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IRRIGATION WATER QUALITY ASSESSMENT USING CROSS IN DUHOK GOVERNORATE, KURDISTAN REGION OF IRAQ

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ABSTRACT:

This study was conducted in the Duhok Governorate, Kurdistan Region of Iraq. A total of eleven natural water samples were collected from different water sources, including Rivers, lakes, wells, and drainage canals. All samples were analyzed in triplicate to ensure accuracy and reproducibility. Electrical Conductivity (EC), pH, Bicarbonate (HCO_3^-), major Cations: Calcium (Ca^{2+}), magnesium (Mg^{2+}), Sodium (Na^+), and Potassium (K^+) were determined.

Sodium (Na) levels ranged from 0.075 to 34.883 $mmol_c\ L^{-1}$, with Kashi exhibiting the highest concentration, while the lowest one was registered in the Khabur River (0.075 $mmol_c\ L^{-1}$). Potassium (K) concentration was generally low across all samples, with a mean of 3.253 mmol/L. Khabur River had the lowest across all samples (0.055 $mmol_c\ L^{-1}$). The highest was in Hishkarow (0.63 $mmol_c\ L^{-1}$). Calcium levels vary widely from 1.05 to 5.4 $mmol_c\ L^{-1}$, with Bedol River showing the highest Ca concentration. Magnesium levels were higher than Ca in some samples. Qasara well 2 had the highest magnesium (Mg) concentration (6.00 $mmol_c\ L^{-1}$), while the lowest was determined in Bedol River (0.6 $mmol_c\ L^{-1}$). The adjusted Ca concentrations ranged from 0.907 to 3.548 mmolc L^{-1}, with the highest value in Duhok Dam. Highest Kashi EC (4.290 dS. m^{-1}) indicates very high salinity, which may affect water usability for irrigation, in contrast to the lowest in Bedol River (0.406 dS. m^{-1}), which suggests good water quality with low dissolved salts. Sodium Adsorption Ratio (SAR) was the highest for Kashi (17.082), indicating a high risk of soil dispersion if used for irrigation; however, the lowest was (0.056) for Khabur River, suggesting no salinity hazard. CROSS values ranged from 0.091 to 18.368, and CROSS (using adj. Ca) ranged from 0.103 (Khabure River) to 24.341 in (Kashi).

The results highlighted variation in all parameters, influencing the suitability of these water sources for irrigation. The best water source for agriculture is the Khabur River, which has the lowest Na, EC, and SAR values, making it the best choice. The worst water source is Kashi, which has extremely high sodium, EC, and SAR values, making it unsuitable for irrigation. Municipal and Dam water, generally moderate in all parameters, making them safer for multiple uses. In contrast, well water varies but tends to have higher magnesium levels.

KEYWORDS: Sodium Adsorption Ratio, Cation Ratio of Structural Stability, irrigation water quality, adjusted Ca, wastewater.

1. INTRODUCTION

Surface water quality is a delicate and essential problem in many countries with arid or semi-arid climates that are easily affected by climate change (Arshad & Bano, 2018). Increasing pressure on agricultural food production in semi-arid areas forces farmers to use low-quality irrigation water. Therefore, anywhere in the world, the sustainability of maintaining a safe and dependable water supply would be more important (Hutson & Ickert, 2012). The exploitation and inefficient use of water, coupled with the increased demand for water resources due to economic and population growth, has led to a scarcity of fresh water (Prajapati *et al.,* 2021; Zhang & Shi, 2019), and affecting the sustainability of agricultural production (Aparicio *et al.,* 2019). Therefore, it has become necessary to find alternative water resources of varying quality (such as brackish water, sewage water, or well water, etc.) for agricultural irrigation, which can reduce the dependence on the supply of fresh water for agricultural production (Yang *et al.,* 2020). However, the other side of the problem is that irrigation with saline water can lead to soil salinization and/or increased sodicity, which leads to the deterioration of soil physical and chemical properties through the dispersion of clay particles (Bouksila *et al.*, 2013; Hack-ten Broeke *et al.,* 2016; Zhang *et al.,* 2018). In addition, one of the major sources of heavy metal contamination in agricultural soils is wastewater irrigation. People's life has attracted more attention to researchers to study the effect of pollutants emitted from industrial activity and other technologies (Muhyadeen & Ramadhan, 2023).

