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ASSESSMENT OF THE SUITABILITY OF GROUNDWATER AND EUPHRATES RIVER BASINS IN WADI JARWA/AL-QAIM IN WESTERN IRAQ FOR AGRICULTURAL USE

Harith Farhan Khalaf[1] **AbduAlKareem Ahmed Meklef** [2]
H96ero@gmail.com ds.dr.abdalkareem@uoanbar.edu.iq
Mays Taha Yaqub Al-Hiti[1]
g.mais.taha@uoanbar.edu.iq

ABSTRACT

Groundwater serves as the primary irrigation source in the arid Wadi Jarwa-Al-Qaim watershed of western Iraq, making quality assessment crucial for sustainable agricultural development. To evaluate suitability for irrigation in this promising agricultural region, water samples were collected from four wells and the Euphrates River during the 2024–2025 seasons.

Key measured parameters included electrical conductivity (EC), sodium adsorption ratio (SAR), and sodium content (Na). Additionally, ArcGIS was utilized to map sampling sites and analyze the spatial distribution of irrigation water characteristics.

The results indicated that groundwater samples were of poor quality, with well water salinity values (EC) exceeding permissible international standards for irrigation, whereas the Euphrates River water remained within allowable limits. Based on these findings, proper groundwater management is highly recommended before application. Due to the elevated salinity levels, effective management techniques must be implemented to rationalize water usage and select salt-tolerant crops. Furthermore, prioritizing the transport and utilization of Euphrates River water, particularly via sprinkler irrigation systems, is essential to sustain soil and crop health while preserving limited groundwater resources.

Keywords: Wadi Jarwa watersheds, Groundwater quality, Western Iraq, Irrigation water quality, Euphrates River water.

INTRODUCTION

In the arid desert regions of Iraq, groundwater serves as the principal water source for agriculture. However, limited rainfall significantly reduces natural aquifer recharge, rendering unsustainable extraction a major challenge. Farmers heavily rely on deep aquifers within sedimentary formations; yet, this overexploitation causes

[1] College of Agriculture, University of Anbar, Al-Anbar, Iraq.
[2] Desert Studies Center - University of Anbar, Al-Anbar, Iraq.

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dropping water tables and deteriorating water quality, necessitating sustainable management and conservation strategies. This resource is vital for maintaining agricultural productivity, domestic supply, economic development, and ecosystem biodiversity, particularly in dry valley watersheds with scarce surface water during droughts.

Globally, numerous studies have evaluated irrigation water quality using diverse methodologies. For instance, Elkhalki *et al.* [16] investigated the Groundwater Quality Index (GWQI) for irrigation in the Nekor-Ghiss plain (Morocco) utilizing Geographic Information System (GIS) techniques. Their GIS-based multi-criteria analysis assessed various water quality attributes, employing Piper and Durov diagrams. The evaluated parameters included the sodium adsorption ratio (SAR), soluble sodium percentage (Na%), residual sodium carbonate (RSC), and permeability index (PI). While most water samples were found suitable for irrigation, calculations for magnesium hazard (MH) and Kelley's ratio indicated that 51.9% of the samples were unsuitable, whereas 59.49% were suitable based on other indices. Similarly, a study in the Alappuzha district of Kerala, India, utilized statistical tools to identify the key factors governing deep aquifer water quality [26].

Sayiter and Can [35] emphasized that surface water quality criteria are essential for assessing the suitability of water for irrigation. Data collected from 32 irrigation stations were analyzed to determine the sodium absorption rate (SAR), sodium percentage (Na %), Kelly index (KI), permeability index (PI), and irrigation water quality index (IWQI) for evaluating surface water quality. The SAR, KI, and Na% values ranged from 0.10 to 9.43, 0.03 to 1.37 mmEq/L, and 3.16 to 57.82%, respectively. Analysis of PI values indicated that 93.75% of water samples were classified as "suitable," while 6.25% were "unsuitable." The IWQI values in the study area ranged from 30.59 to 81.09. Regarding irrigation water quality, 12.5% of samples were categorized as "good," 15.62% as "poor," 68.75% as "very poor," and 3.12% as "unsuitable." The IWQI was subsequently estimated using a multiple regression model based on SAR, Na%, KI, and PI values.

The regression coefficient (R2) was found to be 0.6 in the multiple regression analysis, indicating a moderately significant relationship ($P < 0.05$). The analysis demonstrated a relationship between the dependent and independent variables. Model performance was evaluated using statistical measures including mean value (μ), standard error (SE), standard deviation (σ), R2, root mean square error (RMSE), and mean absolute percentage error (MAPE). Aly *et al.* [10] emphasized the global significance of groundwater for irrigation. Evaluating groundwater quality in the Toshka area is critical to determine its suitability for large-scale agricultural activities, particularly as this region depends on groundwater to mitigate water scarcity and support major development projects in arid environments. A total of fifty-two samples were collected from wells in the Nubian region within the sandy aquifer of the Toshka area. Groundwater quality was assessed through hydrochemical analysis, Piper diagram interpretation, and indices such as Na%, SAR, RSC, KR, MH, and PI. The hydrochemical analysis indicated an improvement in groundwater quality, attributed to ongoing recharge from Lake Nasser. The Piper diagram classified most water samples as "secondary salinity." Nearly all wells were suitable for irrigation, with only two wells deemed unsuitable based on MH values and six wells based on KR values. All samples were classified as "soft." The results indicated that all samples complied with the WHO and FAO irrigation guidelines.

