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Evaluation of the water quality of the Sirwan River in the Garmian region for irrigation purposes using the Irrigation Water Quality Guidelines (IWQG)

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Abstract: The water quality index (WQI) is one of the simplest ways of converting complex water quality data into an individual value that expresses the state of water quality. The present study aims to assess and classify the quality of water in the Sirwan River within Garmian Region for irrigation uses through using the Irrigation Water Quality Guideline (IWQG). The IWQG determines the risks of soil salinity and sodicity as well as the risks of water toxicity to various types of crops. The water samples were collected from (24) sampling stations in the Sirwan River downstream of Darbandikhan Dam and Jalawlaa Sub-district in December 2021. All the samples were analyzed in terms of physicochemical parameters, including (Ca^{+2}), (Mg^{+2}), (Na^{+}), (HCO_3^{-}), (Cl^{-}) and (EC). The results indicated that the (IWQI) values ranged from (42.34) to (56.70) with an average of (53.7), and most of the stations fall within the high restriction category. This indicates that the water quality of Sirwan River is suited for plants with moderate to high salt tolerance, and it can be used in high permeability soils. Salinity control practices should be implemented, except in water that contains low concentrations of (Na^{+}, Cl^{-} and HCO_3^{-}).

Key words: Irrigation, Irrigation Water Quality Guideline (IWQG), Sirwan River, Garmian Region, Restrictions.

Introduction

Water is considered the most invaluable natural resource, and it plays an indispensable role in the existence of life on our planet. Global pollution has increased due to increasing population, urbanization, industrialization and traffic. So, there is a need for accurate monitoring, database and information regarding water quality. The condition of the water is described by the term water quality, which includes the biological, physical and chemical characteristics regarding its suitability for different purposes.

Domestic waste is responsible for approximately 80% of water pollution in developing countries[1]. Also, mismanagement of water resources causes significant issues in the quantity and quality of water[2]. The quality of water resources has been deteriorating because of natural and anthropogenic activities. The anthropogenic factors include mining, waste disposal, animal production and agricultural processes, and fertilizers applications[3,4]. It is significant to study surface water bodies in terms of quality. Surface water worldwide is used for different purposes such as drinking, irrigation and industrial needs. Water quality monitoring is a significant part of the water management process. Also, data analysis is essential to identify and describe water quality problems. Moreover, the water quality monitoring process by the water quality index (WQI) is regarded as the foundation of water quality management[5].

Researchers in the past years proposed many irrigation water quality guidelines and classifications. These guidelines are essential; none have been satisfactory due to the variety of field conditions. Also, each does not give a comprehensive water quality in the rivers or reservoirs. A practical solution to this issue is utilizing an index that automatically combines all water quality parameters and provides an understood and readily description of water. The water quality index is considered a straightforward and effective tool for evaluating water quality by combining different parameters[6,7]. Thus, it converts the parameters to a single value which ultimately expresses the condition of water quality[8]. The water quality index has been used widely to evaluate different water sources, including surface and groundwater quality in various areas[9,10]. The concept of WQI relies on the comparison of parameters with standard values[11]. The primary aim of this study is to apply Irrigation Water Quality Guideline (IWQG) to the Sirwan River to assess its quality for irrigation uses. The IWQG has been developed recently to evaluate the quality of Iraqi water resources and help Iraqi people properly manage water resources.

Materials and methods

Study area

The Sirwan River is considered one of the main tributaries of the Tigris River, and it covers a distance of more than 445 km. The study area includes a distance of 80 km, starting from the downstream of Darbandikhan Dam to Jalawlaa Sub-district and passing through Kalar City, one of the largest districts in Sulaymaniyah Governorate. Twenty-four sampling stations were selected along the study area, as shown in figure (1).

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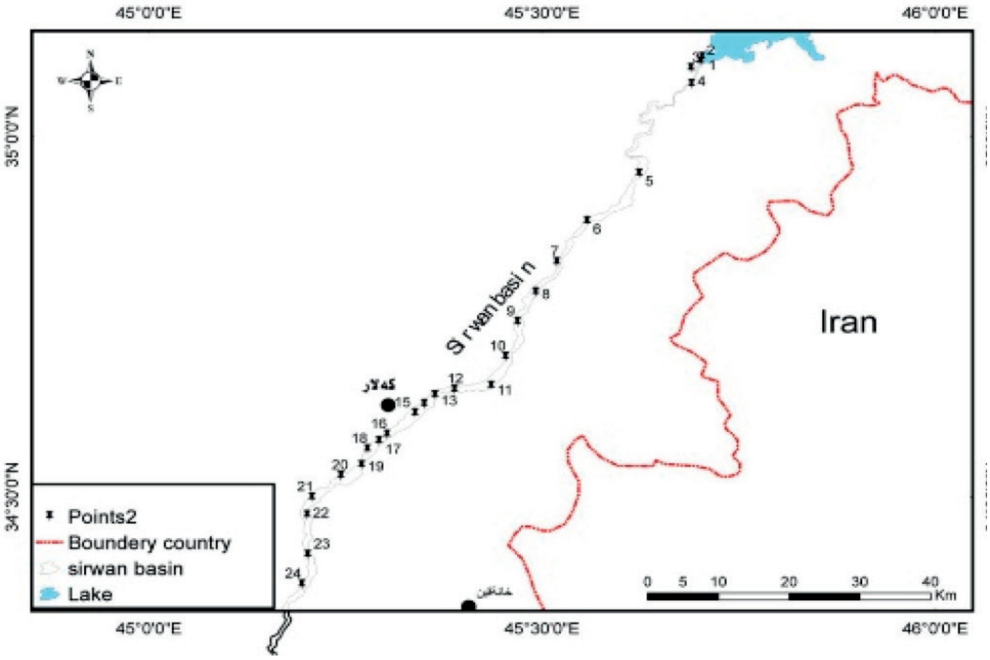

Figure 1. Sampling stations in the study area.

