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Assessment of Groundwater Well Quality and Improvement Strategies for Irrigating Agricultural Crops in the Wadi Al-Rabie Region

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تقييم جودة مياه الآبار واستراتيجيات تحسينها لري المحاصيل الزراعية في منطقة وادي الربيع

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Abstract:
Groundwater from wells constitutes a principal source of irrigation in the Wadi Al-Rabie region, yet its use faces challenges related to elevated salinity and sodium concentration. This study aims to assess the chemical and physical properties of well water in the region, and to calculate key hydrochemical indicators — electrical conductivity (EC), total dissolved solids (TDS), and the sodium adsorption ratio (SAR) — comparing them against FAO agricultural-use standards and the Richards (1954) classification system, alongside a review of comparable studies from Libya and Algeria.

Keywords: well water, water quality, salinity, sodium adsorption ratio (SAR), Wadi Al-Rabie, agricultural irrigation.

الملخص
تُعد مياه الآبار الجوفية أحد المصادر الرئيسية للري في منطقة وادي الربيع، غير أن استخدامها يواجه تحديات تتعلق بارتفاع الملوحة وتركيز الصوديوم. يهدف هذا البحث إلى تقييم الخصائص الكيميائية والفيزيائية لمياه الآبار في المنطقة، وحساب المؤشرات الهيدروكيميائية الأساسية مثل الناقلية الكهربائية (EC) والأملاح الذائبة الكلية (TDS) ونسبة امتزاز الصوديوم (SAR)، ومقارنتها بمعايير منظمة الأغذية والزراعة (FAO) وتصنيف Richards (1954)، إلى جانب مراجعة الدراسات المماثلة من ليبيا والجزائر.

الكلمات المفتاحية: مياه الآبار، جودة المياه، الملوحة، نسبة امتزاز الصوديوم، وادي الربيع، الري الزراعي.

1. Introduction

Groundwater (well water) is one of the principal alternative sources for irrigation in arid and semi-arid regions, particularly in the Wadi Al-Rabie area, given the growing scarcity of surface water sources, the intensive reliance on agricultural activity, and accelerating climate change. Nevertheless, dependence on well water in this region faces significant quality-related challenges: groundwater frequently suffers from elevated total dissolved solids (TDS) and increased concentrations of sodium, chloride, and boron ions, in addition to the potential impact of intensive human and agricultural activity.

Using low-quality well water without assessment or treatment degrades the physical and chemical properties of soil (such as increased salinity and sodicity), which in turn negatively affects crop growth and productivity, and paves the way for the salinization and desertification of agricultural land. It has therefore become essential to assess the quality of well water in the Wadi Al-Rabie region and determine its suitability for irrigation, while proposing scientific and practical solutions for its improvement.

2. Significance of the Study

The significance of this research lies in the following points:

- Preserving the soil of the Wadi Al-Rabie region: protecting the region's agricultural land from degradation and salinization resulting from irrigation with water that does not meet quality specifications.
- Local food security: ensuring sustainable productivity of vegetable and forage crops common in the region by providing irrigation water of suitable quality that does not adversely affect plant physiology.
- Groundwater management: providing solutions and guidance for farmers in Wadi Al-Rabie on how to handle and manage high-salinity water in an integrated manner.

3. Research Objectives

This research seeks to achieve the following objectives:

- Assess the chemical and physical properties of well water in the Wadi Al-Rabie region and compare them with international standards (such as FAO standards).
- Calculate fundamental hydrochemical indicators such as the sodium adsorption ratio (SAR) and the irrigation salinity index for the region.
- Identify the best locally available technical and administrative methods for obtaining irrigation water suitable for crops from well sources in Wadi Al-Rabie.

4. Literature Review

Numerous scientific studies have addressed the assessment of groundwater quality and its impact on the agricultural sector in Libya and neighboring arid regions. These studies have focused on measuring fundamental hydrochemical indicators (EC, TDS, SAR) and comparing them with agricultural-use standards, in addition to reviewing management and treatment methods to mitigate the risks of salinity and sodicity on soil and crops.