Spatial distribution maps were used to visualize the results [27]. Groundwater is considered a primary source of irrigation in many agricultural regions, Such as in Hungary, where surface water is limited. This study examines how groundwater quality evolves over time and its implications for sustainable irrigation. The research combines hydrochemical assessment with machine learning to enhance the spatiotemporal assessment of irrigation water quality. Groundwater samples from the Debrecen region (2019–2024) were analyzed using hierarchical cluster analysis (HCA), irrigation indices (SAR, Na%, and IWQI), and self-organizing maps (SOMs) to understand spatial and temporal patterns. Groundwater quality index (IWQI) assessments confirmed the overall suitability of the soil for irrigation, despite the identification of risks due to salinity and sodium. The CNN model achieved high predictive accuracy (R^2 >0.97), which simplifies the estimation of the water quality index and demonstrates the usefulness of machine learning in groundwater quality monitoring. It supports more sustainable and adaptive irrigation to protect long-term soil productivity and achieve food security. Hydrology and water resources in Iraq depend heavily on the Tigris and Euphrates Rivers.

National water resources constitute 40% of the total, including 8% groundwater resources [3]. There is deep groundwater in the Western Desert, but these reservoirs contain geological supplies that are not renewed after withdrawal. The study area is located within the Tertiary Carbonates groundwater system [33]. The Euphrates River is the main source of irrigation water in the study area adjacent to the river, where water is distributed to fields via a network of irrigation canals in the floodplain. As for the newly cultivated areas within the study area, they depend on transporting the Euphrates River water through pipes carrying sprinklers, which is the main source of irrigation or use of groundwater, especially in areas far from the river. The depths of this water are estimated at (20-50 meters) [33], where water is distributed to farms via pipes and pumping stations.

Therefore, the current study aimed to evaluate the quality of groundwater in the Wadi Jarwa watershed area, determine its suitability for agricultural purposes according to the Food and Agriculture Organization of the United Nations approach, and classify it within the plan [31].

MATERIALS AND METHODS

Location

Given the importance of the Western Desert region in Iraq, which is considered a promising agricultural area due to the vast areas that can be exploited using modern irrigation techniques such as drip irrigation, despite the scarcity of water, groundwater can be used with government investment and sustainable agricultural techniques. This can be transformed into productive agricultural areas that contribute to enhancing food security. Therefore, the study area was chosen north of Al-Qa'im District, Anbar Governorate, Iraq, as shown in Figure 1. This area is located 341 km west of Baghdad (41°16'15.9"-41°22'51.95") east and (41°16'15.9"-34°25'13.8") north. It covers an area of 43,113 dunums, with a maximum elevation of 287 meters above sea level in the study area, and a slope of 159 meters towards the Euphrates River. The study area is bordered to the west by the Al-Ubaidi district and the Al-Qa'im-Akashat road, to the north by the Euphrates River, to the west by the Ajbab Valley course, and to the south by the Baghdad-Al-Qa'im railway. Field procedures consisted of a field investigation into the nature of exploitation, type of current land use in area, and the method of soil management followed there.

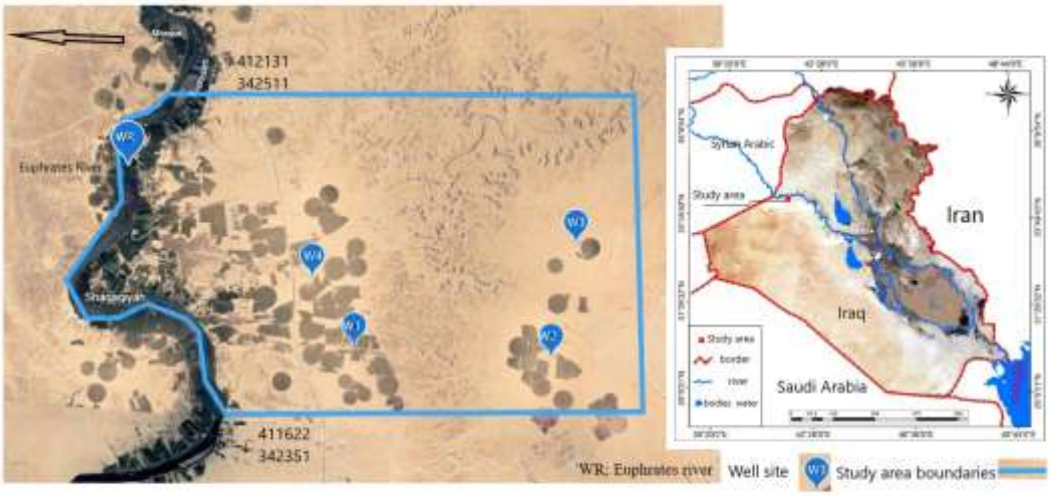

Figure 1. Distribution of the selected well sites in the study (Source: Earth google map, 2023)

Water Sampling and Analysis

Four wells were identified within the study area and their geographic coordinates were determined using a GPS device. Water samples were collected at a rate of two samples per year (summer and winter) from each of the four wells for the year 2024-2025 using sterile, sealed plastic bottles. Electrical conductivity and pH were estimated locally using field equipment. Drops of formalin were added and stored in a field refrigerator until transported to the laboratories of the College of Agriculture, University of Anbar, for the determination of:

1- Calcium and magnesium by titration with 0.01 N French EDTA [31].
2- Sodium and potassium using a flame photometer.
3- Carbonates and bicarbonates by titration with 0.01 N sulfuric acid, using phenonphthalene as a carbonate detector and methyl orange as a bicarbonate detector.
4-Chloride titration using 0.005 N silver nitrate.
5- Nitrates using the phenoldisulfonic acid method.
6- Sulfates using the barium chloride precipitation method, as described in [28].
7- Boron using the hot water method [21].
8- Sodium Adsorption Ratio (SAR) values were calculated according to the methods described in [11]. Water quality was evaluated according to the properties studied for irrigation purposes, based on the standard specifications [13]. Table 1 presents the results of water analysis according to the method [30]. Groundwater was also classified based on its origin. The pH and electrical conductivity (EC) were measured using digital meters and electrical conductivity directly in the field. The samples were transferred and stored in a cooling box and transported from the field to the laboratory. The collected water samples were analyzed for the main ions Ca, Mg, Na, K, HCO3, CO3, SO4, and Cl, for chemical analyses according to the methods mentioned by Chapman and Pratt [15]. The sodium adsorption ratio (SAR) values were calculated according to Al-Zubaidi [11] and the well water was classified according to [31]. The studied well water was evaluated according to the FAO standards for water classification [13].

Table 1: The criteria used in the evaluation process, Table 2: Irrigation water classifications based on electrical conductivity values, Table 3: Irrigation water classification based on sodium absorption rate values.

Table 1: Well water evaluation criteria according to FAO standards

Nature of the problem	The value of the minimum use		
	None	Slight Moderate	To Severe
Salinity value (EC) dSm^{-1}	>0.7	0.7 – 3	< 3
Total dissolved salts ppm	450	450 – 2000	< 2000
Sodium adsorption ratio	Electrical conductivity EC		
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	5 – 2.9	> 2.9
Side effect of ions			
Sodium ($meql^{-1}$) natural irrigation	3 >	3 – 9	< 9
Chloride ($meql^{-1}$) surface irrigation	4 >	4 – 10	< 10
Other incidental effects			
Nitrate ($meql^{-1}$) NO_3- N	0.5 >	5 – 30	< 30
Bicarbonate ($meql^{-1}$)	1.5 >	1.5 – 8.5	< 8.5
pH	6.5 – 8.4		

Table 2: Irrigation water classifications based on electrical conductivity values [8]

Water types	water quality	Electrical Conductivity (EC) (μs/cm)
C1	Low salinity water (excellent for	< 250
C2	Medium brackish water (suitable for	250 – 750
C3	High salinity water (allowed for	750 – 2250
C4	Very high salinity water (not suitable for	> 2250

Table 3. Classification of irrigation water based on sodium absorption rate (SAR) values [8]

Water types	water quality	SAR
S1	Low sodium risk (excellent for irrigation)	0-10
S2	Sodium hazard: Moderate (good for irrigation)	10 -18
S3	High sodium risk (allowed for irrigation)	18-26
S4	Sodium hazard is too high (not suitable for irrigation)	> 26

Climate Conditions

Climate is a major and important factor in determining the suitability of land for various agricultural uses, as well as being a fundamental factor controlling the development and diversity of soils and pedological processes. The climate of the study area is characterized by long, hot summers and short, cold winters. Table 2 shows some climatic data for the period 1918-2024, obtained from the General Authority of Meteorology:

Temperature: The data in Table 2 and Figure 4 indicate that the highest temperature recorded at Al-Qa'im Station was 40.5°C in July, while the lowest temperature recorded at Al-Qa'im Station was 2.2°C in January. The average temperature in winter ranges between 8.8 and 13.1°C, while in summer, the average temperature ranges between 30.1 and 30.1°C. The average annual daily temperature in Al-Qa'im is 20.6°C.

Relative Humidity: The annual average in Al-Qa'im is 20.6°C. 43.4%. The minimum annual relative humidity is 28%, occurring mainly in July, while its peak is 75% in January. In the study area, rainfall is negligible, with a total annual rainfall of 11.8 mm. Average daily evaporation and transpiration are 12.8 mm and 9.6 mm throughout the year. The minimum is 47.2 mm/day in January, while the maximum can reach 435.9 mm/day (Table 2). The prevailing wind direction is from the northwest during May, June, July, and August, with speeds of 3.2, 3.8, 4.1, and 3.4 km/h, respectively. There are no significant changes in wind speed, as the minimum average wind speed in winter is approximately 2.7 km/h, while in summer it reaches a maximum of 4.1 km/h.

To determine the climatic zone class of the study area, concepts developed by previous researchers (Lambert, France) were applied, and degrees of aridity can be estimated: (Q) as follows:

$$Q = R / (M-m) 2 * 100$$

Where (Q) is the degree of aridity, (R) is the annual rainfall rate (mm), and (M&m) are the average maximum and minimum temperatures, respectively.
The value of (Q) at the two Al-Qaim stations was found to range between 1 and 4, which corresponds to arid conditions,The climatic zones were classified according to their annual rainfall rate as follows:

Zone	Arid	Semi-arid	Humid
Rainfall mm/year	0 - 400	400-1000	> 1000

The area under study falls within the arid zone, where the total rainfall ranges at an average of (11.8) mm/year. Drought prevails most of the year, and the rainy periods are relatively short, indicating that the climate of the region is dry (Figures 2 and 3).