Sample collection and analysis

The samples were collected from each mentioned station in figure (1) in December 2021 in 1-L Polyethylene bottles, which were rinsed several times before filling. The pH and EC were immediately measured on-site using a portable pH meter and WTW conductometer. Some anions, including sulfite (SO_4^{-2}) and chloride (Cl^-), were measured by ion selective electrodes (SENTEK) after 24 hours from the date of sample collection; however, (HCO_3^-) was measured by titration. The cations (Ca^{+2}, Mg^{+2}, K^+ and Na^+) were measured using induced coupled plasma optical emission spectroscopy (ICPOES). The values of cations and anions were converted by the (IWQG) into some indices to evaluate water quality for irrigation uses.

IWQG software

Irrigation Water Quality Guidelines (IWQG) is a program that is set to assess water for irrigation uses according to the typical ranges of parameters and indexes according to FAO standard 1994[12] as shown in table (1). It was developed in 2014 at The National Center for Water Resources Management and was lately approved by the Ministry of Water Resources[13,14]. This program calculates water quality indicators for irrigation, as shown in table (2).

Applying the irrigation water quality index (IWQG) includes two main steps. The first is the statistical method or analysis of the main parameters, including HCO_3^-, Cl^-, Na^+, EC and SAR as the most critical indicators for water quality assessment.

The other step is allocating the sub-index quality (Qi) and the weight (Wi) for each parameter (ith). The (Wi) values were determined according to the values of the parameters in the studied area and the criteria according to Ayers and Westcot (1994), as shown in table (3). The total summation of (Wi) values must equal (1). The following equation was applied to calculate the values of (Qi) based on the tolerance limits shown in table (4)[24].

$$Qi = qi\ max - [(Xij - Xinf) * qiamp / Xamp] \qquad (I)$$

Where; (Qimax) is each category's maximum value of (qi). (Xij) is the monitored value of the parameter, and (Xinf) is the minimum value of the same parameter's category.

Parameters	Unit	Normal Ranges
Electric Conductivity (ECw)	$dS.m^{-1}$	0 – 3
Total Dissolved Solids (TDS)	$mg.l^{-1}$	0 – 2000
Calcium (Ca^{+2})	$mg.l^{-1}$	0 – 20
Magnesium (Mg^{+2})	$mg.l^{-1}$	0 – 5
Sodium (Na^+)	$mg.l^{-1}$	0 – 40
Carbonate (CO_3^-)	$mg.l^{-1}$	0 - 0.1
Bicarbonate (HCO_3^-)	$mg.l^{-1}$	0 – 10
Chloride (Cl^-)	$mg.l^{-1}$	0 – 30
Sulphate (SO_4^{-2})	$mg.l^{-1}$	0 – 20
Potassium (K^+)	$mg.l^{-1}$	0 – 2
Sodium Adsorption Ratio (SAR)	$Meq.l^{-1}$	0 – 15
Potential Hydrogen (pH)		6.5 - 8.5
Parameters	Unit	Normal Ranges

Table 1. Normal ranges of chemical parameters in irrigation water [15]

Index	Equation	Unit	References
Sodium Adsorption Ratio SAR	SAR= $Na/\sqrt{Ca+Mg/2}$	$meq.l^{-1}$	[15]
Adjusted Sodium Adsorption Ratio adj.SAR	$adj.SAR=(Na/\sqrt{Ca+Mg/2})*\{1+(8.4+PHc\}$	$meq.l^{-1}$	[15]
Sodium Percentage Na%	Na%=$(Na*100)$ / $(Ca+Mg+Na+K)$	$meq.l^{-1}$	[16]
Potential Salinity	$PS= Cl\text{-}+0.5*SO4\text{-}2$	$meq.l^{-1}$	[17]
Permeability Index (PI)	$PI=(Na+\sqrt{HCO3})x100/(Ca+Mg+Na)$	$meq.l^{-1}$	[17]
Kelley Index (KI)	$KR= Na/(Ca+Mg)$ KR values =<1 indicate suitability for irrigation; However, KR values >1 indicate unsuitability for irrigation uses.	$meq.l^{-1}$	[18], [19]
Magnesium hazard (MH)	MH=$(Mg/Ca+Mg)\times 100$ Values of MH =<50 indicate suitability for irrigation; However, MH values >50 indicate unsuitability for irrigation uses.	$meq.l^{-1}$	[20]
Soluble sodium percentage (SSP)	SSP= $((Na+k)*100)/(Na+Ca+K+Mg)$	$meq.l^{-1}$	[21]
Residual Sodium Carbonate (RSC)	RSC=$(CO_3^{-2}+HCO_3^{-})$ - $(Ca^{+2}+Mg^{+2})$	$meq.l^{-1}$	[22], [23]

Table 2. Irrigation water quality indexes.