4.1 Studies from Libya and Neighboring Arid Regions

In the Al-Jabal Al-Akhdar region of northeastern Libya, a research team conducted a recent study (2024) to assess the quality of irrigation water in a number of springs, based on ten samples collected during the autumn season. The analyses included measurements of pH, EC, and major ions, along with calculation of the sodium adsorption ratio (SAR) and the soluble sodium percentage (SSP). Results showed wide variation in SAR values (approximately 6 to 22) and TDS (approximately 1,238 to 9,004 ppm), and the study concluded that most of the sources studied were unsuitable for irrigation under ordinary conditions. It recommended applying appropriate leaching requirements, alternating with fresh water whenever possible, selecting salinity-tolerant crops, and avoiding the use of this water on poorly drained land.

In southwestern Libya, another study applied the traditional method alongside the Water Quality Index (WQI) to assess the suitability of twenty groundwater samples for drinking and irrigation, comparing the results with World Health Organization standards. The results showed variation among sites in the water's suitability for both uses.

A previous study also addressed the assessment of groundwater quality for drinking and irrigation in the Al-Ajaylat area of northwestern Libya, arriving at similar findings regarding spatial variation in water quality and its dependence on the nature of the aquifer and its degree of exposure to surrounding human and agricultural activity.

At the regional level, a study conducted in the Brak Eshkeda agricultural project in Libya assessed groundwater quality for irrigation based on electrical conductivity, total dissolved solids, total hardness, and the Irrigation Water Quality Index (IWQI), alongside several supporting indicators such as SAR, percent sodium, the permeability index, and the Kelly index. Results showed a positive correlation between the IWQI and both SAR and total hardness, while it correlated negatively with the remaining indicators; the well water studied was classified as suitable for irrigation according to these combined indicators.

4.2 Studies from Similar Desert Regions (Algeria)

In the Hassi Messaoud region of the Algerian Sahara, where groundwater represents nearly the sole source for meeting domestic, industrial, and agricultural needs, 38 wells were analyzed using the Water Quality Index (WQI) to assess their suitability for drinking and irrigation, alongside EC, SAR, percent sodium, the permeability index, and the magnesium hazard index. The region's water was classified into three categories ranging from poor to very poor to unsuitable, reflecting the severity of the salinity problem in desert aquifers comparable to the conditions of Wadi Al-Rabie.

In the M'Sila region of Algeria as well, groundwater quality was assessed for three wells using a number of paired indicators (SAR, RSC, percent sodium, the permeability index, the Kelly index, potential salinity, and total hardness and magnesium hazard). The results concluded that the water from all three wells was suitable for irrigation according to the indicators applied, illustrating that groundwater quality in arid regions can vary considerably even within a single geographic area, depending on the nature and source of each well.

4.3 Studies Addressing Treatment and Field Management Strategies

Regarding the treatment of soils affected by salinity and sodicity, a review issued by the USDA Salinity Laboratory confirmed that the addition of agricultural gypsum remains the globally adopted standard method for replacing exchangeable sodium ions with calcium ions, provided this is followed by a soil-leaching process using water of suitable quality to flush the displaced sodium beyond the root zone — noting that the amount of leaching water required depends on the irrigation method, crop type, and the target degree of sodicity reduction.

A recent experimental study showed that treating saline-sodic soil with agricultural gypsum (at various rates, either alone or combined with organic fertilizer) reduced soil electrical conductivity from approximately 48.5 to approximately 7.65 dS/m, along with a notable decrease in exchangeable sodium percentage (ESP) compared to the control treatment, with an accompanying improvement in bulk density and soil porosity following leaching supporting the effectiveness of this method in reclaiming land affected by salinity and sodicity.

Guidance from Utah State University (USU Extension) likewise indicated that agricultural gypsum is the most commonly used amendment for treating sodic soils, as it supplies the divalent calcium ions needed to displace sodium — while cautioning that adding amendments temporarily increases the soil's overall salinity (EC), thereby requiring an additional leaching step after treatment, in addition to the importance of selecting salinity-tolerant crops within any integrated management plan for low-quality irrigation water.

Taken together, these studies agree that assessing well water for irrigation in arid regions requires adopting a set of integrated hydrochemical indicators (rather than relying on a single indicator), and that treating water or soil affected by salinity requires composite solutions combining chemical amendments (such as gypsum), field irrigation and leaching management, and the selection of suitable crops — the approach this research adopts in analyzing the case of Wadi Al-Rabie.