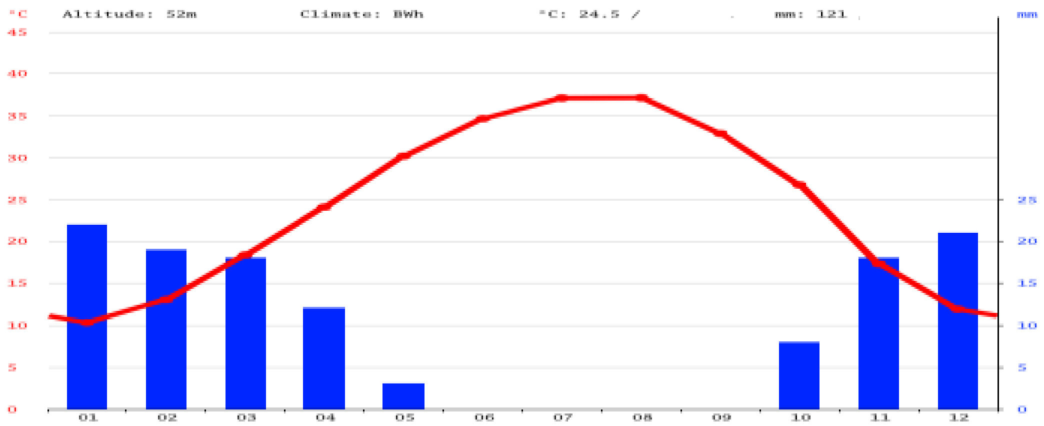

Figure 2. Climatic conditions of the Al-Qaim region

Evaporation: One of the climatic indicators whose effect is evident in arid and semi-arid regions. The intensity of evaporation varies according to the variation in the amount of solar radiation and temperature, as well as wind speed. Its relationship with these elements is directly related, while it is inversely related to relative humidity. This process continues during daylight hours, which range between (75-90%) of the total evaporation rate during the day [25]. It is noted from Table 2 that the total values of evaporation rates are very high, as (435.9 mm) were recorded in July. The reason for the high evaporation in the study area is due to the high temperatures, low relative humidity rates, and clear weather, especially in the summer.

Wind: The action of wind is one of the most important factors in shaping the geomorphological appearance of the Earth's surface, especially in dry and semi-dry areas [8], as its effect appears through the processes of erosion, transport and deposition of soil surface materials. The ability of wind to transport rock fragments increases when the drought intensifies and when the Earth's surface is composed of loose, uncohesive sands, free of obstacles that hinder its work. The effect of wind appears as a constructive or destructive factor depending on its speed and the amount of fragmented materials it carries [2].

The erosion process begins in high areas and the deposition process in low places [32], Important factors in the study of wind are its direction and speed, as the direction of the wind has a major role in some landforms taking on a special position. In addition to the significant role played by rock fragments and sand in the continuous soil erosion process during their transport, especially if the areas they pass through are a permanent source of sand supply, Table 2 shows the dominance of northwesterly winds in the study area. The reason for the dominance of northwesterly winds in the region is due to their influence by the winds accompanying the Mediterranean depressions during the winter season, on the one hand, and the decrease in atmospheric pressure, on the other hand [1]. Wind speed varies from one season to another and from one month to another throughout the year. October and November recorded the lowest average wind speed, reaching 1.9 m/s, while July recorded the highest average, reaching 4.1 m/s.

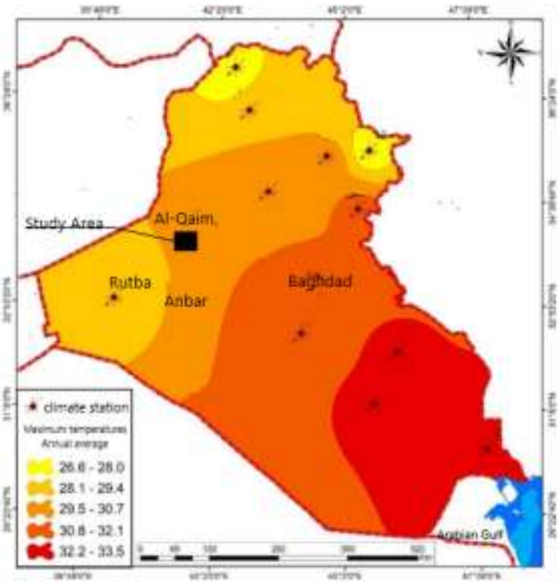

Figure 3: Ranges of annual average maximum temperatures for the study area for the year 2024

Geology of the Area

The study area has undergone geological stages, tectonic movements, and erosion and sedimentary geomorphological processes that led to the formation and development of the dominant landforms in the study area. Structurally, the study area lies within the transitional zone between the stable shelf and the unstable shelf. The exposed geological formations in the study area can be observed, as shown in Figure 4. The geological influence in the study area has a significant impact on the formation of the soils spread throughout the study area and on determining the characteristics and properties of the soils. The geological formations spread throughout the area are as follows:

1- Euphrates Formation (Lower Miocene)

The formation is exposed over a wide area in the study area. This formation consists of massive limestone and calcareous basal conglomerates, ranging in thickness from 2.5 to 9 meters, topped by a layer of shelly limestone up to 18 meters thick, covered by chalk shale and white limestone. The upper layer of the formation contains rolled and protruding surfaces, which are the most prominent feature of the discovery this formation [29].

Faroujan and Hafez [17] mentioned that the sedimentary environment of the Euphrates Formation is warm and shallow marine conditions at a depth of 0-50 meters. This formation is covered by a thin layer of stone fragments and clay soils that does not exceed 2 meters in thickness. The Euphrates Formation is one of the formations that were exposed to effective tectonic movements that caused cracks, fractures and joints in it, and then developed geomorphologically into karst gaps and ground depressions [7]. Many other geological conditions also contributed to making the Euphrates Formation an important groundwater reservoir, due to the abundance of cracks, erosion and interstitial spaces that result from the dissolution of its limestone components [24]. This formation occupied an area of 5,913.12, representing 55.44% of the area of the study area.