Qi	EC (µs/cm)	SAR	Na^+	Cl^-	HCO_3^-
			meq/l		
0 – 35	EC < 200 or	SAR < 2 or	Na+ < 2 or	Cl− <1 or	HCO3− < 1 or
35 – 60	EC ≥ 3000	SAR ≥ 12	Na+ ≥ 9	Cl− ≥ 10	HCO3− ≥ 8.5
60 – 85	1500 ≤ EC < 3000	6 ≤ SAR < 12	6 ≤ Na+ < 9	7 ≤ Cl− < 10	4.5 ≤ HCO3− < 8.5
85 – 100	750 ≤EC < 1500	3 ≤ SAR < 6	3 ≤ Na+ < 6	4 ≤ Cl− < 7	1.5 ≤ HCO3− < 4.5
Wi	200 ≤ EC < 750	2 ≤ SAR < 3	2 ≤ Na+ < 3	1 ≤ Cl− < 4	1 ≤ HCO3− < 1.5

Table 3. The values of sub-index quality (Qi) and their weights (Wi) to calculate (IWQG), EC in (µs/cm) and all others in ($meq.l^{-1}$) [24].

Potential issue of irrigation		Restriction Degree		
		None	**Slight to Moderate**	**Severe**
Salinity	$EC(ds.m^{-1})$ at 25 ◦C	< 0.7	0.7 – 3	> 3
	$TDS(mg.l^{-1})$	< 450	450 – 2000	> 2000
Sodicity	SAR = 0 - 3 and EC	> 0.7	0.7 - 0.2	< 0.2
	SAR = 3 - 6 and EC	> 1.2	1.2 - 0.3	< 0.3
	SAR = 6 - 12 and EC	> 1.9	1.9 - 0.5	< 0.5
	SAR = 12 - 20 and EC	> 2.9	2.9 - 1.3	< 1.3
	SAR = 20 - 40 and EC	> 5	5 - 2.9	< 2.9
SAR		< 3	3 – 9	> 9
Chloride(Cl)($meq.l^{-1}$)		< 4	4 – 10	> 10
HCO_3($meq.l^{-1}$)		< 1.5	1.5-8.5	> 8.5
pH		6.5 - 8.5		

Table 4. The characteristics of water quality for irrigation [15]

(Qiamp) is the normal range of the category. (Xamp) is the normal range of each parameter within a category.

Then, the final step is calculating the (IWQI) as the following equation. The (IWQI) is ranged between (0-100), and its value is unitless.

$$IWQI = \sum_{i=1}^{n} W_i * Q_i \qquad (II)$$

The IWQI values indicate the acceptability of the water for irrigation uses, and its values are divided into five categories, as shown in table (5). The program calculates the ionic accuracy between cations and anions, and the values should not exceed 5%[25].

I

This is only suitable for plants with high salt tolerance, except for water that contains low concentrations of (Na, Cl and HCO_3).

It must not be used for irrigation in normal conditions. However, it can be used occasionally in some exceptional cases. Gypsum application is required for water with low salt concentrations and high SAR values. This type of water must be used only in high-permeability soils. To avoid salt accumulation, excess amounts of water should be applied.

IWQI value	Restriction type	Recommendations	
		Types of plants	Soil
85 - 100	No Restriction (NR)	It is suitable for plants, and there is no risk of toxicity.	It is recommended to be used for most types of soil with a low chance of causing sodicity and salinity issues. Also, It is recommended to be used for leaching within irrigation processes, except for deficient permeability soils.
70 - 85	Low Restriction (LR)	Suitable for most plants except salt-sensitive plants.	It is recommended to be used in light texture soils or moderate permeability, and it can be used for salt leaching. It can cause sodicity, especially in soils with heavy texture. So, it should not be used in soils with high clay content.
55 - 70	Moderate Restriction (MR)	Suitable for Plants that have moderate tolerance to salts.	It could be used in moderate to high permeability soils. It is recommended to be used for medium leaching of salts.
40 - 55	High Restriction (HR)	Suitable for Plants that have moderate to high tolerance to salts. Also, salinity control practices should be implemented, except in water that contains low concentrations of (Na, Cl and HCO_3).	It can be used in high-permeability soils. For water with EC > 2000 dS/m and SAR > 7, a schedule of frequency irrigation should be implemented.
0 - 40	Severe Restriction (SR)	This is only suitable for plants with high salt tolerance, except for water that contains low concentrations of (Na, Cl and HCO_3).	It must not be used for irrigation in normal conditions. However, it can be used occasionally in some exceptional cases. Gypsum application is required for water with low salt concentrations and high SAR values. This type of water must be used only in high-permeability soils. To avoid salt accumulation, excess amounts of water should be applied.

Table 5. Categories and characteristics of IWQG

Results and discussion

The results of the studied chemical parameters are shown below in table (6) and figure (2).

Potential Hydrogen (pH) is an essential factor that works as an indicator of contamination. Changing the pH of water increases the pollutants' toxicity; therefore, measuring the pH of water is very important. The values of pH in the study area varied between (7.19) (and 8.37) with a mean of (7.89).) Based on FAO standards, the acceptable limit of pH value for irrigation water is set between (6.5) (and 8.5). The results were found to be approximately neutral to slightly alkaline.

