1); (488-736 mg L^{-1}) and (437.5-597.3 mg L^{-1}); (299-417.2 mg L^{-1}) and (346.6-266.5 mg L^{-1}); (121.8-160.1 mg L^{-1}) and (121.8-167 mg L^{-1}) in 2021 and 2022, respectively. The average values of pH, Ca^{2+}, and Mg^{2+} lower than standards limitation for irrigation water 8.5, 200 mg L^{-1}, 150 mg L^{-1}, respectively for two consecutive years [39].

2021 Site	pH	EC µS/cm	TDS	Mg^{2+}	Ca^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	PO_4^{3-}	NO_3^{-}	TH	TA
Al-Karkh	7.97 ±0.025	788.5 ±28.41	488 ±18.0	33 ±1.23	63.4 ±0.81	37.8 ±2.4	2.54 ±0.01	54 ±3.4	171.6 ±9.5	0.04 ±2.09	0.9 ±0.06	299 ±6.17	121.8 ±1.5
Al-Rusafa	8.1 ±0.01	927.66 ±24.97	621 ±16.7	29 ±1.08	80.9 ±2.9	53.9 ±1.7	2.6 ±0.01	77 ±2.45	205.6 ±5.61	0.01 ±5.23	0.6 ±0.05	321.7 ±8.01	146.6 ±1.76
Sharq Digila	8.0 ±0.01	979.08 ±22.33	641 ±21.7	33.8 ±1.2	84 ±2.3	55.3 ±1.5	2.55 ±0.01	79 ±2.24	201.8 ±7.8	0.01 ±5.23	1.2 ±0.06	346.6 ±8.88	132.6 ±0.55
Al-Sadir	7.9 ±0.04	990.66 ±20.47	683 ±140	33.8 ±1.2	80.25 ±3.2	56.7 ±1.5	2.73 ±0.01	81 ±2.1	236.75 ±8.4	0.01 ±5.23	0.6 ±0.02	352.5 ±9.8	148.8 ±2.4
Al-Kadhimiya	7.81 ±0.02	1042.8 ±27.87	678 ±18	32.5 ±0.51	104.3 ±5.6	53.3 ±1.2	2.97 ±0.01	76.25 ±1.7	288.3 ±13	0.03 ±0.003	0.8 ±0.1	394.5 ±12.9	128.7 ±6.08
Al-Karama	8.0 ±0.02	1057.3 ±28.55	582 ±15.4	29.8 ±1.19	110 ±5.7	61.4 ±1.0	2.93 ±0.01	87.7 ±1.4	252 ±6.56	0.04 ±0.004	0.9 ±0.08	398.3 ±11.9	132.6 ±5.0
Al-Wathba	7.7 ±0.01	1073.0 ±33.58	714 ±19.5	31.2 ±0.93	108 ±5.7	55.7 ±1.1	2.93 ±0.01	79.6 ±1.5	281 ±16.37	0.02 ±1.04	1.2 ±0.02	385.0 ±13.7	129.8 ±1.7
Al-Baladia	8.0 ±0.04	1067.9 ±28.1	736 ±19.5	36.3 ±1.91	97.3 ±3.1	61.95 ±1.1	2.89 ±0.01	88.5 ±1.55	253 ±10.25	0.01 ±5.23	0.69 ±0.04	392.4 ±13.9	160.1 ±4.28
Al-Qadisya	7.8 ±0.03	1053.6 ±28.87	695 ±19	30 ±0.71	112.8 ±6.6	56.8 ±1.1	2.985 ±0.01	81.3 ±1.6	286.6 ±15.73	0.09 ±0.005	0.8 ±0.03	408 ±15.2	142.6 ±5.16
Al-Dawraa	7.9 ±0.028	1061.7 ±34.6	706 ±19.5	32 ±0.54	114.1 ±6.8	60.2 ±1.3	2.905 ±0.01	85.75 ±1.9	296.5 ±17.4	0.06 ±0.08	0.69 ±0.05	417.2 ±15.9	138 ±5.16

Al-Wahda	7.89 ±0.002	1064.7 ±28.9	713 ±18.8	26 ±053	118.9 ±5.1	53.7 ±1.96	3.72 ±0.01	76.75 ±2.8	279.7 ±8.4	0.18 ±0.003	1.6 ±0.06	403.6 ±14.2	139.6 ±3.58
Al-Rasheed	7.9 ±0.021	1067.4 ±28.67	711 ±20	27.5 ±1.55	118.5 ±5.6	55.6 ±2.27	3.33 ±0.01	79.4 ±3.2	277.1 ±10.9	0.16 ±0.014	1.7 ±0.04	409.3 ±13.4	141.0 ±4.02

2022 **Site**	**pH**	**EC** $\mu S/cm$	**TDS**	Mg^{2+}	Ca^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	PO_4^{3-}	NO_3^{-}	**TH**	**TA**
Al-Karkh	8.06 ±0.02	694.4 ±20.4	437.5 ±13.06	28.58 ±0.66	57.8 ±1.5	29.1 ±1	1.76 ±0.01	41.58 ±1.4	151 ±3.94	0.04 ±2.09	0.81 ±0.07	266.5 ±5.8	113.6 ±2.09
Al-Rusafa	8.1 ±0.01	733.5 ±19.6	491 ±13.1	25.8 ±1.02	67.6 ±1.7	40.4 ±1.6	1.75 ±0.01	57.7 ±2.28	165.4 ±4.2	0.01 ±5.23	0.9 ±0.05	274.08 ±8.2	149 ±1.3
Sharq Digila	8.02 ±0.01	796.7 ±24.2	533 ±16.3	25.6 ±0.8	72.6 ±1.5	41.7 ±1.69	1.93 ±0.01	59.6 ±2.41	172.5 ±5.4	0.01 ±5.23	1.135 ±0.06	284.6 ±6.6	137.5 ±1.19
Al-Sadir	7.9 ±0.037	810.6 ±24.9	558.5 ±17.1	30.3 ±0.99	68.4 ±1.5	43.05 ±1.59	1.775 ±0.01	61.5 ±2.27	182.9 ±7.5	0.01 ±5.23	0.49 ±0.02	294.1 ±7.5	147.5 ±1.8
Al-Kadhimiya	7.8 ±5.3	850.7 ±31.3	552.6 ±20.4	26.6 ±1.2	79.3 ±44	42 ±2.01	2.045 ±0.01	60.08 ±2.8	203.8 ±13.4	0.04 ±0.0046	1.08 ±0.07	303.5 ±12.7	133 ±1.7
Al-Karama	8.1 ±0.021	853.5 ±33.0	469.2 ±18.3	28.8 ±0.84	85.7 ±4.7	48.7 ±1.9	2.18 ±0.01	69.6 ±2.7	206.9 ±7.3	0.028 ±0.002	0.915 ±0.06	332.4 ±13.9	147.1 ±1.3
Al-Wathba	7.8 ±0.025	857.8 ±32.9	583.1 ±23.1	27.75 ±0.96	81 ±4.3	46.1 ±2	1.835 ±0.01	65.9 ±2.9	202.8 ±14	0.023 ±0.009	0.4 ±0.08	319.4 ±13.1	148.4 ±1.84
Al-Baladia	7.9 ±0.03	866.1 ±35.2	597.3 ±23.9	25.6 ±0.855	82 ±3.2	50.1 ±2.1	1.805 ±0.01	71.6 ±3.02	196.5 ±9.8	0.01 ±5.23	0.67 ±0.02	315.8 ±9.9	167 ±1.05
Al-Qadisya	7.8 ±0057	846.6 ±33.6	559 ±22.2	26.75 ±0.73	85.08 ±4.7	44.8 ±1.9	2.93 ±0.01	64.1 ±2.7	200.2 ±12.9	0.13 ±0.0096	0.85 ±0.02	320.8 ±14.6	153 ±1.3
Al-Dawraa	7.9 ±0.02	901.1 ±35.7	571 ±21.5	30 ±1.02	83.2 ±4.5	48.3 ±1.57	2.85 ±0.01	69 ±2.25	230 ±12.4	0.096 ±0.008	0.86 ±0.08	330.3 ±14.7	155.58 ±1.85
Al-Wahda	7.89 ±0.001	856.33 ±32.6	574.5 ±22.1	28.75 ±0.96	90 ±5.31	42.8 ±1.97	2.8 ±0.01	61.1 ±2.8	222 ±15.9	0.17 ±0.009	1.69 ±0.06	343.7 ±13.5	145.75 ±3.59
Al-Rasheed	7.89 ±0.002	868.08 ±33.7	580 ±23.7	28.8 ±0.99	91.58 ±5.4	43.8 ±2.23	2.17 ±0.01	62.58 ±3.2	234 ±16	0.17 ±0.009	1.72 ±0.05	346.6 ±13.7	146.9 ±3.8

