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The Impact of Al-Kharrazi Valley Discharges on the Water Quality of the Tigris River within Mosul City

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ABSTRACT

The water quality of the Al-Kharrazi stream was studied as a potential source of pollution to the Tigris River in various locations along its course. The study aimed to assess the degree of pollution and determine the stream's suitability for irrigation purposes. Parameters analyzed included pH (acidity), electrical conductivity (EC), calcium, magnesium (Mg), sodium (Na), potassium (K), sulfate (SO_4), chloride (Cl), and bicarbonate (HCO_3), as well as the sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), permeability index (PI), and Kelley's ratio (KR). The results indicated that, based on chloride concentrations, the water is not suitable for all types of crops. However, according to the sodium adsorption ratio (SAR), the water is suitable for irrigating most crops, except those highly sensitive to sodium. Overall, the study found that the stream water falls under the C3S1 category in the USSL classification, indicating high salinity with a low sodium hazard.

INTRODUCTION

Wadi Al-Kharazi is one of the natural valleys traversing the city of Mosul. It is considered a potential water resource that can be utilized after evaluating its suitability for irrigation purposes. Water quality is influenced by salinity levels, which in turn affect soil suitability for agriculture **(Shehab *et al.*, 2024)**.

Several factors influence the suitability of water for irrigation, the most significant of which include:

Salinity Hazard: Some dissolved salts such as sodium, calcium, magnesium, sulfates, chlorides, bicarbonates, and nitrates are essential nutrients for plant growth. However, excessive concentrations of these salts may negatively impact plants. Salt accumulation around the root zone reduces water availability to the plant, consequently inhibiting growth and potentially leading to plant desiccation **(Al-Hamadany *et al.*, 2024)**.

Toxicity: Water toxicity is primarily caused by elevated levels of sodium, chloride, and boron ions. High concentrations of these ions can impair plant growth and productivity. Furthermore, the degree of impact depends on plant species, as sensitivity to ionic concentrations varies. Toxicity is often associated with issues of salinity and soil permeability **(Shehab & Kannah, 2023)**.

Sodicity: Sodicity is one of the critical factors in determining irrigation water quality. An increase in sodium ion concentration relative to calcium and magnesium significantly alters soil structure and reduces permeability.

Various studies have demonstrated that different ions present in irrigation water may affect plants physiologically or indirectly by altering the surrounding soil environment, making it less suitable for plant development.

In a study on the Wadi Al-Kharazi basin, **Al-Singari and Al-Safawi (2018)** classified the water as C3 (high salinity) according to the USSL classification system, and as good quality based on the Irrigation Water Quality Index (IWQI). They noted elevated levels of electrical conductivity, salinity, sulfates, bicarbonates, and calcium ions, all of which can reduce the suitability of Wadi Al-Kharazi water for irrigation purposes.

Furthermore, **Abbas and Abdul Razzaq (2006)**, in their study on the upper Diyala River basin, categorized irrigation water into three classes:

Class I: Water suitable for unrestricted use, applicable to all crops (69.1%).

Class II: Water suitable with certain restrictions or precautions (19.9%).

Class III: Water with severe limitations for use in irrigation (11%).

Al-Taif and Al-Hadithi (1988) also emphasized the importance of maintaining salt balance in the plant root zone, a factor highly dependent on water quality and irrigation frequency.

Study area location

The city of Mosul is located in northern Iraq, between longitudes 43°16' and 43°30' E and latitudes 36°15' and 36°27' N. It is the second-largest city in Iraq in terms of population, with an estimated 1,739,800 inhabitants as of 2023 **(World Meter, 2023)**.

Mosul lies within the Low Folded Zone, part of the Arabian Plate, along the southern margin of the Zagros Fold-Thrust Belt **(Jassim & Goff, 2006; Bulmer, 2019)**. The northern and southern parts of the city are characterized by low and undulating terrain. The area is traversed by several narrow, elongated, and nearly parallel valleys that drain toward the Tigris River, making the study area topographically low. The lowest point lies within the floodplain of the Tigris, at an elevation of 215 meters above sea level. The Tigris River flows from north to south through the middle of this broad depression. The valleys of Mosul are located on both sides of the river **(Yaqoob *et al.*, 2012)**.