The results show that the electrical conductivity (EC) values of the Sirwan River ranged between (0.042) to (0.68) ds.m^{-1}. The lowest value of (EC) is at location (1), wherever the river enters the Kalar City border. Then, the values gradually increase until the river exits the city border, knowing that this increase is not a dangerous indicator. Also, this slight increase is attributed to wastewater containing higher concentrations of salt directly discharged into the Sirwan River. The EC mean value is (0.46) ds/m which indicates no saline condition of the river water[25] and no detrimental effects on plants.

The values of Ca^{+2}, Mg^{+2}, K^+ and Na^+ ranged between (61.7), (18.9), (9.8) and (1.1) to (110.3), (50.2), (13.2), (2.1) mg.l^{-1}, with average values of (91.58), (32.53), (11.13) and (1.74) mg.l^{-1} respectively. The abundance of the cations order is as follows Ca^{+2} > Mg^{+2} > Na^+ > K^+, where the Ca^{+2} and Mg^{+2} are the most dominant cations in Sirwan River.

The values of Cl^-, SO_4^{-2} and HCO_3^- ranged between (45), (74) and (130) to (88.3), (150.4) and (201.4) mg.l^{-1}, with average values of (71.62), (120.99) and (181.92) mg/l respectively. However, the importance of CO_3 was found to be very low, so it was neglected. The abundance of the anions order is as follows HCO_3^- > SO_4^{-2} > Cl^-. The results indicated that bicarbonate and sulfite are the dominant anions in the study area. A high concentration of bicarbonate is related to rock and water interaction. The cations and anions concentrations in the study area were within the normal ranges based on (FAO) guidelines.

The results also showed that the values of total hardness (TH) in the study area ranged between (236.75) (and 438) mg.l^{-1}. The lowest value was recorded at a station (1) due to the good quality of water that flows from the Darbandikhan dam and the absence of factories or large cities in that area. The highest concentration was recorded in the station (21) due to the high concentrations of calcium and magnesium. Most effluent dump sites are located within this area, which discharges directly without treatment. The mean value of total hardness (TH) was (365.45) mg.l^{-1}; therefore, the IWQG classified the water river as very hard. Hard water may cause soil organic matter dissolution. Also, it causes clay dispersion which ultimately causes poor soil structure, and water movement through the soil will be very slowly[26].

The cations and anions values were converted into some indexes regarding irrigation water quality, as shown in table (7) and figure (3).

The SAR is the relative concentration values of calcium, magnesium and sodium. It indicates the influence of Ca^{+2} and Mg^{+2} concentrations on Na^+ accumulation in the soil. Thus, a high concentration of Na^+ with a low concentration of Ca^{+2} may lead to a decline in the water within the root zone15,27. The values of SAR varied between (0.22) to (0.33) mg.l^{-1} with a mean value of (0.26) mg.l^{-1}; so, Sirwan River water is classified under excellent class, and it is suitable for irrigation uses. Based on the IWQG software results, the sodium adsorption ratio (SAR) values indicate a low sodium hazard of the Sirwan River water.

Adjusted Sodium Adsorption Ratio (adj.SAR) is an index that is usually used to determine the risk of alkalinity in irrigation water. The adj.SAR values with less than (3) are considered a good category; however, the bet will appear when the values range between (3-9). The risk becomes severe when the values are above (9)[15]. The results of the