Table 5. The averages and standard errors of hydrochemical analysis over two years ($mg\ L^{-1}$).

Hydrochemical Facies of Samples (General Hydrochemistry).

Major chemical ions are plotted in a trilinear chart in which the cations are displayed in the left triangle and the anions are shown in the right triangle (Figure 2).

The results are also presented in the central diamond shape for assessment of the chemical facies to give a clear view of the chemical facies in water.

The majority of the samples in the cation triangle are located on its left corner where Ca^{2+} concentrations more than 50%, indicating the dominance of Ca^{2+} over magnesium, sodium and potassium ions for two consecutive years (Figure 2).

Similar results reported by Ghimire et al. [40] showed that the calcium ion dominance in the Tamor River.

The majority of the samples in the anion triangle are located on its right side where SO_4^{2-} concentrations more than 50%, indicating the dominance of sulfate over chloride and bicarbonate ions for two consecutive years (Figure 2).

By analyzing the diamond plot in the center of a Piper diagram for 2021 and 2022. The samples in the upper section are calcium plus sulfate and chloride plus magnesium. The samples in the left section are calcium bicarbonate and magnesium. The samples in the right section are mixed of sodium chloride, potassium, sulfate and bicarbonate. The samples in the bottom section are sodium bicarbonate and potassium. These results are typical for running surface water most of the time.

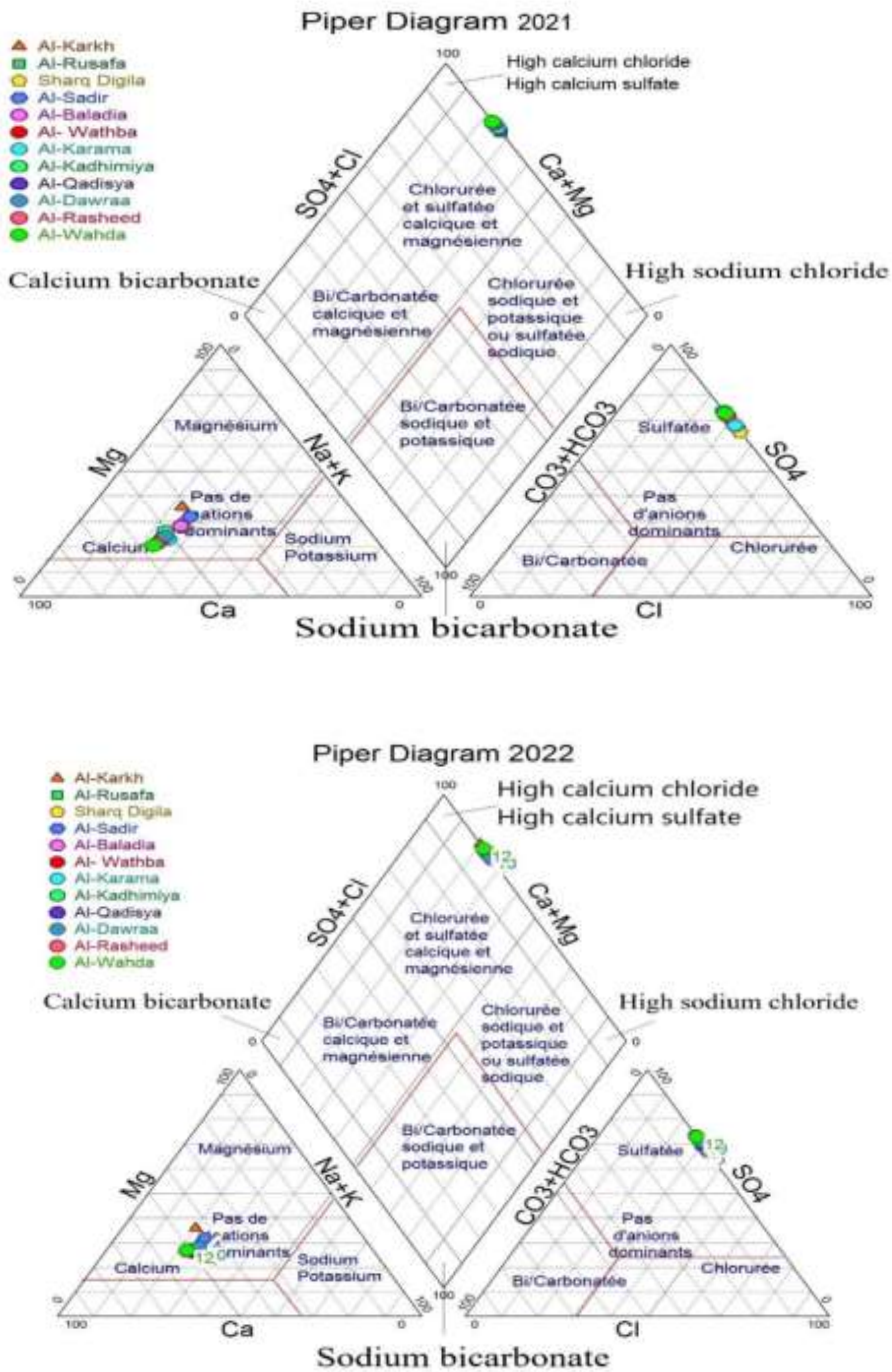


FIGURE 2. Piper diagram showing the river water samples' hydrochemical facies in 2021-2022.