Al-Khrazayi Valley lies on the left (eastern) bank of the Tigris River, within the eastern part of Mosul. It extends from the northeastern part of the city, carrying stormwater runoff and rainwater, along with domestic waste. The valley is approximately 5.3 kilometers long and consists of two branches:

- The first branch originates from the villages of Al-Sadah and Al-Buawiza, passing through the Al-Hadbaa area, and enters Mosul University from the northeastern side **(Al-Sinjari & Al-Safawi, 2018)**.
- The second branch begins from Al-Kindi facility, passing through the Al-Kindi area, where it receives solid and liquid waste, such as sewage and household refuse, and enters the Presidential Palaces area within Mosul University.

Fig. 1. Satellite image showing the sampling sites for the study area (Google earth)

Study objective

The aim of this study was to evaluate the suitability of Wadi Al-Kharazi water within the boundaries of Mosul University for irrigating agricultural research fields and ornamental plants. The assessment is based on multiple water quality indicators, including:

Soluble Sodium Percentage (SSP)

Sodium Adsorption Ratio (SAR)

Permeability Index (PI)

Residual Sodium Carbonate (RSC)

Potential Salinity (PS)

Kelly's Index (KI)

Additional parameters such as individual ion concentrations, pH level, and electrical conductivity were measured.

Greywater sustainability

Greywater sustainability is a critical aspect of water conservation. Greywater, which is wastewater from sinks, showers, and washing machines, contains relatively low levels of contaminants compared to black water. By implementing effective greywater treatment systems, we can significantly reduce our reliance on potable water. These systems typically involve filtration, sedimentation, and disinfection processes to ensure that the treated greywater is suitable for non-potable uses such as irrigation, toilet flushing, and car washing. The benefits of greywater sustainability are numerous, including reduced water consumption, decreased wastewater treatment costs, and a smaller environmental footprint **(Sergio, 2023)**.

MATERIALS AND METHODS

In this study, three sampling sites were identified for collecting water samples from the Khrazawi stream within Mosul City, as shown in Fig. (1). Three samples were collected monthly for the year 2021. Electrical conductivity, pH, calcium, magnesium, sodium, potassium, nitrates, chloride, sulfates, and bicarbonates were measured following the international standard methods for water sample collection and analysis **(APHA, 2005)**, as shown in Table (1). Sodium Adsorption Ratio (SAR), Sodium Soluble Percentage (SSP), and Permeability Index (PI) were calculated according to **Nag and Das (2014)**. Residual Sodium Carbonate (RSC), Potential Salinity (PS), and Kelly Index (KI) were also calculated using the methods described by **Nag and Das (2014)** and **Moghimi (2016)**. All units were expressed in mill equivalents per liter (meq/L), calculated using the following equations:

$SAR = [Na] \ / \sqrt{([Ca + Mg]/ 2)}$

$PI = Na \ [(HCO3)1/2/(CA + Mg + Na)$

$RSC = (CO3+HCO3) - (Ca + Mg)$

$PS = Cl + 1/2 \ SO4$

$KR = Na / [\ Ca + Mg]$

Table 1. Chemical and physical analysis

Parameter	Method	Reference
Total Dissolved Solids (TDS)	Gravimetric Analysis at 108 C	APHA, 2005
Alkalinity	Titration with Sulfuric Acid	
Calcium Ca^{+2}	EDTA Titration	
Magnesium Mg^{+2}	Calculation	
Chloride Cl^{-1}	Argentometric Titration	
Total Hardness	EDTA Titration	
Sodium (Na^{+2})	Flame Photometry	
Potassium (K^{+})	Flame Photometry	
Phosphate PO_3^{-4}	Spectrophotometry	
Nitraten^{-3}	Multiparameter Bench Photometer	
Sulfate SO_4^{-2}	Spectrophotometry	
Electrical Conductivity (EC)	Electrical Conductivity meter	APHA, 2005
Turbidity	Turbidimeter	
pH	pH - meter	APHA, 2005

RESULTS

The water from Wadi Al-Kharazi is classified as C2S1, indicating medium salinity and low sodium hazard, and is considered *suitable* for irrigation based on Soluble Sodium Percentage (SSP) and Magnesium Hazard (MH) values. Additionally, it is rated as *moderate to good* for irrigation according to Permeability Index (PI) and Potential Salinity (PS) values. The water is also classified as *safe* for irrigation based on Residual Sodium Carbonate (RSC) levels. However, its use for irrigation is deemed *unsuitable* according to the Kelley Index (KI).