No.	Location	pH	EC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	$SO4^{-2}$	HCO_3^{-}	Ion balance
			$ds.m^{-1}$	$mg.l^{-1}$							%
1	35°06'37.2"N 45°42'12.1"E	7.61	0.409	61.70	19.60	11.10	1.12	45.00	74.0	130.00	3.6
2	35°06'17.2"N 45°42'06.0"E	8.25	0.598	80.40	18.90	10.60	1.3	48.90	86.6	155.40	1.5
3	35°05'42.1"N 45°41'21.9"E	7.99	0.359	81.20	19.88	10.70	1.16	50.30	90.4	160.30	1.3
4	35°04'26.6"N 45°41'22.3"E	7.86	0.392	90.35	19.39	9.87	1.1	50.32	95.9	178.40	1.1
5	34°56'59.9"N 45°37'21.3"E	8.13	0.358	91.90	19.50	13.20	2.01	58.95	98.8	180.90	1.16
6	34°53'00.7"N 45°33'17.8"E	8.1	0.391	91.56	20.35	11.88	1.99	60.80	97.8	180.55	1.22
7	34°49'32.3"N 45°31'07.4"E	8.37	0.611	95.95	22.60	9.99	1.8	70.60	96.0	183.33	1.28
8	34°47'04.1"N 45°29'31.6"E	8.12	0. 43	100.54	23.66	9.90	1.67	76.45	100.6	188.50	1.08
9	34°44'33.3"N 45°28'11.9"E	8.2	0.42	110.30	26.80	9.80	1.18	78.76	120.4	195.65	2.08
10	34°41'41.1"N 45°27'24.3"E	8.36	0.412	99.60	30.33	11.11	1.78	77.90	125.8	180.00	1.06
11	34°39'15.3"N 45°26'05.8"E	7.25	0. 42	95.30	31.46	10.45	1.88	76.77	130.5	177.59	1
12	34°38'57.5"N 45°23'19.0"E	7.67	0.419	95.00	33.20	11.15	1.90	80.40	129.4	180.30	1.01
13	34°38'29.5"N 45°21'50.0"E	8.05	0.429	90.90	37.55	11.09	1.65	80.90	125.9	188.40	1.23
14	34°37'44.0"N 45°21'01.2"E	7.44	0.385	95.96	39.60	11.13	1.59	88.30	130.4	190.60	1.37
15	34°36'57.0"N 45°20'20.4"E	7.89	0.62	90.87	35.00	12.12	1.90	78.77	120.5	180.50	1.45
16	34°35'11.2"N 45°18'10.0"E	7.95	0.631	91.55	40.40	10.30	1.80	79.00	130.6	178.99	2.4
17	34°34'40.1"N 45°17'27.3"E	7.49	0.617	100.01	39.50	12.80	2.10	78.99	142.5	190.50	3.03
18	34°33'56.4"N 45°16'46.5"E	8	0.516	89.65	39.95	12.65	1.99	69.90	141.7	200.30	1.55
19	34°32'45.1"N 45°16'02.7"E	8.08	0.436	90.67	43.50	11.01	2.00	74.50	145.8	201.40	1.66
20	34°31'45.6"N 45°14'39.2"E	7.56	0.684	95.67	44.33	10.90	1.95	78.60	150.4	200.54	1.87
21	34°29'59.6"N 45°12'27.6"E	7.19	0.593	90.98	50.2	11.01	2.01	80	148.9	199.3	3.1
22	34°28'31.0"N 45°12'02.3"E	8.1	0.515	89.98	39.95	11.00	1.95	78.60	133.8	188.50	1.09
23	34°25'11.2"N 45°12'07.2"E	7.89	0.677	88.93	39.88	11.30	1.98	76.56	140.0	175.50	2.36
24	34°22'43.5"N 45°11'38.9"E	7.9	0.602	88.87	45.30	12.01	2.00	79.60	147.1	180.54	3.33

Table 6. The studied physicochemical parameters.

present area showed that the adj.SAR values are varied between (0.26) to (0.39) with an average of (0.31). Therefore, the Sirwan River water is classified under the excellent category, and there is no risk associated with adj.SAR.

The values of sodium percentage (Na%) ranged between (5.6%) (and 9.73%). These values indicated excellent conditions which never impact soil structure, and the plants can increase. However, excess amounts of sodium in irrigation water adversely affect soil structure, and the plants cannot survive growth easily[28].

All irrigation water 'regardless of its sources' contains several dissolved salts. These dissolved salts are the leading indicators determining irrigation water quality due to their role in raising the osmotic pressure of soil solution and the deterioration of soil properties over the long term of irrigation. A table (2) mentioned, the potential salinity index (PS) is defined as the summation of chloride and half of the sulfate concentrations. The PS values of all the water samples ranged between (2.14) (and 4.23) with an average of (3.53). The values of PS in all the water samples of Sirwan River are classified under the safe category. So, it is suitable for all types of soil textures.

Each of (Na^+, Ca^{+2}, Mg^{+2} and HCO_3^-) concentrations affects water's permeability index (PI) for irrigation uses. The PI values of the water samples ranged between (5.2) (and 9.21) with a mean value of (6.34). The PI values of all the samples are classified under the suitable category. Also, these results indicate that the water in the Sirwan River is ideal for soil permeability which is not influenced by long-term irrigation.

Soluble sodium percentage (SSP) is also one of the most critical parameters implemented to evaluate irrigation water's hazard. The soluble sodium percentage (SSP) values ranged from (5.6) to (9.73) with a mean value of (6.86). The results of (SSP) reflect that all the water samples in the river are classified under the good category.

The magnesium hazard (MH) is expressed in terms of magnesium hazard or magnesium adsorption rate (MAR), which is mentioned in table (2). The magnesium hazard computed values of the water in the studied dam ranged between (26.16) (and 47.89) with an average of (36.46). Based on the results, the water samples are less than (50), thus safe and suitable for irrigation.

The Kelly's ratio index (KR) is another way to determine the risk of sodium on water quality for irrigation uses. It also illustrates the potential impacts of sodium on irrigation water. According to the results, the Kelly ratio values of the water samples varied between (0.05) to (0.1) with a mean value of (0.07). These results fall under the (<1) limit and are considered suitable for irrigation usage.

Increased the concentration of Na^+ in irrigation water, thus, causing soil dispersion, and Na^+ is replaced with Ca^{+2} [25]. Therefore, the values of Kelly ration for irrigation water must not exceed (1) [29] [30]. Based on the results of the studied area, all water samples fall under suitable water for irrigation, and there is no significant excess of Na in the studied area.

Residual sodium carbonate (RSC) is one of the most significant parameters in determining the suitability of water for irrigation. According to the results of the present study, all the RSC values are less than (0). Therefore, the water samples of Sirwan River are classified under the excellent category for irrigation uses as there are no RSC-associated problems.