Table 4: Climate data for the study area for the period (2018-2024*)

month / Variables	Jan.	Febr.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Octo.	Nove.	Dece.	Annual average
Average temperature °C	7.6	9.6	16.4	20.5	25.4	30.1	32.4	32.0	27.6	22.7	14.6	8.8	20.6
Minimum temperature °C	2.2	3.7	11.7	13.1	17.6	22.2	24.3	23.9	19.6	15	7.8	3.2	13.6
Maximum temperature °C	13	15.6	21.2	27.9	33.3	38	40.5	40.2	35.6	30.5	21.5	14.5	27.6
Average wind speed m/s	2.1	2.7	2.9	2.8	3.2	3.8	4.1	3.4	2.2	1.9	1.9	2	2.7
(%) Relative humidity	75	65	56	45	36	30	28	30	36	45	60	64.9	43.4
Rainfall rate mm	26.1	21.5	23.2	14.1	6	0.3	0.0	0.0	2.2	9.9	73	48	11.8
Total evaporation mm	47.2	74.9	119.8	203.1	300.8	389.5	435.9	418	293.7	204.9	105	53.5	2503.8

*Source: Republic of Iraq, General Authority of Meteorology and Seismic Monitoring, Climate Department Al-Qaim Station

2- Al-Fatah Formation (Lower Miocene)

This formation dates back to the Middle Miocene, which is estimated at 20 million years [9]. The formation was deposited under shallow marine conditions or a semi-isolated coastal lagoon environment. It consists of evaporite deposits such as gypsum and anhydrite gypsum [12]. The upper layers of the formation contain rolling or protruding surfaces, and the formation appears on slopes. This formation is distinguished by its high salt content of sulfates, as its rocks contain a high percentage of gypsum and anhydrite gypsum. It contributes significantly to the feeding of the springs in the Hit area [19]. The thickness of the formation ranges between 50-60 meters. This formation covers an area of 3,617.53 m^2, representing 33.93% of the area.

3- Floodplain Sediments

These are the sediments resulting from the flooding of the Euphrates River and the deposition of its load on the areas surrounding its course. The repetition of this process creates the alluvial plain. The role of the slope, the kinetic energy of the river, and the nature of the river banks. It consists of fine sand grains mixed with fine clay. It is considered fertile land and is used for agricultural purposes [4]. The sediments constitute an area of 1,134.35 hectares, representing 10.4%.

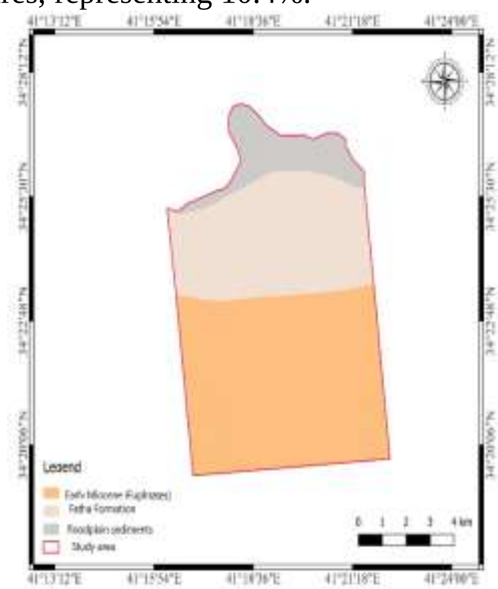

Figure 4. Geological formations map

Agricultural Exploitation and Natural Vegetation

The natural vegetation map of Iraq prepared by [20] shows that Anbar Governorate is located within the sub-desert area, where the zonal distribution of natural vegetation is within the semi-desert area (Sub-desert zone). Many plant species have been identified within the area. It became clear through field observations that the natural vegetation in the study area is sparse and weak in growth, due to the lack of rain and dry climate. It was represented by the thorn *Lagonychium farctum*, *Alhagi mororum*, *Cynodon dactylon*, *Carthamus oxicanthas*, *Imperata cylindrica*, *and Convolvulus pilosellifolius*. The soils of the study area are exploited for irrigation purposes, especially in the deep soils within the floodplain close to the Euphrates River. As for the soils far from the river, the method of exploiting them is by following appropriate management methods. Farmers used center pivot sprinkler systems using either water transported from the Euphrates River or well water. The most important crops grown are wheat, barley, yellow corn, sesame, sunflowers, and some vegetables such as tomatoes, eggplant, cucumbers, and peppers, some of which are grown under protected cultivation through plastic tunnels. In addition, watermelon, lettuce, cauliflower, Swiss chard, onions, and fodder crops such as jatropha are grown. Some orchards also house fruit trees (pomegranates, grapes, and olives) in very narrow spaces on the banks of the Euphrates River. The natural vegetation is distributed in the study areas according to the nature of agricultural exploitation, the type of soil and its hydrological conditions. In the soils close to the Euphrates River, the plants (*Achillea santolina L., Adiantum capillus-veneris L., Alyssum desertorum, Alyssum homalocarpum, Anisosciadium lanatum)* are spread. As for the soils far from the river, the plants *(Prunus Arabica, Alhagi camelorum, Astragalus annularis, Hippocrepis unisiliquosa, Lotus corniculatus, Sophora gibbosa, Trifolium purpureum, Vicia villosa, Cleome amblyocarpa*) are spread. Reed plants are spread in the low-lying areas near the Euphrates River. It was also noted in the soils not exploited for agriculture, the plants (Salmas, Aloe vera, Aqool and Kisum) are spread. As for the lands exploited for agriculture, the plants (Kalgan, Fejeela and Wild oats) are spread. The Thiel and the Extended) are identical to the studies of both Al-Khatib and al-Din [6] and Sarkahia [34].