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Marchuk *et al.* (2014) indicated that sodium alone does not cause soil dispersion because dispersion depends on the chemical component of clay structure, which is mainly a function of ionic valence and hydration radius. Sposito *et al.* (2016) showed that irrigation water with high concentrations of potassium for long periods may create substantial challenges in preserving good soil structure and adequate infiltration rates. K^+ is not as effective as Na^+ in generating soil particle dispersion and swelling problems. However, Marchuk (2014) pointed out that K^+ could substitute Na^+ on exchange sites to encourage Na^+ leaching and increase water conductivity to some extent. Recent research and experiments have shown that high concentrations of potassium and magnesium in wastewater and recycled water, which are now widely considered for reuse as irrigation water due to the global shortage of natural water resources, may negatively impact the permeability of irrigated soils (Arienzo *et al.,* 2012; Buelow *et al.,* 2015; Marchuk & Rengasamy, 2011; Smith *et al.,* 2015;). A newly proposed equation, the cation ratio of soil structural stability (CROSS) is used because traditional SAR ignored the role of K^+. Rengasamy and Marchuk (2011) pointed out that CROSS integrates the effects of Na^+ and K^+ in soil, which is an important indicator for assessing the quality of saline water. Oster *et al.* (2016) proposed substitution of CROSS for SAR in irrigation water quality guidelines as a generalization of Sodium hazard to include the relative deleterious impact on soil hydraulic properties of the four common cations (Na, K, Ca, and Mg).

Therefore, it is necessary to revisit the assessment of irrigation water not only for the risk of sodium but also for potassium and the risk of soil permeability more broadly. So, the study focuses on how potassium concentrations in irrigation water influence soil permeability and proposes using the Cation Ratio of Structural Stability (CROSS) as an improved indicator compared to the traditional Sodium Adsorption Ratio (SAR).

2. MATERIALS AND METHODS

This study was conducted in the Duhok Governorate, Kurdistan Region, north of Iraq. Eleven natural water samples were collected from different sources, including Rivers, lakes, wells, and drainage canals. The selection of water sources aimed to represent a range of salinity levels and varying concentrations of sodium (Na) and potassium (K).

The water samples were collected from different sources, namely, Lenava River, Bedol River, Khabur River, Hishkarow River, and Kashi (as municipal water), Duhok dam, Screen dam, Tin dam, Agricultural Engineering Sciences College well, Qasara well (1), and Qasara well (2), as shown in Figure 1.