Irrigation water with high residual sodium carbonate (RSC) causes high sodium hazards. Also, alkaline soil (high pH) causes infertility in the soil due to Na_2CO_3 deposition[31]. Excessive values of HCO_3 and CO_3 in irrigation water causes reactions with Ca^{+2} and Mg^{+2} in the soil solution. This will allow the adsorbed Na^+ to dominate the clay surfaces.

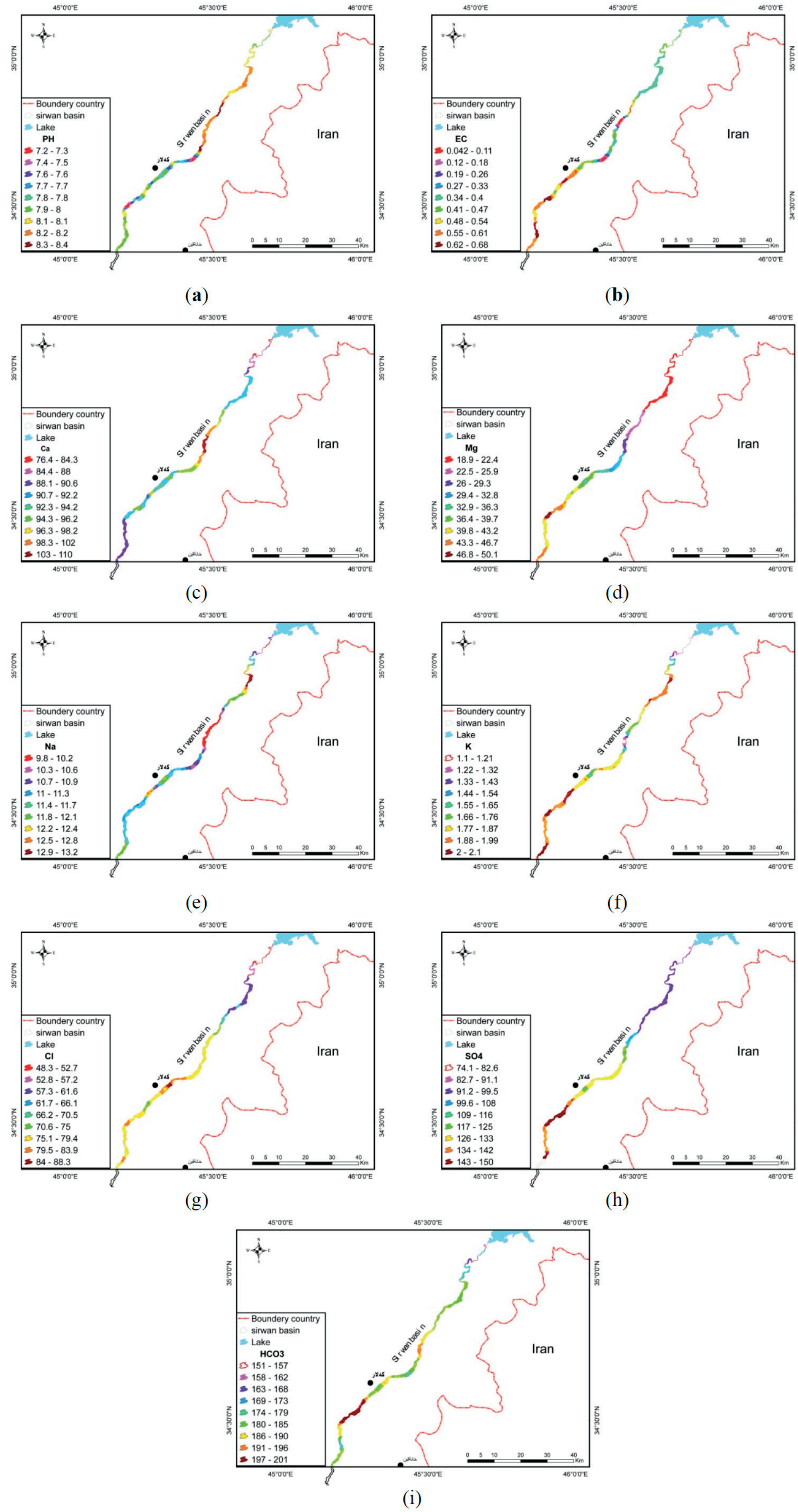

Figure 2. Distribution of (pH, EC, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, SO_4^{-2} and HCO_3^{-}) values within the study area.

The results of IWQG in more than (58.3%) of the studied sampling stations have high limitations in use for most crops, as shown in table (8) and figure (4). Most of the sampling stations located between Kalar District and Jalawalaa Sub-district have high restrictions due to discharging significant amounts of effluent wastewater into the river daily without any treatment. Kalar District is the largest city within the study area, and its population is over (250) thousand people. Irrigation water with high restriction is suitable for plants with moderate to high salt tolerance.