RESULTS AND DISCUSSION

Chemical Variations in Water Resources Quality

Table 5 displays the results of the physical and chemical variables in surface and groundwater in the study area during the summer (dry) and winter (wet) seasons.

pH:

A measure of the acidity/alkalinity of a water resource, it is an important water quality parameter that determines the solubility and bioavailability of various chemical components. The pH of the surface waters of the Euphrates River ranges between 7.1 and 7.3, with an annual average of 7.3 for both the summer and winter seasons. Higher pH values were recorded in the summer compared to the winter (Table 5). The lower pH values in the winter are attributed to limited photosynthetic activity, in addition to the dilution of the river water by the large amount of low-acid water entering Iraqi territory. The relatively higher pH values during the summer can be attributed to the removal of carbon dioxide through photosynthesis by algae, as a result of higher temperatures, sunlight, and nutrients. Which increases the bloom of algae within the riverbed, which causes the deposition of calcium and magnesium carbonates. The acidity values of the annual averages of the well waters studied ranged between 7.3-7.7 for wells W 4 and W 2, respectively, i.e., within the neutral and slightly alkaline categories, based on [36].

Electrical Conductivity (EC)

Water salinity can be determined based on electrical conductivity (EC) or total dissolved solids (TDS). Electrical conductivity of water expresses the water's ability to carry an electric current and is directly related to the amount of total dissolved solids (TDS) and major ions. TDS reflects the presence of inorganic salts and small amounts of organic matter in the water. The electrical conductivity value in the water studied depends on the presence of ions and the pH. Potential sources of salinity in surface and groundwater stem from the nature and condition of the surrounding watershed and geological reservoirs (i.e., weathering and rock erosion). The average electrical conductivity value in the surface water of the Euphrates River during the summer ranged from 1.3 dSm^{-1}, with an annual average of 1.2 dSm^{-1}, while in the winter it ranged from 1.0 to 1.1 $dS\ m^{-1}$.

The spatial distribution of annual groundwater electrical conductivity rates during the summer and winter showed a trend. Similarly, the highest values were recorded in the eastern part of the study area (sites W 3 and W 4) in the central regions of the study area, and the results were consistent with those of [5], when studying the quality of groundwater in the Faheeda Oasis near the study area, while the lowest values of electrical conductivity were observed in the western part of the study area near the western borders of the study area (sites W1 and W 2). The high electrical conductivity values in these sites can be attributed to rock weathering within the aquifers, the amount of rainfall in the area, and soil erosion, based on the USDA Irrigation Water Salinity Laboratory classifications based on electrical conductivity values (Table 5 [8]). Surface water samples are classified as C3: High-salinity water (permissible for irrigation), while the well samples were all classified as C4: Very high-salinity water (unsuitable for irrigation).

Major cations

The major cations in surface water are influenced by the nature and geology of the surrounding area, as well as weathering processes affecting rocks and soil. [23] The content of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) in the surface water of the Euphrates River varied as an annual average. 3.5, 4.0, 1.8, and 0.1 meql-1, respectively. The annual average for these ions for all water resources within the region, including well water, was 21.1, 10.3, 16.3, and 0.4 meql-1, respectively. (The figure shows the predictive distributions of the most important water characteristics affecting the irrigation process.)

The results in Table 5 shows that calcium was the dominant cation in both summer and winter, constituting the highest percentage of total cations compared to other cations. This explains why limestone (CaCO3) and dolomite (CaMg(CO3)2) are the dominant rocks in the study area. Calcium and magnesium are important factors in water quality, affecting its quality. These two elements are extremely important biologically, as calcium is essential for healthy growth and is essential for building the skeleton of living organisms, while magnesium is essential for chlorophyll growth.

The highest recorded Sodium and potassium concentrations in groundwater were (16.2-25.6 $meql^{-1}$), (0.4-0.7 $meql^{-1}$) for wells (W1-W2) respectively. The high evaporation rate, agricultural operations, fertilizer application and livestock grazing waste in the study area may be the reason for the high sodium and potassium concentrations and may be caused by the precipitation of calcium and magnesium carbonates during the dry season. The low sodium and potassium concentrations in the surface water of the Euphrates River can be attributed to the influence of rainwater and springs in the headwater areas. The data (Table 5) shows that the highest sodium concentration was observed in the highlands of the study area and decreased within the central areas. Sodium concentration was observed in most locations, relatively close during the summer and winter seasons.

Major Anions

The concentrations of anions (bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl) in the surface waters of the Euphrates River (Table 5) ranged between 3.2, 3.8, and 2.6 meql^{-1} during the summer and winter seasons, with average concentrations for all water resources ranging from 5.06 to 31.6 and 10.5 meql^{-1}. The highest concentrations of HCO3 (6.4 meql^{-1}) were recorded at well W3. This value was associated with the rainy season due to high rainfall, surface runoff, and weathering processes. This explains the high concentration of HCO3 at the high elevations near the upper reaches of Wadi Jarwa (Figure 1). The lowest concentrations of HCO3 were observed at well W2, at the western end of the highlands. Bicarbonate was found to be the least dominant anion among those studied, Chloride (Cl) is generated in natural waters. From geological formations resulting from the dissolution of minerals and fertilizer salts, the low value in the Euphrates River water reached an average of 2.6 meql^{-1}. This value increased in well water to 12.2, 16.5, 6.4, and 114.8 meql^{-1} for wells (W 1, W 2, W 3, and W 4), respectively. Sulfate (SO4) in surface water comes from rocks and soil (which contain gypsum, sodium sulfate, and other sulfur compounds [14]. Table 5 shows that the highest concentrations of sulfate in groundwater were observed, and the anion chemistry is dominated by chloride and sulfate, followed by bicarbonate.