Irrigation Suitability Assessment

Irrigation water suitability is usually assessed based on the presence of undesirable dissolved salts or elements [20]. By implementing seven individual specific indices such as sodium adsorption ratio, sodium percent, magnesium hazard, total hardness, soluble sodium percentage Kelly's index and potential salinity.

Sodium Adsorption Ratio (SAR)

Based on the analyses, SAR values in the studied samples varied between 1.53-2.43 meq/L and 0.94-2.28 meq/L in 2021 and 2022, respectively (Table 6).

According to Richard's [12] and Wilcox's [13] classification applied to the calculated SAR values, the water sample falls in the 'excellent' (S1 class) lower than 10 meq/L (Figure 3), and is safe to use for irrigation on practically all soil types without any risk. Similarly, Al-Saady and Abdullah [41] found the SAR values of Tigris River water within Missan accrued within excellent class. Al-Sabah [42] showed that the SAR values of the Tigris River water in Amara City ranged from 3.63 to 4.41 0.96 meq/L. Also, Al-Mayyahi et al. [43] showed that the SAR values of Tigris River water within Kut City within excellent class lower than 10 meq/L. In Mosul City, Al-Soyffe et al. [44] found that the SAR values of the Tigris River water were within the excellent class, less than 10 meq/L. As well, Allawi et al. [45] found that the SAR values of the Tigris River water in Salah Al-Din City fall into excellent class based on Richards classification. Mohsen and Al-Mohammed [46] found that the average values of SAR in the water of the Hilla Main Canal varied between 8.9 and 10.5 meq/L, falling within the excellent class in terms of irrigation water.

Globally, in Indonesia Wantasen et al. [47] showed that the SAR values of Panasen River water varied between 0.10 meq/L and 0.40 meq/L very suitable for irrigation water. Pivi´c et al. [48] indicated that the SAR values of three Morava Rivers in Serbia ranged between 0.01 and 10.34 meq/L; all water samples fell into the excellent class except one sample with a good class. In mid-western USA, Alam et al. [49] found that Indiana's White River's water quality degraded downstream the river and the SAR values fluctuated between excellent and good class. In China, similar findings obtained by Min et al. [50] found that the SAR values of the Sui River and Tang River water were very applicable. In Nigeria, Ogunfowokan et al. [51] found that low SAR values in three streams -Amuta, Agbogbo and Abagbooro- range from 9.07 to 1.04 within excellent class.

Sodium Percent (Na%)

The values of Na% ranged between 28.4-33.9 meq/L and 26.31-32.53 meq/L for two consecutive years (Table 6). According to Wilcox [13] and Elsayed et al. [52] sodium percentage for irrigation water varied between excellent and good class (Table 4). The result is consistent with earlier studies carried out on the Tigris River. Al-Mayyahi et al. [53] showed that the Na% values of Tigris River water within Kut City within good class ranged between 31.2-34.5 meq/L and 36-38.1 meq/L in 2017 and 2018 respectively. In Mosul City, Al-Soyffe et al. [44] found that the Na% values of the Tigris River water within the good class for irrigation, less than 30 meq/L.

In global studies, Pivi´c et al. [48] indicated that the Na% values of three Morava Rivers in Serbia fluctuated between 0.49 and 51.89 meq/L, within excellent and good class in terms of irrigation. In Nepal, Acharya et al. [54] showed that the Na% values of the Karmanasha River water fluctuated between good and excellent classes (6.53-30.30 meq/L). In Egypt, Gad et al. [55] found that the Na% values of the Nile River ranged between 26.98 meq/L and 45.92 meq/L, with an average of 35.85, falling within the good to permissible classes of Wilcox's classification [13].

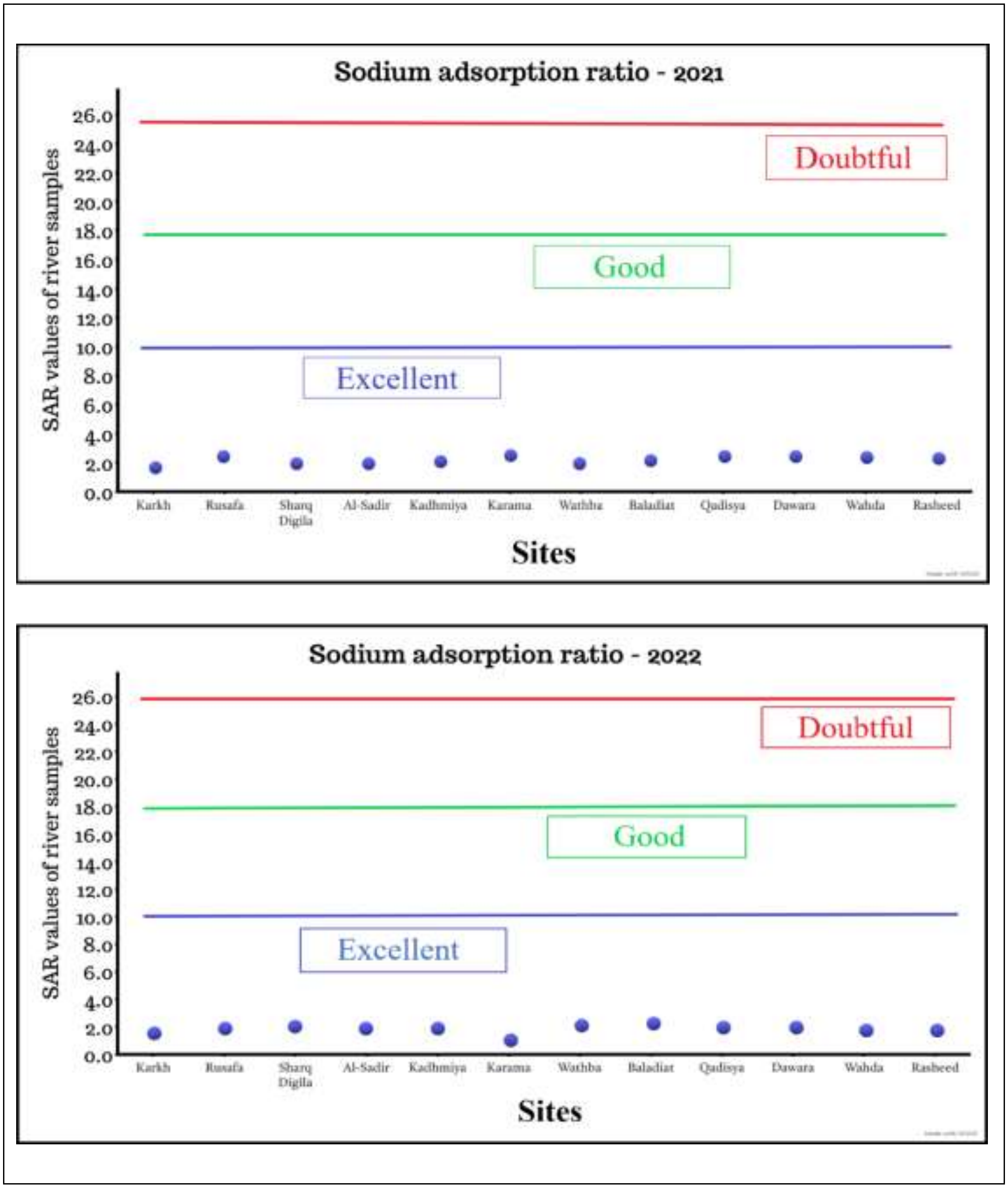


FIGURE 3. SAR values of river samples in 2021 and 2022.