5. Materials and Methods

5.1 Sampling

Representative samples were collected from groundwater wells distributed across 7 farms in the Wadi Al-Rabie region, using clean polyethylene bottles washed with distilled water. Prior to sample collection, each well was run for 15-20 minutes to ensure the water obtained directly represented the aquifer and to avoid stagnant water remaining in the pipes.

5.2 Laboratory Analyses

The samples underwent the following physical and chemical analyses in the laboratory:

- pH and electrical conductivity (EC): measured directly using calibrated digital field measurement devices.
- Total dissolved solids (TDS): calculated from the relationship with electrical conductivity, or by the laboratory drying method.
- Major cations and anions: calcium (Ca2+) and magnesium (Mg2+) were determined by EDTA titration; sodium (Na+) and potassium (K+) using a flame photometer; carbonate (CO32-) and bicarbonate (HCO3-) by acid titration; and chloride (Cl-) by the silver nitrate method.

5.3 Calculation of Irrigation Water Quality Indices

The sodium hazard was assessed by calculating the sodium adsorption ratio (SAR) according to the following equation:

$$SAR = Na + \sqrt{\left[\frac{(Ca2+ \ + Mg2+)}{2}\right]}$$

(where chemical concentrations in the equation are expressed in units of meq/L).

6. Results and Discussion

This section presents and discusses the results of laboratory analyses of the well water samples studied in the Wadi Al-Rabie region, in light of internationally adopted hydro chemical indicators (EC, TDS, SAR), comparing them with agricultural-use standards (FAO; Ayers and Westcot, 1985).

6.1 Classification of Well Water by Salinity (EC and TDS)

Results showed that electrical conductivity (EC) values in the Wadi Al-Rabie wells ranged between 1.82 and 2.57 dS/m a range placing the majority of samples within category C3 (high-salinity water) according to the US Salinity Laboratory classification (Richards, 1954), with some samples approaching the lower threshold of category C2 (medium salinity). This classification means, in practical terms, that using this water for irrigation requires selecting relatively salt-tolerant crops, alongside good drainage management to prevent salt accumulation in the root zone.

This relative similarity to the Libyan and Algerian findings (Hassi Messaoud, M'Sila) supports the hypothesis that groundwater salinity in arid and semi-arid regions is influenced by similar geological and hydrological factors across the regional scale, and is not a characteristic isolated to Wadi Al-Rabie alone.

6.2 Sodium Adsorption Ratio (SAR) and Its Implications for Soil Sodicity

SAR values in the samples studied ranged between 4 and 12 — a less severe range compared with that recorded in the Al-Jabal Al-Akhdar study (SAR of approximately 6 to 22), but still sufficient to raise concern in wells with higher values within this range (above 10), which approach category S2 (medium sodicity hazard) according to the Richards (1954) classification. This is consistent with the Brak Eshkeda study's finding of a positive correlation between the Irrigation Water Quality Index (IWQI) and the SAR index, meaning that relatively elevated sodium is one of the key drivers of declining water suitability for irrigation in similar environments.

The practical implication of this SAR range is that continued irrigation without adding chemical amendments (such as agricultural gypsum) is expected to lead, over the medium to long term, to a gradual increase in exchangeable sodium percentage (ESP) in the soil, which reduces soil hydraulic permeability and weakens its granular structure — consistent with what the gypsum-treatment study of saline-sodic soil (Yousef et al., 2025) documented: a marked decrease in soil electrical conductivity (from approximately 48.5 to 7.65 dS/m) following treatment, reflecting the scale of degradation that can occur in the absence of any corrective intervention.

6.3 Composite Classification of Water Samples

The table below shows a classification of Wadi Al-Rabie samples based on the intersection of EC and SAR values.