Table 2. Classification of Khirazai Valley irrigation water based on key indicators

Chapter	E.C	SAR	SSP	P.S	RSC	PI	KI	MH
Winter	C2	S1	Suitable	good	safe	moderate	unsuitable	Suitable
Summer	C2	S1	Suitable	moderate	safe	good	unsuitable	Suitable

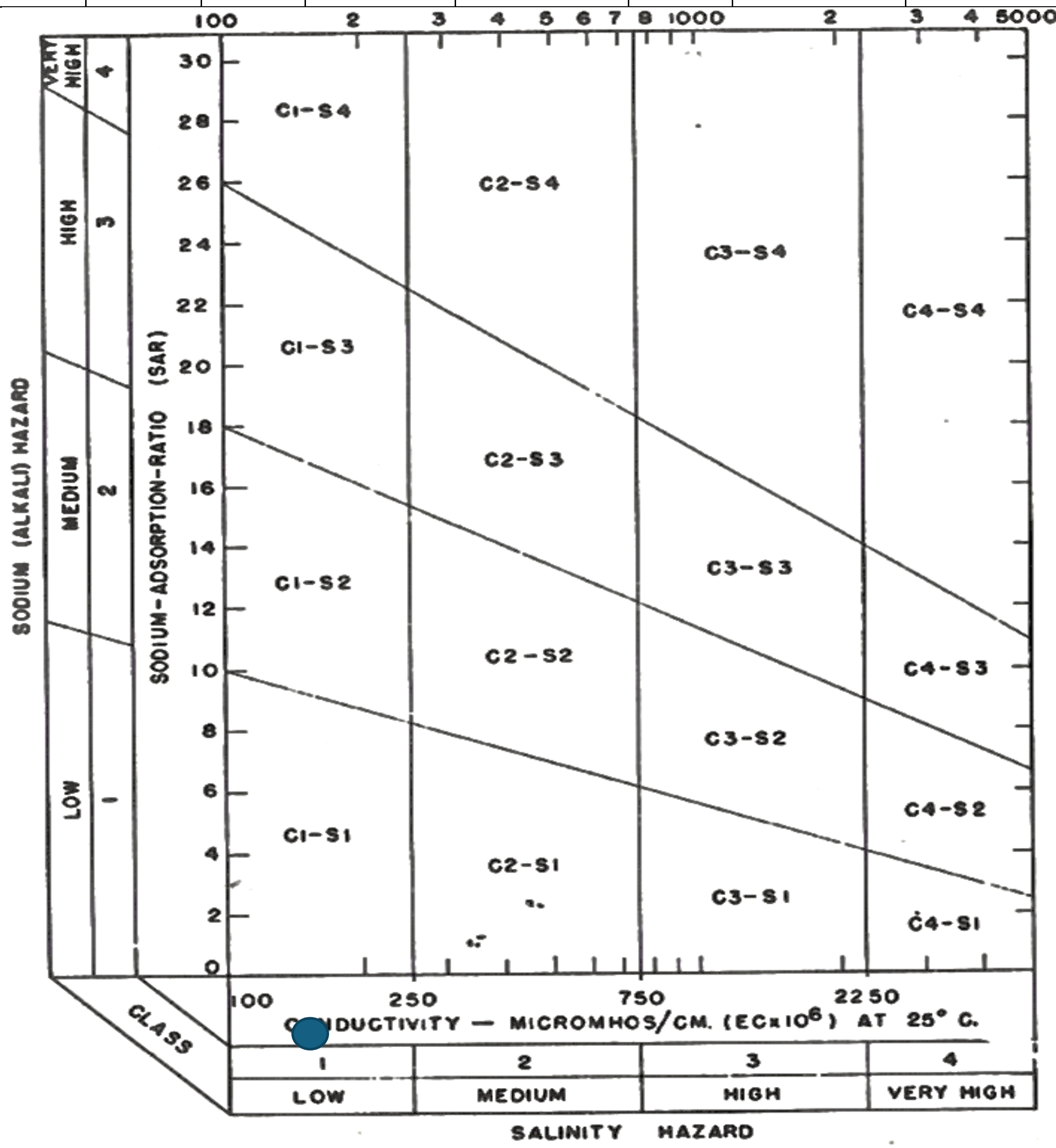

Fig. 2. Classified Wadi Al-Khrazeh waters based on the US Salinity Laboratory classification (S1-C2)

DISCUSSION

Soluble salts are a major factor in determining the suitability of water for irrigation, as they directly affect plant growth. Salinity, particularly electrical conductivity (EC), is a key indicator in assessing irrigation water quality **(Abawi & Salman, 1990)**.