Soluble Sodium Percentage (SSP)

The soluble sodium percentage is also one of the most critical parameters implemented to evaluate irrigation water's quality in terms of soil permeability. The SSP values of the river water samples varied between 27.04-32.86 meq/L and 25.19-31.75 meq/L for two consecutive years (Table 6).

The results also revealed that all surface water samples were suitable for irrigation use, and there is no negative effect on the permeability of the soil. In Diyala, Al Obaidy et al. [56] found that the SSP values of Mahrut River ranged between 36.16 and 54.53 meq/L within safe criteria. Also, Ewaid [57] found that the SSP values of Al-Gharraf Canal water varied between 37.05 and 39.07 meq/L within safe criteria. Also, Mohsen and Al-Mohammed [46] found that the average values of SSP in the water of the Hilla Main Canal varied between 33.8 and 43.6 meq/L, falling within safe criteria in terms of irrigation water.

In Nigeria, Ukoha-Onuoha et al. [58] found that the SSP values for ten different rivers fluctuate between safe and unsafe criteria (39.82 and 111.32 meq/L). Subramanian and Baskar [59] showed that the SSP values in the Noyyal River water lower than 60 meq/L, ranged between 36 and 56.85 meq/L within safe criteria in terms of irrigation. In Kosovo, Laze et al. [60] demonstrated that the SSP values in the White Drin River and Peja's Lumbardh River water are within safe criteria in terms of irrigation water.

Kelly's Index (KI)

The water samples in this evaluation had varying values of KI ranged between 0.37-0.49 meq/L and 0.33-0.46 meq/L for two consecutive years (Table 6). These results fall under the (<1) limit and are considered suitable for irrigation usage. Similarly, Al-Sabah [42] showed that Kelly's index values for the Tigris River water in Amara City ranged between 0.78 and 0.96 meq/L. In Mosul City, Al-Soyffe et al. [44] found that the KI values of the Tigris River water less than 1 meq/L, acceptable for irrigation usage. In contrast, Allawi et al. [45] found that the KI values of the Tigris River water within Salah Al-Din City exceed the allowed limit of 1, ranging from 0.19 to 1.19 meq/L.

Globally, In Kosovo, Laze et al. [60] found that the KI values of the White Drin River and Peja's Lumbardh River water were within the permissible limits for irrigation water <1. As well. as, Subramanian and Baskar [59] showed that Kelly's index values for the Noyyal River water varied between 0.57 and 1.37 meq/L related to increasing sodium content. In Nigeria, Ukoha-Onuoha et al. [58] found that the KI values for ten different rivers fluctuate between 0.66-1.58 meq/L, varied between suitable and unsuitable for irrigation purposes. In Serbia Pivi´c et al. [48] demonstrate that the KI values of the three Morava Rivers varied between 0.004 and 4.416 meq/L, fluctuated between suitable and unsuitable classes in term of irrigation water. In Ethiopia, Kasa et al. [61] found that KI values in Wabe River water were below 1 meq/L, ranged between 0.25 and 0.37 meq/L in wet season and 0.77-0.99 meq/L in dry season.

Magnesium Hazard (MH)

The magnesium hazard values of the water samples varied between 18-34 meq/L and 24.02- 33.11 meq/L for two consecutive years (Table 6). Based on the MH results, all surface water samples (100%) fell into the suitable class lower than 50 and are acceptable for irrigation.

The results, in agreement with Al-Sabah [42] showed that water from the Tigris River in Amara City is appropriate for irrigation activities, the MH values less than 50 meq/L ranged from 22.39 to 37.44 meq/L. In Mosul City, Al-Soyffe et al. [44] found that the MH values of the Tigris River water, less than 50 meq/L, suitable for irrigation uses.

In global studies, Subramanian and Baskar [59] indicated that the majority of the Noyyal River's water samples had MH values of less than 50 meq/L, which qualified them for irrigation. In Kosovo, Laze et al. [60] demonstrated that the MH values in the White Drin River and Peja's

Lumbardh River water less than 50 were within suitable class in terms of irrigation water. In Nepal, Acharya et al. [54] showed that the MH values of the Karmanasha River water were less than 50 meq/L and suitable for irrigation.

Potential Salinity (PS)

The value of potential salinity ranged between 139.83-234 meq/L and 117.08 184.08 meq/L in two consecutive years (Table 6). Based on the PS results, all surface water samples (100%) fell into the unsatisfactory class more than 5 and are unsuitable for irrigation use (Table 2). A rising amount of PS is due to elevated levels of sulfate and chloride ions (Table 5). The results are in contrast to those of Allawi et al. [45], who found that low PS values in Tigris River water within Salah Al-Din province ranged from 1.00 to 15.16 meq/L. Also, Al-Soyffe et al. [44] showed that low values of PS in Tigris River water within Mosul City ranged from 0.94 to 1.79 meq/L.

In southern Nigeria, Ukoha-Onuoha et al. [58] showed that the values of PS in several river within Niger Delta region ranged between 0.52 and 0.84 meq/L, excellent for irrigation. In Serbia, Pivi´c et al. [48] showed that the values of PS in the three Morava Rivers fluctuated between excellent and poor class. In Ethiopia, Kasa et al. [61] found that low values of PS in Wabe River water, less than 3 meq/L, varied between 0.65-1.57 meq/L in rainy season and 0.8-1.62 meq/L in dry season.

Water Quality Evaluation from Graphical Representation

According to the USSL classification [12]. Figure 4 showed that 100% of Tigris water samples were within the appropriate class C3S1 associated with risks of high salinity and low sodium in 2021. While in 2022, 10 of 12 sites 83.33% were within appropriate class (C3S1) and the rest 16.66% were within good class C2S1 this is due to medium salinity (EC < 750 µS/cm) and low sodium hazards (SAR < 10 meq/L) as explained in Tables 3, 4 and 6. Similar results were presented by Abdulrazzaq and Kamil [62], who found that the Tigris water varied from good class C2S1 upstream of Tarmiyah City to appropriate class C3S1 downstream of Tarmiyah City.