However, approximately (41.7%) of the samples have moderate limitations. So, irrigation water with reasonable regulations is suitable for plants that have moderate tolerance to salts and could be used in average to high permeability soils. It is recommended to be used for medium leaching of salts. Also, salinity control practices should be implemented, except in water that contains low concentrations of (Na^+, Cl^- and HCO_3^-). For water with an EC value of more than 2000 dS/m and SAR value above (7), a schedule of frequency irrigation should be implemented.This is example 2 of an equation:

Conclusions

The Iraqi Irrigation Water Quality Guide (IWQG) has been used to evaluate and prove the suitability of water in the Sirwan River for irrigation uses. The results of this program will help the decision-makers, researchers, experts and farmers to design and calculate water quality quickly and properly. The values of electrical conductivity (EC) and the concentrations of cations and anions in all the study locations were within the permissible limits according (to FAO). Still, there were slight increases in these values within the Kalar City border due to disposing of large amounts of wastewater into the river. Also, the results revealed that the total hardness exceeded the permissible limits and reached the degree of extreme hardness in most of the sites, and it got more than (350) mg/l in most of the sampling stations. Moreover, the results of IWQG in most of the studied stations have high limitations. Therefore, the water quality of Sirwan River is suited to be used in irrigating crops with high or moderate tolerance to salt; thus, the farmers in the study area must avoid culturing salts-sensitive plants.

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Station	Na%	SAR	Adj. SAR	PS	TH	MH	PI	KI	SSP	RSC
1	9.73	0.31	0.37	2.14	236.75	34.67	9.21	0.1	9.73	<0
2	8.03	0.27	0.32	2.49	280.78	28.16	7.58	0.08	8.03	<0
3	8.03	0.28	0.33	2.61	286.79	28.97	7.58	0.08	8.03	<0
4	6.97	0.25	0.3	2.71	307.3	26.38	6.54	0.07	6.97	<0
5	9.18	0.33	0.39	2.94	311.81	26.16	8.52	0.09	9.18	<0
6	8.32	0.29	0.35	2.86	314.31	27.07	7.65	0.08	8.32	<0
7	6.69	0.24	0.29	3	334.83	28.25	6.17	0.07	6.69	<0
8	6.29	0.23	0.27	3.18	350.35	28.14	5.79	0.06	6.29	<0
9	5.6	0.22	0.26	3.61	388.39	28.87	5.25	0.06	5.6	<0
10	6.47	0.25	0.3	3.7	376.39	33.64	6	0.06	6.47	<0
11	6.45	0.24	0.29	3.79	370.39	35.54	5.85	0.06	6.45	<0
12	6.69	0.25	0.3	3.84	376.9	36.79	6.11	0.07	6.69	<0
13	6.34	0.24	0.29	3.75	384.42	40.76	5.88	0.06	6.34	<0
14	6.02	0.24	0.29	3.95	406.44	40.76	5.58	0.06	6.02	<0
15	7.2	0.27	0.32	3.62	373.9	39.09	6.63	0.07	7.2	<0
16	5.81	0.23	0.27	3.82	397.94	42.39	5.36	0.06	5.81	<0
17	6.84	0.27	0.32	4.12	415.95	39.71	6.31	0.07	6.84	<0
18	7.13	0.28	0.33	3.99	391.43	42.58	6.57	0.07	7.13	<0
19	6.09	0.24	0.29	4.05	408.95	44.43	5.55	0.06	6.09	<0
20	5.77	0.23	0.27	4.21	424.97	43.58	5.25	0.06	5.77	<0
21	5.71	0.23	0.27	4.23	438	47.89	5.2	0.05	5.71	<0
22	6.33	0.24	0.29	3.91	392.43	42.47	5.77	0.06	6.33	<0
23	6.49	0.25	0.3	3.98	389.43	42.8	5.93	0.06	6.49	<0
24	6.48	0.26	0.31	4.23	411.96	45.93	5.94	0.06	6.48	<0

Table 7. This is a table. Tables should be placed in the main text near to the first time they are cited.