Sodium Adsorption Ratio (SAR)

4The sodium adsorption ratio (SAR), also known as the sodium or alkali hazard, is an important indicator for assessing the quality of irrigation water and represents the ratio of sodium (Na) concentration to calcium (Ca) and magnesium (Mg) concentrations. The sodium adsorption ratio (SAR) was calculated. Based on the following equation [8]:

$$SAR=Na/ \sqrt{}Ca+Mg/2$$

The sodium absorption rate (SAR) value in irrigation water is closely related to the sodium content in the soil. High sodium content in irrigation water affects soil permeability and reduces the rate of infiltration. Sodium displaces calcium and magnesium absorbed from the soil, causing soil particles to disperse, affecting plant growth [18. [

Table 5 showed that the sodium absorption rate (SAR) values in the Euphrates River surface water were within 0.9%, with an average value for all water resources of 3.9. The highest value for this characteristic was 5.0 in the water of Well W4, and the lowest value was 4.2% in Well W1, located to the west of the study area. According to irrigation water classifications based on SAR values [8] (Table 3), all samples collected in this study belonged to the (S1) category, indicating that the surface and groundwater in the Jarwa Valley watershed are low in sodium and excellent for irrigation.

Irrigation Water Classification

The USSL (United States Salinity Laboratory) [37] chart is a graph showing the hazardous salt content (EC) on the x-axis, and the SAR (Sodium Adsorption Ratio) values (Tables 2, 3) on the y-axis, as shown in Figure 5. This chart was developed by the United States Salinity Laboratory in 1954 to determine the suitability of water for irrigation purposes [8]. This chart classifies water based on its salinity content (EC) into four categories: C1 (low salinity), C2 (medium salinity), C3 (high salinity), and C4 (very high salinity). The water categories based on its sodium hazard (SAR) are: S1 (low sodium), S2 (medium sodium), S3 (high sodium), and S4 (very high sodium). Data based on the chart (Figure 5) showed that the samples collected from the Euphrates River surface water during the study period belonged to the category (C3S1) (medium to high salinity and low sodium). Wells 1, 4 and 3 were classified as C4S1 (very high salinity and low sodium), while well 2 was classified as C4S2 (very high salinity and medium sodium). Therefore, the water resources of the area are suitable for irrigating most soil types with little risk of harmful levels of salts in the groundwater. Therefore, special salinity management and selection of crops with good salt tolerance are required.

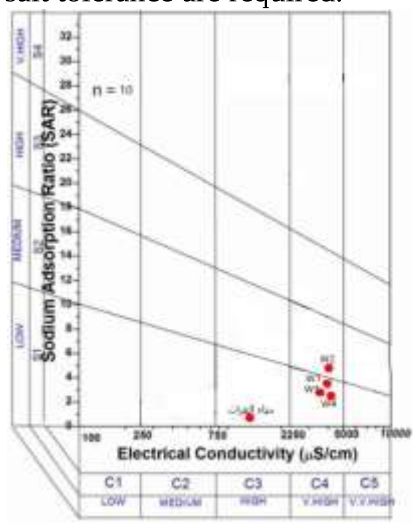

Figure 5: USSL diagram of water resource samples collected in the study areas

Water Resources Assessment

These waters were evaluated based on the Food and Agriculture Organization (FAO) [13] irrigation water standards (Table 1). The results showed the minimum use value for all water resource characteristics studied within the study area. The electrical conductivity values of surface water were within the (None) rating, while most of the saline content of all studied wells were within the (Severe) rating. The sodium assessment ranges were within the (Severe) rating for all wells. The chloride content of all wells was (Severe) except for well W3, which was within the (Slight Moderate) rating. As for bicarbonate, all of them were within the (Slight Moderate) rating.

Geochemical Evaluation of Water

When interpreting the results based on the geochemical properties of the tested water, as shown in Figure 6, which is known as Pipe [30] and is used in the geochemical evaluation of groundwater [22], it was shown that the tested water, in terms of the main positive ions, is of a water quality dominated by Na and Ca, while in terms of the group of negative ions, it is of a sulfur-chloride quality. This is due to the predominance of negative ions in the following order: SO4, Cl, and finally HCO3. The basicity of the tested water distribution is predominant. It appears from Figure 6 that a visual representation of the average concentrations of the main ions in the examined water could be used to show the similarity and difference between the well water and the Euphrates River based on its geochemical properties. The Piper diagram is considered the tool used to distinguish between the groundwater interfaces in the study area to explain the intrusion of salt water. Based on Table 5, the studied well water for each of the wells w1, w3 was classified within the sodium-chloride facies where the non-carbonate alkalis exceed 50%, while the wells w2, w4 were within facies (mixed type).