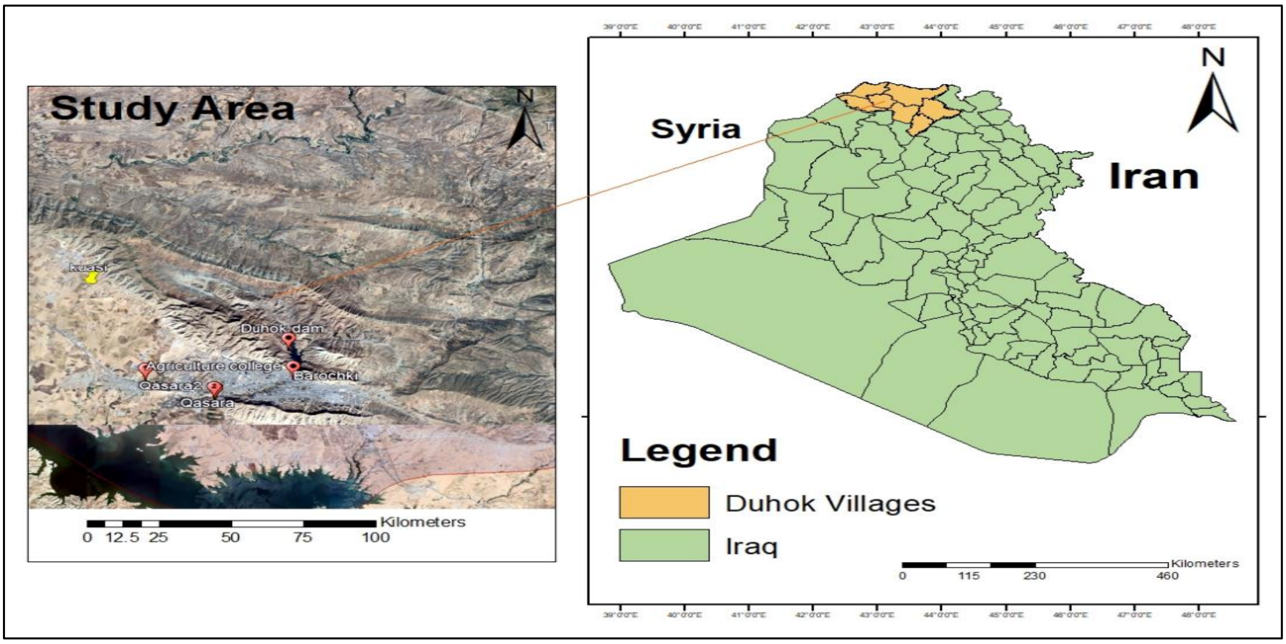

Figure 1: The map illustrates the location of water samples.

Water samples were collected in 500 mL polyethylene bottles, pre-rinsed with the sample water to prevent contamination. Samples were filtered to remove particulate matter. The collected water was transported to the laboratory, stored at 4°C in a refrigerator for analysis within 24 hours. All samples were analyzed in triplicate to ensure accuracy and reproducibility. The methods followed for the analysis of different chemical parameters of water have been adopted from APHA (2005).

A brief description of analytical methods was: Electrical Conductivity (EC) measured using a conductivity meter model (BC3020) and expressed by $dS.m^{-1}$ according to (Rowell, 1996), pH determined using a pH meter model (BP3001) as described by (Jackson, 1958). Major Cations: Calcium and magnesium were determined by titration with (EDTA 2Na) (0.01N) with the presence of murexide (ammonium purareate) and EBT as an indicator (Rowell, 1996). Sodium (Na^+) and Potassium (K^+) were determined using a flame photometry model (JENWAY/PFP7). Titration method using 0.02N HCl with phenolphthalein as an indicator for the determination of Bicarbonate (HCO_3^-) (Estefan *et al.,* 2013).

Water quality assessment parameters were calculated as follows:

SAR was calculated using the following equation according to (Richards, 1954):

$$SAR = (Na) / \sqrt{(Ca+ Mg)/2}. \quad \text{…eq (1)}$$

The cation concentrations are expressed in $mmol_c\ L^{-1}$

The CROSS (Cation Ratio of Structural Stability) index was used to evaluate irrigation water quality, focusing on the balance of cations (Ca, Mg, Na, and K).

CROSS was calculated using the following equation according to Rengasamya and Marchuka (2011)

CROSS= (Na + 0.56K)/√ (Ca+ 0.6Mg)/2. …. eq. (2)

Adjusted Ca^{+2} calculated according to Lesch and Suarez (2009).

3. RESULTS AND DISCUSSION

Table 1 presents chemical parameters of water samples collected from different sources, including Rivers, municipal supplies, dams, and wells. The key parameters include sodium (Na), potassium (K), calcium (Ca and Ca adjusted), magnesium (Mg), electrical conductivity (EC), sodium adsorption ratio (SAR), and SAR corrected using Ca and Ca adjusted ($CROSS_0$).