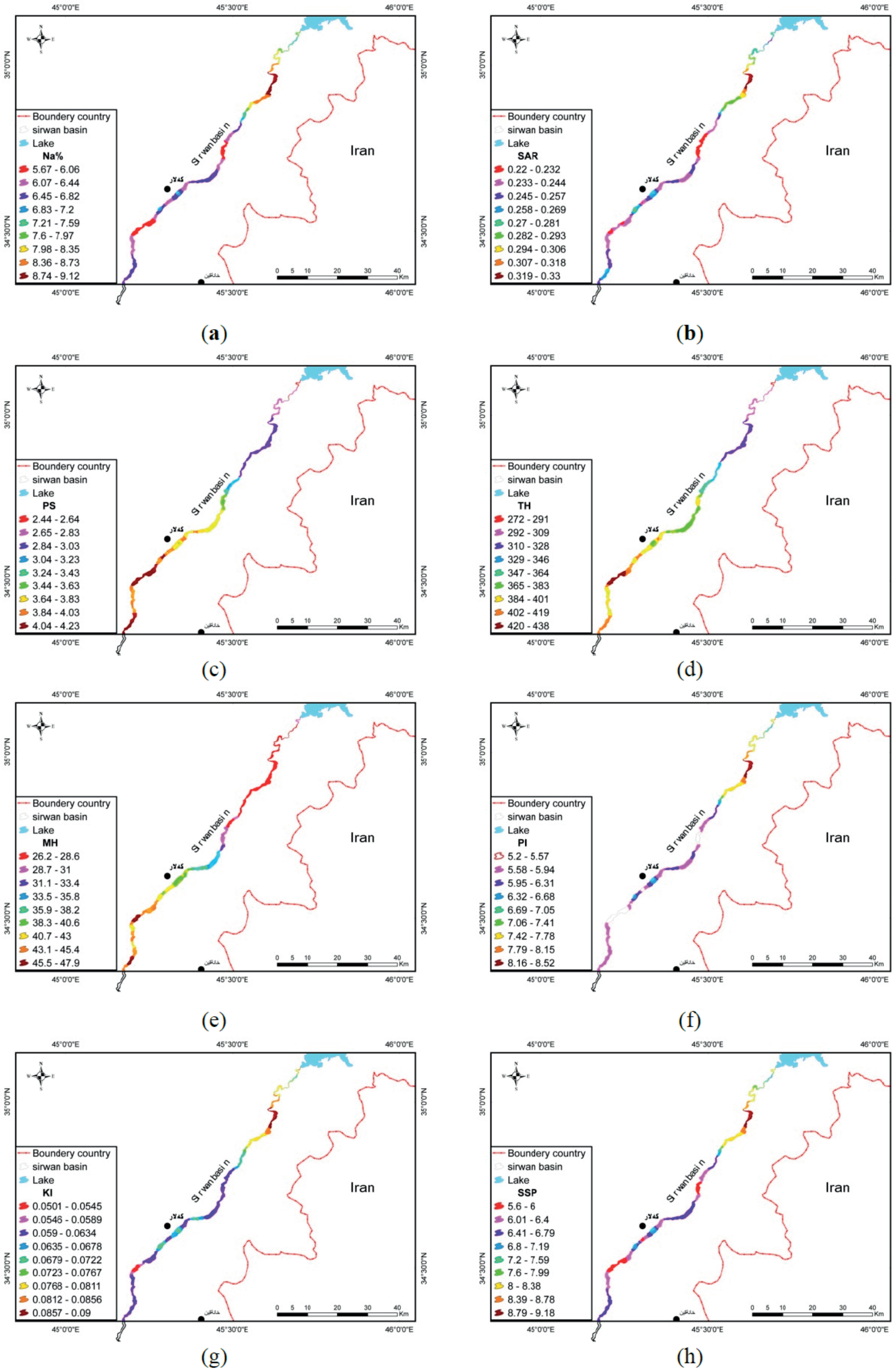

Figure 3. Distribution of (Na%, SAR, PS, TH, MH, PI, KI and SSP) values in the study area.

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No.	WQI	Restriction type
1	56.49	Moderate Restriction (MR)
2	54.58	High Restriction (HR)
3	56.7	Moderate Restriction (MR)
4	56.53	Moderate Restriction (MR)
5	55.96	Moderate Restriction (MR)
6	56.08	Moderate Restriction (MR)
7	54.43	High Restriction (HR)
8	43	High Restriction (HR)
9	55.87	Moderate Restriction (MR)
10	55.57	Moderate Restriction (MR)
11	42.34	High Restriction (HR)
12	55.37	Moderate Restriction (MR)
13	55.44	Moderate Restriction (MR)
14	55.75	Moderate Restriction (MR)
15	53.43	High Restriction (HR)
16	53.53	High Restriction (HR)
17	52.85	High Restriction (HR)
18	53.82	High Restriction (HR)
19	54.98	High Restriction (HR)
20	52.55	High Restriction (HR)
21	53.39	High Restriction (HR)
22	54.41	High Restriction (HR)
23	52.7	High Restriction (HR)
24	53.06	High Restriction (HR)
Average	53.7	High Restriction (HR)

Table 8. This is a table. Tables should be placed in the main text near to the first time they are cited.

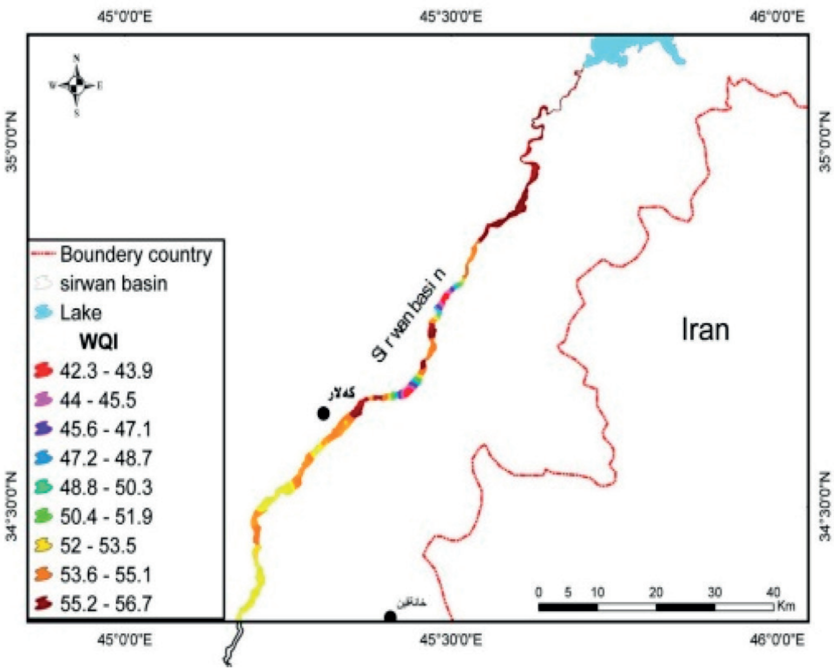

Figure 4. Distribution of WQIG values within the study area.

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