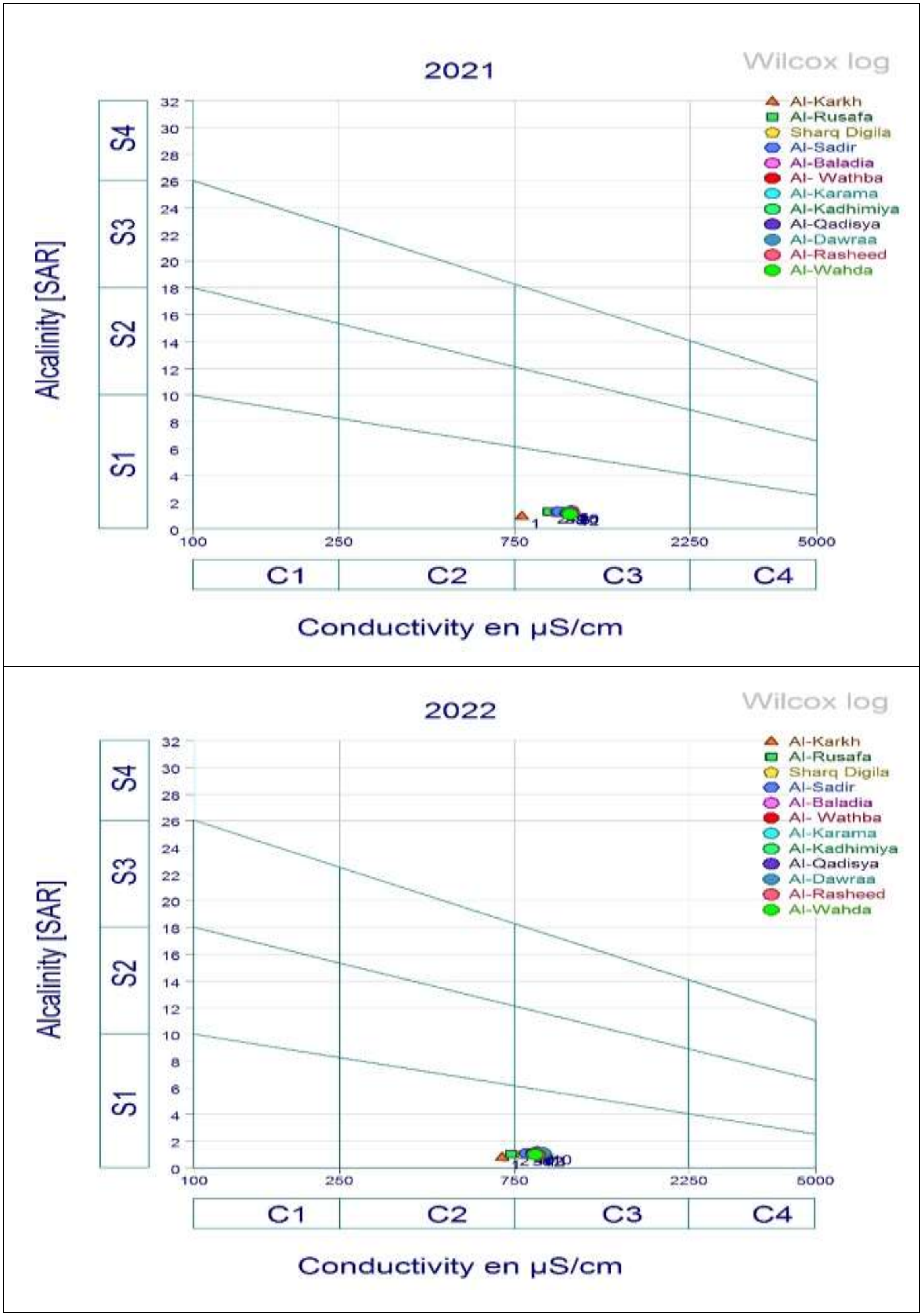
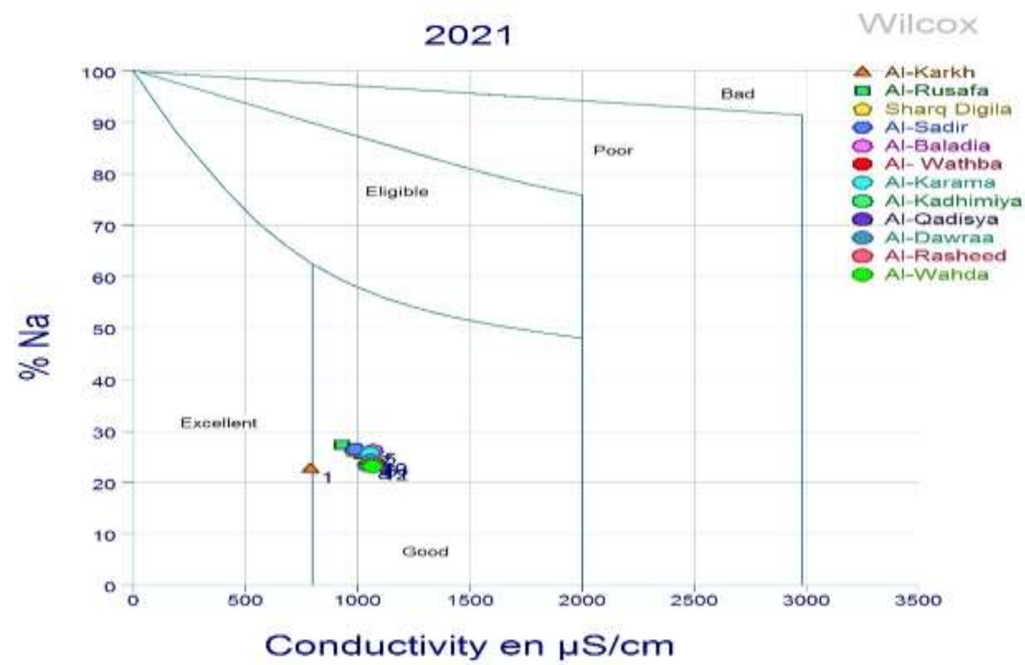


FIGURE 4. USSL diagram for irrigation purposes.

The relationship between electrical conductivity and sodium percentage was established by the Wilcox diagram for determining irrigation water quality. Figure 5 shows that the majority (91.66%) of samples collected from the river were within the good class medium salinity/ low sodium and the rest (8.33%) were within the excellent to good class in 2021. Whereas in 2022, 16.66% of the samples fell within excellent, low salinity/low sodium and 83.33% were within the good class in terms of irrigation usage (Tables 5 and 6).