Table 1: Chemical analysis and water quality parameters data

Parameters			Na^+	K^+	Ca^{2+}	Ca adj	Mg^{2+}	EC dS. m^{-1}	SAR	$CROSS_0$	SAR	$CROSS_0$
			mmol$_c$ L^{-1}						Using Ca (mmol$_c$ L^{-1})$^{0.5}$		Using Ca adj (mmol$_c$ L^{-1})$^{0.5}$	
Water Source	Rivers	Lenava River	3.400	0.14	2.50	2.066	2.40	1.189	2.174	2.482	2.278	2.631
		Bedol River	1.150	0.11	5.40	1.888	0.60	0.406	0.663	0.713	1.031	1.428
		Khabur	0.075	0.055	1.45	0.907	2.03	0.426	0.056	0.091	0.619	0.103
	Municipal	Hishkarow	3.180	0.63	2.10	1.254	1.65	0.947	2.307	2.821	2.639	3.335
		Kashi	34.883	0.34	5.21	2.406	2.35	4.290	17.082	18.368	21.639	24.341
	Dams	Duhok Dam	2.290	0.16	2.10	3.548	1.80	0.894	1.644	1.895	1.404	1.571
		Screen Dam	1.110	0.23	1.60	1.490	3.20	0.408	0.694	0.933	0.725	0.949
		Tin Dam	0.950	0.11	1.05	1.134	4.55	0.502	0.567	0.735	0.564	0.728
	Wells	College Well	1.310	0.04	1.50	2.426	4.20	0.887	0.781	0.949	0.724	0.855
		Qasara Well 1	1.152	0.14	2.85	1.960	5.90	0.731	0.550	0.694	0.583	0.742
		Qasara Well 2	1.150	0.14	2.65	2.531	6.00	0.732	0.550	0.688	0.557	0.702

Sodium (Na) levels ranged from 0.075 to 34.883 mmolc L^{-1}, with Kashi exhibiting the highest Na concentration (34.883 mmol$_c$ L^{-1}). This suggests very high salinity, which could indicate contamination or mineral dissolution, followed by Lenava River (3.40 mmol$_c$ L^{-1}). Many researchers reported that high concentrations of Na in soil have often shown to disrupt soil structure which led to changes in many soils physical properties such as infiltration rate (Halliwell *et al.,* 2001; Olsson & Rengasamy,1991; Menner *et al.,* 2001; Steven *et al.,* 2003). While the lowest registered in Khabur River (0.075 mmol$_c$ L^{-1}) which could indicate very low sodium levels, making it suitable for irrigation.

Potassium (K) concentration was generally low across all samples with a mean of 3.253 mmolc L^{-1}. Khabur River had the lowest across all samples (0.055 mmol$_c$ L^{-1}). The highest was in Hishkarow River (0.63 mmol$_c$ L^{-1}), but still relatively low compared to sodium levels. Calcium levels vary widely from 1.05 to 5.4 mmol$_c$ L^{-1}, with Bedol River showing the highest Ca concentration. The highest adjusted calcium (3.548 mmol$_c$ L^{-1}) was with Duhok dam. Magnesium levels were higher than Ca in some samples (e.g., Tin dam: Mg (4.55 mmol$_c$ L^{-1}), and Ca (1.05 mmol$_c$ L^{-1}). Qasara well 2 had the highest magnesium (Mg) concentration (6.00 mmol$_c$ L^{-1}), while the lowest determined in Bedol River (0.6 mmol$_c$ L^{-1}).

The adjusted Ca concentrations ranged from 0.907 to 3.548 mmol$_c$ L^{-1}. Duhok dam (3.548 mmol$_c$ L^{-1}) had higher adj. Ca, indicating better ability to counteract sodium effect in irrigation.

Highest Kashi EC (4.290 dS.m^{-1}) indicates very high salinity, which may affect water usability for irrigation, in contrast to the lowest in Bedol River (0.406 dS.m^{-1}) which suggests good water quality with low dissolved salts. Sodium Adsorption Ratio (SAR), as expected, was the highest for Kashi 17.082 (mmol$_c$ L^{-1})$^{0.5}$ indicating a high risk of soil dispersion if used for irrigation; however, the lowest was (0.056) for Khabur River, which suggests no salinity hazard. When SAR values are corrected using calcium, Kashi has the highest corrected SAR 21.639 (mmolc L-1)0.5, making it unsuitable for irrigation, and Qasara well 2 has the lowest corrected SAR 0.557 mmol$_c$ L^{-1})$^{0.5}$, making it the best choice for agricultural use.

CROSS values ranged from 0.091to18.368(mmol$_c$ L^{-1})$^{0.5}$, which were higher than SAR values, same results obtained by Oster *et al.* (2016). CROSS (using adj. Ca) values followed a similar trend but slightly increased across most samples. CROSS (using adj. Ca) ranged from 0.103 (Khabure River) to 24.341 (mmol$_c$ L^{-1})$^{0.5}$ in (Kashi).