During the summer season, electrical conductivity values ranged between 5.271 and 595 deciSiemens per meter (dS/m). The highest EC was recorded at Site 5, while the lowest was observed at Site 1, located within the University of Mosul near the confluence with the Tigris River. These findings align with those reported by **Safawi and Assaf (2014)** in their study of the Danfili Valley waters, which showed EC values between 0.51 and 0.65 dS/m. The elevated EC in Wadi Al-Kharazi is attributed to increased salt loads from wastewater discharge and microbial activity during organic matter decomposition **(Tali & Al-Rihawi, 2000)**.

Based on the U.S. Salinity Laboratory classification (Fig. 2), the water is categorized as C3 (high salinity), indicating it is only suitable for irrigating salt-tolerant crops and requires well-drained soil **(Richards, 1969)**.

The pH of Wadi Al-Kharazi water also influences its quality. The highest average pH value (8.04) was recorded at Site 3 during winter within the University of Mosul, while the lowest (6.75) was observed at Site 4, near the Al-Andalus neighborhood. Seasonal increases in pH, particularly in winter and spring, are attributed to rainfall and the oxidation of organic matter and pollutants **(Talat, 2012)**.

Carbonate and bicarbonate ions play a significant role in buffering acidity. Without this buffering capacity, the aquatic ecosystem would be more vulnerable to negative impacts **(Al-Singary & Al-Safawi, 2018)**. Bicarbonate concentrations ranged from 161 mg/L at Site 3 to 250.1 mg/L at Site 5. This variation is linked to chemical reactions in water, as described by **Ishaku *et al.* (2015)**:

CO2 + H2O ----- 2H2CO3 CaCO3 + 2H2CO3 ----- Ca+2 + 2H2CO3

According to international irrigation water standards (Ayers & Westcot, 1985), Wadi Al-Kharazi water is considered suitable for irrigation.

The concentration of nitrates is another important factor. While essential for plant nutrition, excessive nitrate levels can hinder plant growth **(Srivastava & Kumar, 2013)**. Nitrate concentrations were relatively consistent across the first three sites (within the University of Mosul) and decreased to 1.86 mg/L at Site 5 near the Tigris River.

Based on the overall results and according to the **Ayers and Westcot (1985)** classification (Table 3), the water of Wadi Al-Kharazi is generally considered good for irrigation purposes.

Table 3. Ayers and Westcot classification

Degree of Use Restriction	Salinity Level (ECw) (decimeters/meter)	Category
No restrictions	0.7>	Excellent
Slight to moderate restrictions	0.7_3.0	Good
Significant restrictions	3.0_ 6.0	Acceptable
Severe restrictions	6.0<	Unacceptable

Although sulfate ions do not have a direct toxic effect on soil or plants, they contribute to increased soil salinity, which can negatively affect crop productivity **(Nag & Das, 2014)**. In the summer season, the sulfate concentration reached 102.4mg/ L at Site 2 (within the University of Mosul), while the highest concentration was recorded at Site 4 during winter, reaching 230.3mg/ L.

Sulfate ions also influence potential salinity (PS) and electrical conductivity. PS values ranged from 85.71mg/ L at Site 2 to 149.28mg/ L at Site 4, reflecting the spatial variation in sulfate levels.

Magnesium hazard is one of the key quantitative indicators used to assess irrigation water quality **(Al-Salim, 1996)**. Excess magnesium increases soil salinity and can be harmful if it exceeds 50% of the total cation concentration. However, the results show that magnesium concentrations in Wadi Al-Kharazi water remain within safe limits, indicating its suitability for irrigation.

Chloride ions can be toxic to plants at elevated levels. Water is generally considered suitable for irrigation when chloride concentrations are below 100mg/ L. The chloride concentration in Wadi Al-Kharazi water ranged from 34.08mg/ L at Site 4 to a maximum of 41.5mg/ L at Site 1. These values fall well within the safe range, and according to the **Ayers and Westcot (1985)** classification, the water is considered good for irrigation.