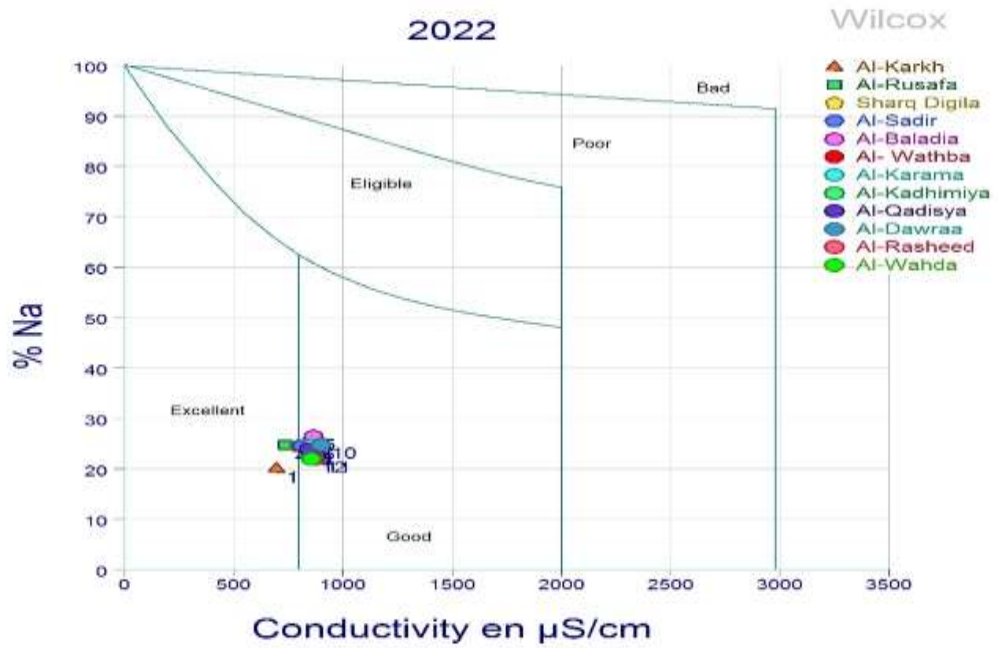


FIGURE 5. Wilcox diagram for assessing irrigation water quality

TABLE 6. Summary of irrigation indices (2021-2022).

2021 Site Name	SAR	MH	Na%	PS	KI	SSP	TH	USSL Class	Wilcox Class
Karkh	1.53	34	29.5	139.83	0.39	28.16	299	C3S1	Excellent-Good
Rusafa	2.29	27	33.9	179.83	0.49	32.86	321.8	C3S1	Good
Sharq Digila	2.12	29	32.9	180	0.47	31.94	346.7	C3S1	Good
Al-Sadir	2.06	32	33.6	199.45	0.48	32.60	352.5	C3S1	Good
Kadhmiya	2.01	24	29.2	220.41	0.39	28.06	394.5	C3S1	Good
Karama	2.43	22	31.5	213.75	0.43	30.50	398.3	C3S1	Good
Wathba	2.14	23	29.7	220.12	0.40	28.61	385.1	C3S1	Good
Baladiat	2.23	27	32.7	215	0.46	31.66	392.4	C3S1	Good
Qadisya	2.22	22	29.5	224.58	0.39	28.46	408	C3S1	Good
Dawara	2.23	23	30	234	0.40	29.05	417.3	C3S1	Good
Wahda	2.24	18	28.4	216.62	0.37	27.04	403.7	C3S1	Good
Rasheed	2.25	19	28.8	218	0.38	27.57	409.3	C3S1	Good

2022 Site Name	SAR	MH	Na%	PS	KI	SSP	TH	USSL Class	Wilcox Class
Karkh	1.32	33.11	26.31	117.08	0.33	25.19	266.5	C2S1	Excellent
Rusafa	1.91	27.56	31.08	140.45	0.43	30.18	274.08	C2S1	Excellent
Sharq Digila	1.95	26.1	30.78	145.91	0.42	29.82	284.66	C3S1	Excellent-Good
Al-Sadir	1.83	30.68	31.22	152.95	0.43	30.35	294.16	C3S1	Good
Kadhmiya	1.89	25.42	29.38	162	0.39	28.40	303.5	C3S1	Good
Karama	0.94	25.5	30.77	173.12	0.42	29.85	332.41	C3S1	Good
Wathba	2.02	25.77	30.61	167.33	0.42	29.78	319.41	C3S1	Good
Baladiat	2.28	24.02	32.53	169.83	0.46	31.75	315.83	C3S1	Good
Qadisya	1.98	24.28	29.94	164.20	0.40	28.62	320.83	C3S1	Good
Dawara	2.00	26.73	31.11	184.08	0.42	29.89	330.33	C3S1	Good
Wahda	1.80	24.7	27.75	172.16	0.36	26.50	343.75	C3S1	Good
Rasheed	1.83	24.46	27.63	179.6	0.36	26.67	346.66	C3S1	Good

4. Conclusion and future scope

According to the results, Tigris River water within Baghdad city is appropriate for irrigation of agricultural land. because all of the SSP, Na%, SAR, MH and KI values fall within the international accepted standards suitable for irrigation. The results were consistent with many international and local studies conducted on the Tigris River. Additionally, the research provides baseline information on the water's quality and suitability for irrigation in the future.

Acknowledgments

The researchers express gratitude to the Baghdad Mayoralty Water Office (Amanat Baghdad) for supplying the raw data necessary for this study.

Conflicting Interest

A researcher announces no conflicts of interest

Reference

[1] N. Al-Ansari, Water resources of Iraq. Journal of Earth Sciences and Geotechnical Engineering, **11**(2), 15–34 (2021). https://www.researchgate.net/publication/345639908

[2] M. Abdullah, N. Al-Ansari, and J. Laue, Water Resources Projects in Iraq, Irrigation. Journal of Earth Sciences and Geotechnical Engineering, **9(4)**, 249–274 (2019). https://www.researchgate.net/publication/337317793

[3] M. Abdullah, N. Al-Ansari, N. Adamo, V. K. Sissakian, and J. Laue, Major irrigation systems on Tigris River within Mesopotamia. Journal of Earth Sciences and Geotechnical Engineering, **10(4),** 175–198 (2020). https://www.researchgate.net/publication/340116508

[4] M. Abdullah and N. Al-Ansari, Irrigation projects in Iraq. Journal of Earth Sciences and Geotechnical Engineering, **11(2)**, 35–160 (2021). https://doi.org/10.47260/jesge/1123

[5] E. van Zandwijk, F. Monji, L. Mento, R. van Opstal, K. Mahdi, J. Snertlage, Water and Saline Agriculture in Central-Southern. A scoping study on the conditions, solutions, and actors in the field of saline farming. Technical Report, (2021). https://www.researchgate.net/publication/378463195

[6] T. A. Bauder, R. M. Waskom, J. G. Davis and P. L. Sutherland, Irrigation water quality criteria. Fort Collins: Colorado State University Extension, (2011). pp. 10–13.

[7] H. Pirasteh-Anosheh, G. Ranjbar, H. Pakniyat and Y. Emam, Physiological mechanisms of salt stress tolerance in plants: An overview. Plant-Environment Interaction: Responses and Approaches to Mitigate Stress, 141–160, (2016). DOI: 10.1002/9781119081005.ch8

[8] M. Zaman, S. A. and Shahid, L. Heng, "Irrigation Water Quality," in *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, edited by M. Zaman, S. A. Shahid, L. Heng, (Springer Nature, Switzerland, 2018), pp. 113–131. https://doi.org/10.1007/978-3-319-96190-3

[9] H. A. Awaad, "Salinity and Its Impact on Sustainable Crop Production," in *Salinity Resilience and Sustainable Crop Production Under Climate Change*, edited by H. A. Awaad, Earth and Environmental Sciences Library (Cham: Springer Nature, Switzerland. 2023), pp. 29–92. https://doi.org/10.1007/978-3-031-48542-8_2

[10] A. El-Defan, S. El-Raies, H. El-Kholy and A. Osman, A summary of water suitability criteria for irrigation. Journal of Soil Sciences and Agricultural Engineering, **7(12),** 981–989 (2016).