The above results highlight variations in all parameters, influencing the suitability of these water sources for irrigation. The best water source for agriculture is Khabur, which has the lowest Na, EC, and SAR values, making it the best choice. The worst water source is Kashi which has extremely high sodium, EC, and SAR values, making it unsuitable for irrigation. Municipal and Dam water, generally moderate in all parameters, making them safer for multiple uses. While Well water varies but tends to have higher magnesium levels.

The SAR values vary significantly across water sources (Figure 2). Kashi has the highest SAR (indicating sodicity risk). Most other water sources maintain low SAR values, reducing soil permeability issues. The use of SAR is recommended only when cations predominance is Na as stated by Murchuk *et al.* (2012), and CROSS recommended for cases with varying ratios of cations. Some sources (like Kashi) remain high in SAR, while others are consistently low. Similar to SAR, Kashi shows an extreme EC value Figure 3, reinforcing its high salinity risk. Most other sources maintain lower EC levels, indicating better irrigation suitability.

Considering water sources impact on soil, water sources with both high SAR and high EC (Kashi) should be avoided or treated before irrigation. Water with low EC but moderate SAR (e.g., Screen dam, Tin dam) can still pose risks and should be monitored. Well and Hishkarow River water sources generally show stable and safe levels, making them preferable for irrigation.

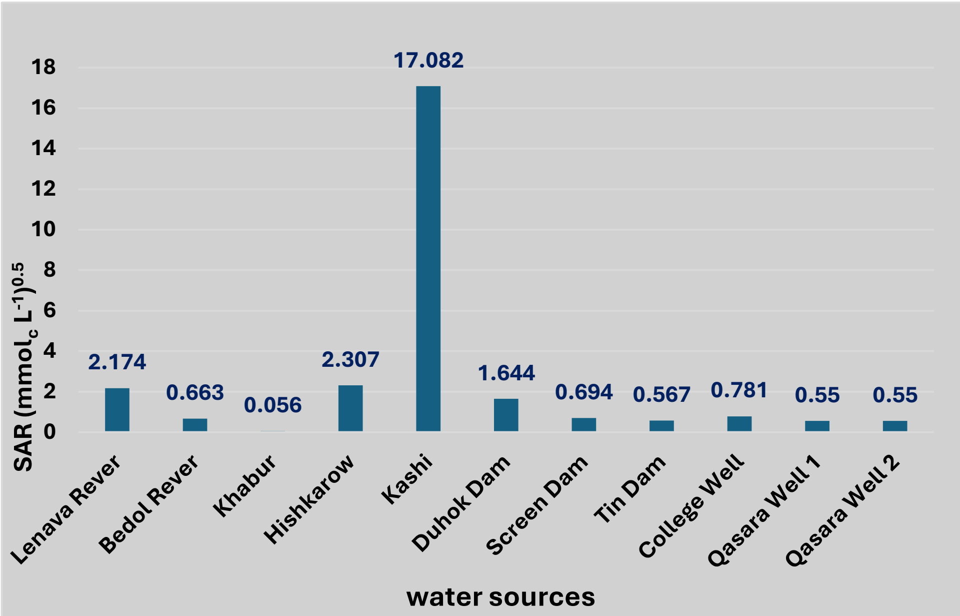

Figure 2: Trend analysis of SAR across water sources.