The Soluble Sodium Percentage (SSP) is an important indicator of sodium hazard in irrigation water. When SSP exceeds 60%, sodium can accumulate in the soil, negatively impacting its physical structure by reducing aeration and water infiltration **(Jamil & Shehab, 2021; Safawi, 2023)**. High sodium levels can displace essential calcium and magnesium ions, especially in clay-rich soils. However, Wadi Al-Kharazi water shows SSP values below 50%, as presented in Table (4), indicating it is suitable for irrigation based on the **Wilcox (1955)** classification.

Table 4. Classification of water based on (SSP) **(Wilcox, 1955)**

SSP	Water Suitability for Irrigation
20%<	Excellent
20-40%	Good
40-60%	Permissible
60-80%	Doubtful
80%<	Unsuitable

The Kelley's Ratio (KR) values showed a relative decrease due to the higher concentrations of calcium and magnesium ions compared to sodium ions. KR values ranged from 0.3 to 7.7 during both the winter and summer seasons. According to the classification by **Nag and Das (2014)**, these values indicate that the water is unsuitable for irrigation, as KR values greater than 1 suggest excessive sodium relative to calcium and magnesium.

The Sodium Adsorption Ratio (SAR) is a key parameter for assessing the potential sodium hazard in irrigation water. High SAR values are associated with sodicity, which can lead to soil compaction, reduced permeability, and poor water infiltration **(Shakir *et al.*, 2016)**. In this study, SAR values ranged from 1.6 to 2.26 milliequivalents per liter during both seasons. According to **Hem**'s classification **(1991)**, these values place the water in the "excellent" category for irrigation, posing minimal risk of sodium-induced soil degradation (Table 5).

Table 5. Water classification based on (SAR) **(Hem, 1991)**

SAR	Alkalinity Hazard	Quality of Water
10>-2	S1	Excellent
10-18	S2	Good
18-26	S3	Doubtful
26<	S4	Unsuitable

There is a strong correlation between the Sodium Adsorption Ratio (SAR) and sodium uptake by soil, as noted by **Subra Rao (2006)**. When the sodium concentration in irrigation water exceeds 180mg/ L, it becomes unsuitable due to saturation of the soil's ion exchange complex with sodium, which leads to soil structure degradation **(Todd, 1980)**.
The Permeability Index (PI) is another important factor influenced by the concentrations of sodium and bicarbonate ions, as well as the ratios of magnesium to calcium. In this study, PI values ranged between 95% in winter and 54.7% in summer, indicating that the

water is generally suitable for irrigation. The PI is also influenced by total dissolved solids (TDS), sodium, and bicarbonate content. Based on PI classification **(Nag & Das, 2014)**:

- **First-class water**: PI > 75%
- **Second-class water**: PI between 75% and 52%
- **Third-class water**: PI < 52%

Accordingly, Khirazai Valley water falls within the first and second-class categories, making it suitable for agricultural irrigation.

The Residual Sodium Carbonate (RSC) is an indicator of the excess carbonate and bicarbonate ions in water, which tend to precipitate calcium and magnesium as their respective carbonates, thereby lowering their concentration in the soil solution and increasing the relative sodium hazard **(Eaton, 1950)**. According to **Wilcox's** classification **(1955)**, and based on the results shown in Table (4), Khirazai Valley water is considered suitable for irrigation and falls into the first-class category.

A summary of the water quality indicators for Khirazai Valley within the boundaries of Mosul City is provided in Table (2).

CONCLUSION

The waters of the Kharzai stream are classified as having a somewhat acceptable quality for irrigation purposes. They do not pose a risk to the soil, since their quality is close to natural conditions and clean levels based on the Sodium Adsorption Ratio (SAR), Sodium Percentage (SSP)%, and Residual Sodium Carbonate (RSC). Most samples were suitable for irrigation based on the Magnesium Hazard (Mg).

The studied results showed a significant increase in most variables, especially the concentrations of calcium ions, sulfates, and electrical conductivity. Therefore, the water is classified as high salinity water (C3) according to the US Salinity Laboratory (USS.LAB) classification and is unsuitable regarding the Kelley's Ratio (KR) for potential salinity.

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