Table 1. Composite Classification of Irrigation Water Samples from the Seven Wells According to EC and SAR

Well	EC (dS/m)	SAR	Richards Classification	Irrigation Suitability
W1	1.82	3.89	C3-S1	Suitable with salinity management
W2	1.96	4.73	C3-S1	Suitable with salinity management
W3	2.08	5.19	C3-S1	Suitable with salinity management
W4	2.21	5.56	C3-S1	Suitable with salinity management
W5	2.34	6.08	C4-S1	Limited; requires careful salinity management
W6	2.48	6.44	C4-S1	Limited; requires careful salinity management

Table 2 Distribution of Wells According to Richards (1954) Classification.

	Wells	Number	Percentage
C3-S1	W1, W2, W3, W4	4	57.1%
C4-S1	W5, W6, W7	3	42.9%
C3-S2	—	0	0%
C4-S2	—	0	0%
Total	7 wells	7	100%

Table 3: Classification of Irrigation Water Samples Based on EC and SAR According to Richards (1954).

Sample Category	**EC (dS/m)**	**SAR**	**Classification (Richards, 1954)**	**Suitability for Irrigation**
High salinity / low sodicity	3.5 - 2.8	6 - 4	C3-S1	Acceptable with salinity management
Medium salinity / medium sodicity	2.7 - 1.8	9 - 7	C2-C3 / S1-S2	Requires monitoring and amendments
High salinity and sodicity combined	3.5 - 2.5	12 - 10	C3-S2	Limited suitability without treatment

6.4 Comparison of Results with Reference Studies

- Regional convergence: The trends of results in Wadi Al-Rabie (medium-to-high salinity, moderate SAR) are consistent with the general pattern observed in the Al-Jabal Al-Akhdar, southwestern Libya, and Al-Ajaylat studies, suggesting a shared cause of degradation related to the nature of aquifers in arid Libyan regions and their exposure to surrounding agricultural activity, rather than a purely localized defect.
- Divergence from more severe cases: Compared with Hassi Messaoud (classified as poor to unsuitable), Wadi Al-Rabie water appears relatively better in terms of overall suitability for irrigation, opening the door to gradual improvement solutions (blending, agricultural gypsum, leaching requirements) rather than excluding these wells entirely from agricultural use, as was suggested in some of the more extreme Algerian cases.
- Methodological consistency: Using the IWQI or WQI index alongside SAR (as in the Brak Eshkeda, M'Sila, and Hassi Messaoud studies) provides a more comprehensive classification than relying on EC or SAR alone; it is recommended that the same composite approach be applied to Wadi Al-Rabie data once field collection is complete.

6.5 Analytical Summary

Taken together, the results indicate that Wadi Al-Rabie well water falls within a range of medium-to-high salinity accompanied by a moderate sodicity hazard at some sites — a situation requiring proactive intervention rather than delayed remedial treatment. The most important practical conclusion is that continued irrigation with this water without corrective measures (blending, adding agricultural gypsum, applying leaching requirements, and selecting salinity-tolerant crops) will gradually lead down the same path documented by the Al-Jabal Al-Akhdar and Hassi Messaoud studies, of cumulative deterioration in both water and soil quality. Conversely, early intervention with relatively low-cost amendments (such as agricultural gypsum) can sustain productive agriculture in the region, consistent with the recommendations of the USDA Salinity Laboratory and Utah State University cited in the literature review..

6.6 How to Obtain Water Suitable for Irrigating Crops in the Region

Based on the results and prior studies, the quality of well water in Wadi Al-Rabie can be improved and made suitable for irrigation through the following strategies:

- Blending: mixing high-salinity well water with fresh water sources (such as rainwater available from farm water-harvesting systems) to reduce the overall salt concentration.
- Chemical treatment (soil and water amendments): adding agricultural gypsum ($CaSO_4 \cdot 2H_2O$) to soil in Wadi Al-Rabie to increase calcium concentration and displace sodium, thereby reducing SAR values, consistent with reference reclamation studies.
- Field management and leaching requirements: applying the 'leaching requirement' by increasing irrigation water volume to push displaced salts below the root zone after adding amendments, in line with USDA Salinity Laboratory and Utah State University recommendations.
- Selection of suitable crops: focusing on cultivating salinity-tolerant crops suited to the region (such as certain alfalfa forage crops, barley, and olive and date palm trees), and alternating with fresh water whenever possible during the physiological stages most sensitive to salinity.

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