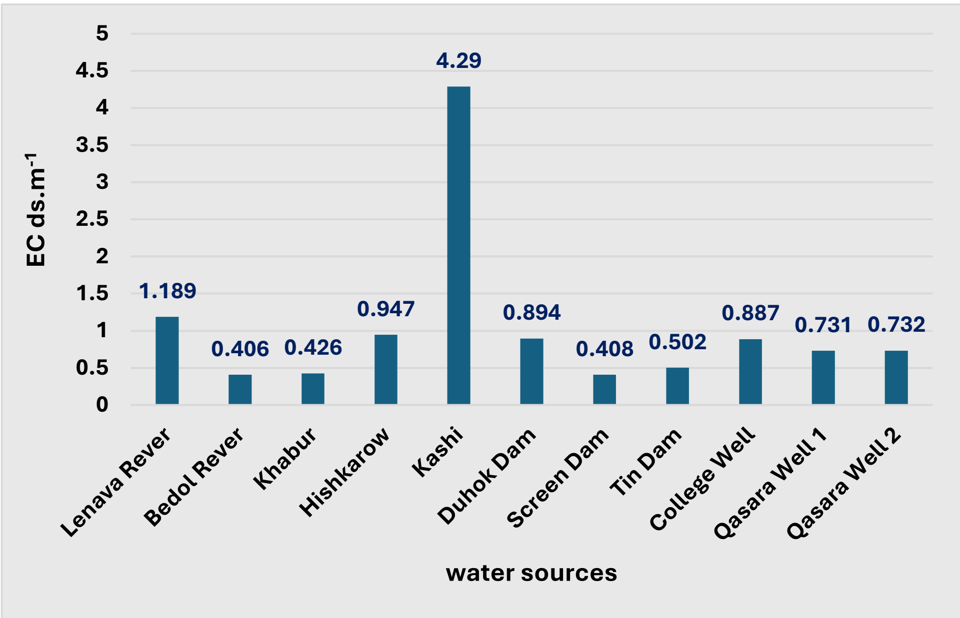

Figure 3: Trend analysis of EC across water sources.

Figures 4 and 5 show variation in CROSS values. With exception of Kashi, Hishkarow has the highest CROSS values, while Khabur River has the lowest CROSS values. Marchuk and Rengadsamy (2010) stated that clay dispersion highly correlated to CROSS rather than SAR.

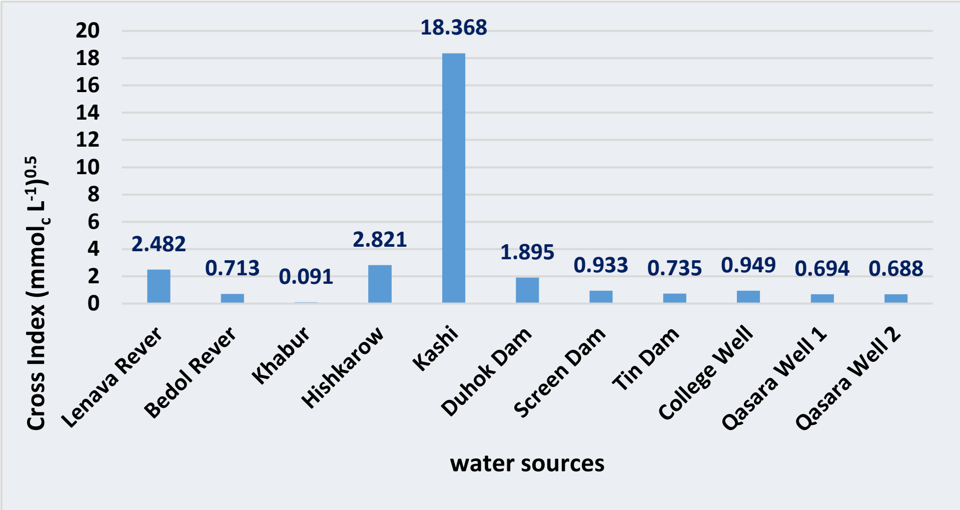

Figure 4:CROSS index across different water sources.