[11] A. M. Piper, A graphic procedure in the geochemical interpretation of water-analyses. Eos, Transactions American Geophysical Union, **25(6)**, pp. 914–928 (1944).

[12] L. A. Richards, Diagnosis and Improvement of saline and alkali soils. USDA Agricultural Handbook No. 60, US Department of Agriculture Handbook, Washington DC, p. 160 (1954).

[13] L. V. Wilcox, Classification and Use of Irrigation Waters; United State Department of Agriculture: Washington, DC, USA, p. 19 (1955).

[14] K. Pandian and K. Sankar, Hydrogeochemistry and Groundwater Quality in the Vaippar River Basin, Tamil Nadu, Geological Society of India, **69(5)**, 970–982 (2007). https://www.geosocindia.org/index.php/jgsi/article/view/81371

[15] O. S. Majeed, M. R. Nashaat and A. J. Al-Azawi, "Effect of Tharthar Canal water on composition and diversity of cladocera in Tigris river northern of Baghdad, Iraq, in *2nd International Conference of Mathematics, Applied Sciences, Information and Communication Technology*, AIP Conf. Proc. 2834, (AIP Publishing 2023) pp. 1–17. https://doi.org/10.1063/5.0161533

[16] O. S. Majeed and A. K. Ibraheem, Using Heavy Metals Pollution Indices for Assessment of Tigris River Water Within Al-Tarmiya City, Northern Baghdad, Iraq. Ecological Engineering & Environmental Technology, **25(3)** pp.113–123. DOI: https://doi.org/10.12912/27197050/178457

[17] R. B. Baird, A. D, Eaton and E.W. Rice, *Standard Methods for the Examination of Water and Wastewater*. 23 rd edition. (Am. Public Health Assoc, AWWA. Environmental Federation Publishers, Washington, DC, 2017).

[18] F. R. Spellman, *Handbook of Water and Wastewater Treatment Plant Operations*. (CRC Press, United States, 2020) p 722. https://doi.org/10.1201/9781003038351

[19] M. K. Hossain, M. M. Rahman and S. Haque, Quantitative assessment of water contaminants in the Rupsha river of Khulna region for irrigation usage. Journal of Environmental Science and Natural Resources, **11(1/2)**, 145–151 (2018). DOI: https://doi.org/10.3329/jesnr.v11i1-2.43381.

[20] S. Shil, U. K. Singh and P. Mehta, Water quality assessment of a tropical river using water quality index (WQI), multivariate statistical techniques and GIS. Applied water science, **9(168**), 1–21 (2019). DOI: 10.1007/s13201-019-1045-2

[21] K. V. Paliwal, *Irrigation with Saline Water*. Monogram No. 2 New Series (Indian Agriculture Research Institute, New Delhi, 1972) p 198.

[22] H. Abdelbakia, A. Belkendilb, A. Maazouzia and A. Mekkaouic, Assessment of hydrochemical properties of groundwater in the alluvial aquifer of the arid zone of the Igli Region, South-West of Algeria. Desalination and Water Treatment, **268**, 153–169 (2022).

[23] Z. I. González-Acevedo, D. A. Padilla-Reyes amd J. A. Ramos-Leal, Quality assessment of irrigation water related to soil salinization in Tierra Nueva, San Luis Potosí, Mexico. Revista Mexicana de Ciencias Geológicas, **33(3),** 271–285 (2016). http://hdl.handle.net/11627/3595

[24] Y. A. El-Amier, W. K. Kotb, G. Bonanomi, H. Fakhry, N. A. Marraiki and A. M. Abd-ElGawad, Hydrochemical assessment of the irrigation water quality of the El-Salam canal, Egypt. Water, **13(17)**, 2428 (2021). https://doi.org/10.3390/w13172428

[25] D. K. Todd, *Groundwater Hydrology*. 2nd edition, (John Wiley & Sons, New York, 1980) p 552.

[26] D. K. Todd and W. M. Larry, Groundwater hydrology, 3rd edition (John Wiley & Sons, New Jersey, 2005) p 656.

[27] A. R. Sarhat, and B. S. Al-Obaidi, Evaluation of the water quality of the Sirwan River in the Garmian region for irrigation purposes using the Irrigation Water Quality Guidelines (IWQG). Revista Bionatura, **7(4)**, 27 (2022). http://dx.doi.org/10.21931/RB/2022.07.04.27

[28] W. P. Kelly, Permissible composition and concentration of irrigated waters. in Proceedings of the American Society of Civil Engineers, 66, 1940), pp. 607–613.

[29] W. P. Kelley, *AIkali soils. Their formation, properties and reclamation*. (Reinhold Publishing Corporation, New York, 1951). A. C. S. Monograph Series, No. 111. p 176.

[30] M. R. Uddin, M. U. Khandaker, S. Ahmed, M. J. Abedin, S. M. M. Hossain, M. A. Al Mansur, ... and A. M. Idris, Assessment of coastal river water quality in Bangladesh: Implications for drinking and irrigation purposes. Plos one, **19(4)**, e0300878 (2024). https://doi.org/10.1371/journal.pone.0300878

[31] L. D. Doneen, Notes on Water Quality in Agriculture (Department of Water Science and Engineering, University of California, Oakland, CA, USA, 1964) p 48.

[32] P. Xu, W. Feng, H. Qian and Q. Zhang, Hydrogeochemical characterization and irrigation quality assessment of shallow groundwater in the Central-Western Guanzhong Basin, China. International journal of environmental research and public health, **16(9)**, 1492 (2019). https://doi.org/10.3390/ijerph16091492

[33] F. R. Spellman, The Science of water Concepts and Applications 3rd edition (CRC Press, Taylor & Francis Group, London, 2015) p 550. https://doi.org/10.1201/b17484

[34] G. N. Sawyer and D. L. McCarthy, *Chemistry of sanitary engineers*, 2nd edition. (McGraw Hill, New York,1967). p 518.

[35] O. S. Majeed, M. R. Nashaat, A. J. Al-Azawi, "Physicochemical Parameters of River Water and their Relation to Zooplankton: A Review", in *IOP Conference Series: Earth and Environmental Science* (Vol. 1120, No. 1, p. 012040). IOP Publishing (2022a). DOI: 10.1088/1755-1315/1120/1/012040

[36] O. S. Majeed, A. J. Al-Azawi and M. R. Nashaat, The Effect of Tharthar-Tigris Canal on the Environmental Properties of the Tigris River Northern Baghdad, Iraq. Baghdad Science Journal, **19(6)**, 1177–1190 (2022b). https://doi.org/10.21123/bsj.2022.6483

[37] L. V. Wilcox, *The quality of water for agricultural use*. (USDA. Technical Bulletin, Washington, DC, 1948). Vol. 962. p 40.

[38] D. Marghade, D. B. Malpe and A. B. Zade, Geochemical characterization of groundwater from northeastern part of Nagpur

urban, Central India. Environmental Earth Sciences, **(62)** 1419–1430 (2011).

[39] R. S. Ayers and D. W. Westcot, *Water quality for agriculture*, (Food and Agriculture Organization of the United Nations, Rome, 1985), Vol. 29, p. 174.

[40] N. P. Ghimire, N. Adhikari, R. R. Pant and S. Thakuri, Characterizations of water quality in west-Seti and Tamor river basins, Nepal. Scientific World, **14(14)**, 106–114 (2021). https://doi.org/10.3126/sw.v14i14.35021

[41] Y. I. Al-Saady and E. J. Abdullah, Water Quality of Tigris River within Missan Governorate eastern part of the Mesopotamia Plain–Iraq. Journal of University of Babylon, **22(9)**, 2489–2502 (2014).

[42] B. J. Al-Sabah, Evaluation of water quality index of Tigris river for irrigation purposes in Amara City, Southern Iraq. Kufa Journal for Agricultural Sciences, **6(4)**, 16–33 (2014). https://search.emarefa.net/detail/BIM-541773

[43] S. O. M. Al-Mayyahi, E. A. A. Ameer and H. A. A. AL-Zamili, Hydrochemistry and Validity of Tigris River Water in Kut City. Journal of Wasit for Science and Medicine, **11(1)**, 1–16 (2018). https://doi.org/10.31185/jwsm.436

[44] M. A. Al-Soyffe, Y. M. Al-Shaker and A. Y. T. A. Saffawi, Assessment of Water quality For Irrigation Using The Sub-Index Model: A case Study of Tigris River Water In Mosul City, Iraq. Journal of Pharmaceutical Negative Results, **13(6)**, 1019–1028 (2022). https://doi.org/10.47750/pnr.2022.13.S06.136

[45] K. A. Allawi, S. F. Ali and A. M. Ahmed, Evaluation of Tigris River Quality for Irrigation Purposes within Salah Al-Din province/Iraq. South Asian Research Journal of Medical Sciences, **5(5)**, 89–95 (2023).

[46] M. H. Mohsen, F. M. Al-Mohammed, Assessment of Irrigation Water Quality Using the Canadian Water Quality Index (CWQI) in the Hilla Main Canal, Iraq. Instrumentation, Mesure, Metrologie, 22(3), 105 (2023). https://doi.org/10.18280/i2m.220303

[47] S. Wantasen, J. N. Luntungan and A. E. Tarore, "Determination of the water quality of Panasen River as a source of irrigation water", in *IOP Conference Series: Earth and Environmental Science*, 314 (1), 012034, (IOP Publishing, 2019). DOI:10.1088/1755-1315/314/1/012034

[48] R. Pivić, J. Maksimović, Z. Dinić, D. Jaramaz, H. Majstorović, D. Vidojević and A. Stanojković-Sebić, Hydrochemical assessment of water used for agricultural soil irrigation in the water area of the three Morava Rivers in the Republic of Serbia. Agronomy, **12(5)**, 1177 (2022). https://doi.org/10.3390/agronomy12051177

[49] M. S. Alam, B. Han and J. Pichtel, Irrigation suitability of White River in Indiana, Midwestern USA. Environmental Geochemistry and Health, **43(10)**, 4179–4200 (2021). https://doi.org/10.1007/s10653-021-00905-2

[50] N. Min, G., Liu, J. Ma, M. Lin, Y. Yang and Z. Heng, Hydrochemical Characteristics, Ion Source Analysis and Irrigation Water Quality Evaluation of Rivers in Huaibei Plain. Polish Journal of Environmental Studies, **32(2)**, 1301–1311 (2023). https://doi.org/10.15244/pjoes/156790

[51] A. O. Ogunfowokan, J. F. Obisanya and O. O. Ogunkoya, Salinity and sodium hazards of three streams of different agricultural land use systems in Ile-Ife, Nigeria. Applied Water Science, **3(1)**, 19–28 (2013). DOI: 10.1007/s13201-012-0053-2

[52] S. Elsayed, H. Hussein, F. S. Moghanm, K. M. Khedher, E. M. Eid and M. Gad, Application of irrigation water quality indices and multivariate statistical techniques for surface water quality assessments in the Northern Nile Delta, Egypt. Water, **12(12)**, 3300 (2020). https://doi.org/10.3390/w12123300

[53] S. O. M. Al-Mayyahi, E. A. A. Ameer and H. A. A. AL-Zamili, Hydrochemistry and Validity of Tigris River Water in Kut City. Journal of Wasit for Science and Medicine, **11(1)**, 1–16 (2018). https://doi.org/10.31185/jwsm.436

[54] A. Acharya, M. L. Sharma, K. Bishwakarma, P. Dahal, S. Kumar, A. B. Chaudhari and R.R. Pant, Chemical characteristics of the Karmanasha river water and Its appropriateness for irrigational usage. Journal of Nepal Chemical Society **41(1)**, 94–102 (2020). https://doi.org/10.3126/jncs.v41i1.30494

[55] M. Gad, A. H. Saleh, H. Hussein, S. Elsayed and M. Farouk, Water quality evaluation and prediction using irrigation indices, artificial neural networks, and partial least square regression models for the Nile River, Egypt. Water, **15(12)**, 224 (2023). https://doi.org/10.3390/w15122244

[56] A. H. M. J. Al Obaidy, E. S. Awad, A. J. Kadhem and A. A.Al Mashhady, Evaluating water quality of Mahrut River, Diyala, Iraq for irrigation. Engineering and Technology Journal, **33(4)**, 830–837 (2015).

[57] S. H. Ewaid, "Irrigation water quality of Al-Gharraf Canal, south of Iraq," in *IOP conference, Journal of Physics* (Vol. 1003, No. 1, p. 012006) (IOP Publishing, 2018). DOI 10.1088/1742-6596/1003/1/012006

[58] E. Ukoha-Onuoha, I. Fubara-Manuel, R. B. Jumbo, and E. Ikrang, Assessment of river water quality for irrigation using multiple indices. Journal of Research in Environmental and Earth Sciences, **8(3)**, 53–56 (2022).

[59] A. Subramanian and S. Baskar, Water quality assessment of Noyyal river using water quality index (WQI) and multivariate statistical techniques. Water Science, **36(1)**, 85–98 (2022). https://doi.org/10.1080/23570008.2022.2129146

[60] P. Laze, S. Rizani and I. Alban, Assessment of irrigation water quality of Dukagjin basin in Kosovo. Journal of International Scientific Publications, **4**, 544–551 (2016). https://www.scientific-publications.net/en/article/1001070/

[61] T. Kasa, A. L. Bassa, G. T., Negatu, Z. A. Sahile, D. Reddythota, Investigation of Wabe River water fitness for agricultural and industrial purposes. Heliyon, **8(12)**, e11865 (2022). https://doi.org/10.1016/j.heliyon.2022.e11865
K. A. Abdulrazzaq and W. S. Kamil, Construction water suitability maps of Tigris River for irrigation and drinking use. Journal of Engineering, **16(04)**, 5822–5841 (2010