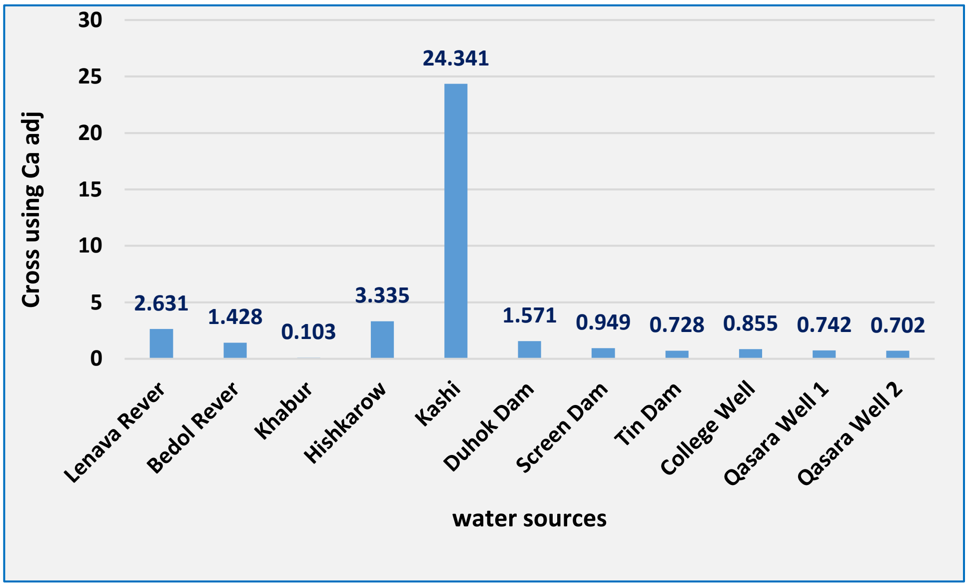

Figure 5: CROSS index (using Ca adj) across different water sources

The data in Figure 6 has been grouped into four main water categories: rivers (Lenava, Bedol, Khabur), Municipal (Hishkarow River, Kahi water), Dams (Duhok dam, Screen dam, Tin dam), and Wells (College Well, Qasara Well 1; Qasara Well 2). The comparative bar chart visually represents differences in SAR, CROSS, and EC across these water categories.

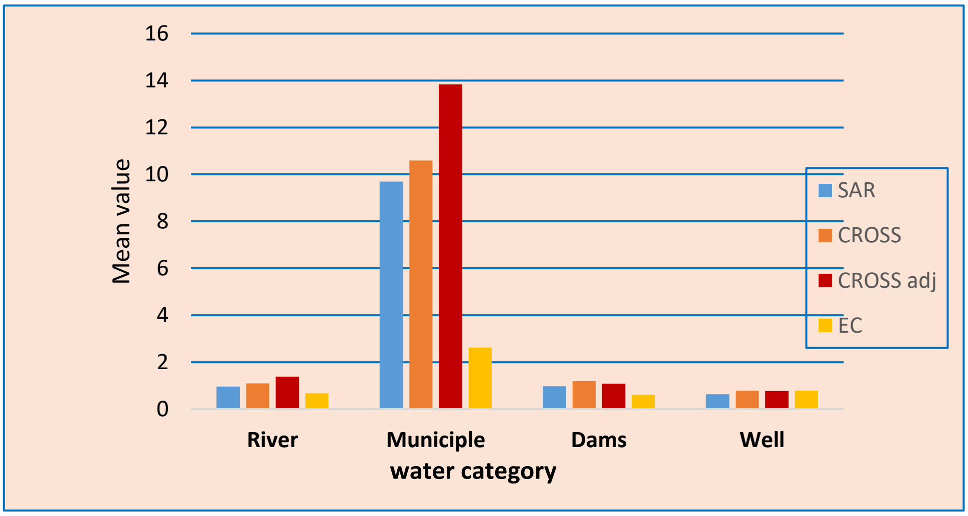

Figure 6: Comparative Analysis of Water Categories

Rivers have a higher SAR than wells and dams, suggesting potential sodium accumulation risks. Municipal water has a high SAR and a relatively high CROSS. Dams show the most balanced SAR and CROSS values, making them the most stable irrigation water sources. Wells have the lowest SAR and CROSS values, suggesting some sodicity risks, but their impact on soil permeability remains low to moderate.

Marchuk (2013), in his research outcomes, clarified that CROSS provides an accurate and more suitable guideline for the use of irrigation water of different cation composition, which enables management on suitability and rate of irrigation water.

Table 2: Interpretive guideline for assessing the combined effect of SAR and EC in irrigation water on soil infiltration problems.

Degree of impact of SAR according to EC			
SAR	None	Slight to moderate	Severe
$(mmol_c\ L^{-1})^{0.5}$	$dS.m^{-1}$		
0-3	>0.7	0.7-0.2	<0.2
3-6	>1.2	1.2-0.3	<0.3
6-12	>1.9	1.9-0.5	<0.5
12-20	>2.9	2.9-1.3	<1.3
20-40	>5.0	5.0-2.9	<2.9

Source Ayers and Westcot 1985

Using the SAR and EC data from Table 1 and based on the guidelines in Table (2), Table 3 classifies each water source into the "None," "Slight to Moderate," or "Severe" categories. Observations were:

1. Water sources with no impact on Soil Permeability ("None"): include Lenava River, Hishkarow Water, Duhok dam, College Well, Qasara Well 1 and 2. These sources have low SAR values and sufficient EC, preventing significant permeability problems. For example, Lenava River has an SAR of 2.174 $(mmol_c\ L^{-1})^{0.5}$ and an EC of 1.189 dS. m^{-1}, which is above the threshold for severe impact.
2. Water sources with “Slight to Moderate” impact include Bedol River, Khabur River, Screen dam, Tin dam. These sources fall in the slight to moderate category due to moderate SAR values and lower EC levels, example, Bedol River has an SAR of 0.663 $(mmol_c\ L^{-1})^{0.5}$ and an EC of 0.406 dS.m^{-1}, which puts it in the slight to moderate range.
3. Kashi case is categorized as "None" for SAR but "Slight to Moderate" for CROSS0 (SAR corrected with Ca adjustments). Oster *et al.* (2016) found an increase from (none) to (slight to moderate) when using cross instead of SAR in two wastewater and River water. This suggests that without adjustments, SAR is not a major issue, but after correction, potential risks appear. Kashi has an extremely high Na (34.883 mmolc. L^{-1}) and EC (4.290 dS.m^{-1}), indicating severe salinity issues, which can still impact infiltration over time.

Table 3: Natural water quality assessment (degree of impact on soil permeability) based on the guidelines in Table (2) and data in table 1.

Water source		**Water quality assessment**			
		Ca		**Ca adj**	
		SAR	**$CROSS_0$**	**SAR**	**$CROSS_0$**
Rivers	Lenava River	None	None	None	None
	Bedol River	Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate
	Khabur	Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate
Municipal	Hishkarow	None	None	None	None
	Kashi	None	None	Slight to moderate	Slight to moderate
Dams	Duhok Dam	None	None	None	None
	Screen Dam	Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate
	Tin Dam	Slight to moderate	Slight to moderate	Slight to moderate	Slight to moderate
Wells	College Well	None	None	None	None
	Qasara Well 1	None	None	None	None
	Qasara Well 2	None	None	None	None

When considering the implications for agricultural use, the best water sources for irrigation are Lenava River, Hishkarow water, Duhok dam, College Well, and Qasara Wells. These sources are safe for irrigation as they do not pose soil permeability issues. Farmers using these water sources will not face infiltration problems due to sodium. Bedol River, Khabur River, Screen dam, and Tin dam had moderate risk water sources. These sources should be monitored for sodium buildup.

Special consideration for Kashi is that the high sodium concentration with high SAR and EC suggests potential long-term soil structure damage. Though classified as "None" in SAR impact, the high salinity could lead to soil degradation over time. Kruger *et al.* (1995) reported that values SAR in the range of 6-8 present problems that can be ameliorated with gypsum but irrigation with water of SAR> 8 is not generally recommended.
Table 3 shows how different water sources fall into different risk categories based on SAR and EC. Water sources with high SAR and low EC pose infiltration risks; water sources with moderate SAR and moderate EC are borderline cases. However, Kashi is an outlier with very high EC and SAR, suggesting significant salinity and sodicity risks.

Conclusions and Recommendations:

For irrigation, most water sources (Hishkarow, Duhok dam, College Well, and Qasara Wells) are safe. Monitoring is necessary for the Bedol, Khabur, Screen, and Tin dams, as well as any potential amendments (such as gypsum or organic waste). Despite its SAR classification, Kashi poses a possible long-term salinity concern. It is always best to examine EC and SAR together to improve irrigation management. Because of its high SAR and EC, kashi should not be used for irrigation or intensive management. Time-series or seasonal data may be used in future studies to see if patterns develop over time.

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Ethical Statement:

The Ethical Committee of the University of the Zakho, Kurdistan region approved the current experiment.

Author Contributions:

All authors have made substantial intellectual contributions to this work. K.A.H was primarily responsible for the acquisition, analysis, and interpretation of the data and for drafting the initial manuscript. S.M.T.Y conducted the essential laboratory work, providing the foundational data for the study. Furthermore, all authors have collectively reviewed and approved the final version to be published and agree to be accountable for all aspects of the work, ensuring the integrity and accuracy of the research.

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