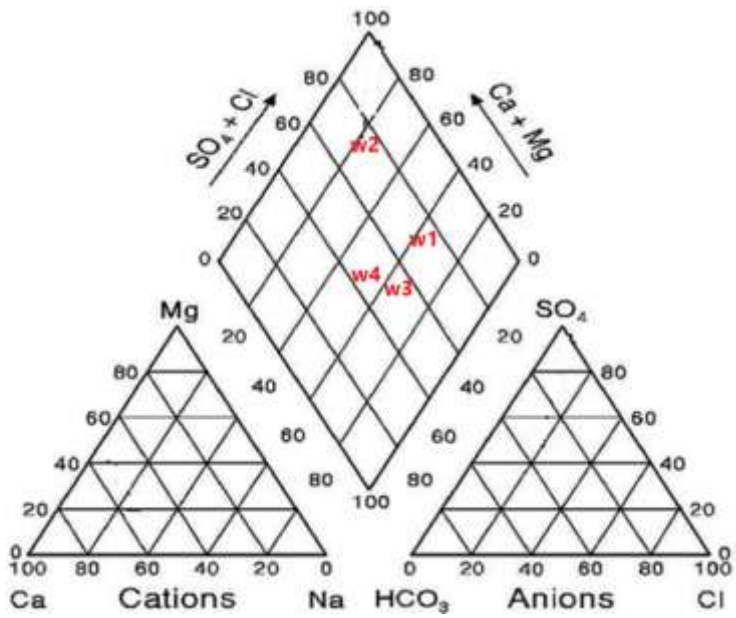

Figure 6: Geochemical evaluation of water from the Piper diagram

Statistical Analysis of Water Resources Characteristics

Descriptive statistics (mean, range, and coefficient of variation) were used to assess the variability in water chemical characteristics as follows: most of the water characteristics were low variance. The relationships between water characteristics were used. The results from Table 6 showed a high correlation between Ca and most other elements with EC (r=0.97563) for Ca, as well as with Mg. A high correlation was also found between Na and SAR values (r=0.99567) and with CL (r=0.94005). Table 6 illustrates these relationships.

Table 5: Chemical Characteristics of Water Samples in the Study Area

Well Number	Location coordinates		TDS mgl^{-1}	pH	EC dSm^{-1}	Cations ($meql^{-1}$)			Anions($meql^{-1}$)					SAR %
	Long.	Lat.				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3	HCO_3	SO_4	Cl^{-}	
WR*	41.3182833	34.4510269	742.4	7.3	1.2	3.5	4.0	1.8	0.1	–	3.2	3.8	2.6	0.9
W 1	41.2940792	34.3903046	2777.6	7.6	4.3	23.9	7.3	16.7	0.5	–	5. 5	31. 2	12. 2	4.2
W 2	41.2828282	34.3396656	2739.2	7.7	4.3	27.7	14.5	25.6	0.7	–	4.7	48. 7	16.5	5.6
W 3	41.3286725	34.3674740	2867.2	7.5	4.5	25. 8	12.5	16.2	0.4	–	6.4	43. 3	6. 4	3.7
W 4	41.3077568	34.4054734	3091.2	7.3	4.8	24.9	13.5	21.5	0.5	–	5. 5	31. 2	14. 8	5.0
Mean			2443.5	7.4	3.8	21.1	10.3	16.3	0.4	-	5.1	31.6	10.5	3.9
SD σ*			859.2	0.16	1.32	8.91	4.03	8.04	0.195		1.074	15.3	5.08	1.62
Variance σ^2			73836	0.02	1.74	79.5	16.2	64.7	0.038		1.154	234.4	5.90	2.64

Deviation: SD*

Table 6: Pearson correlation matrices showing the statistical relationships between selected irrigation water quality characteristics based on annual averages.

	pH	EC	Ca	Mg	Na	K	HCO_3	SO_4	CL	SAR
pH		0.45151	0.27265	0.55026	0.30029	0.16387	0.62647	0.16371	0.3912	0.31068
EC	0.44605		0.004551	0.093742	0.039869	0.081786	0.048922	0.060204	0.14689	0.033309
Ca	0.61195	*0.97563		0.069047	0.017977	0.034639	0.084991	0.014755	0.12425	0.017909
Mg	0.36125	*0.81376	*0.84866		0.039194	0.10496	0.27367	0.054284	0.18126	0.061399
Na	0.58486	*0.89557	**0.93887	*0.89677		0.004771	0.28457	0.040075	0.026188	0.000342
K	0.72719	*0.83025	**0.90501	*0.79886	**0.97485		0.37886	0.048559	0.021339	0.004696
HCO_3	0.29783	*0.88012	*0.82576	0.61094	0.60018	0.51106		0.16078	0.56992	0.27626
SO_4	*0.72738	*0.86207	**0.94645	*0.87139	*0.89521	*0.88072	0.73074		0.21522	0.055903
CL	0.49982	*0.74692	0.77431	0.70759	**0.9213	**0.93141	0.34474	0.67076		0.017459
SAR	0.57484	*0.90748	**0.93902	*0.86022	**0.99567	**0.97511	0.60838	*0.86881	**0.94005	
*WR; Euphrates river Standard										

Conclusions

This study was conducted on a portion of the Wadi Jarwa watershed, a promising area for agricultural investment in western Iraq, to utilize water resources for irrigation purposes and use them sustainably. This study aims to identify the quality of these resources, and to evaluate and classify their suitability for agricultural use. The results of this study showed that most physical and chemical parameters in groundwater vary spatially, with the highest concentrations of these parameters recorded in different locations within the study area. This is attributed to natural discharges from the watershed areas, from the upper reaches of the watershed to the lower reaches towards the Euphrates River, and the effects of rock weathering and soil erosion.

The highest EC concentrations were recorded at higher elevations in the study areas, attributed to weathering, rock dissolution, and soil erosion during the rainy season. The highest concentrations of Na, Cl, and SO4 were recorded in well W2, attributed to high evaporation rates, carbonate deposition, agricultural activities (such as fertilizers), and natural runoff from secondary branches surrounding Wadi Jarwa. The dilution effect of rainwater may be responsible for the lower values recorded for these parameters during the rainy season. Given the high salt content in the water from the studied wells, it is recommended to adopt management techniques to rationalize its use and to prefer using water from the Euphrates River for agricultural purposes. This is to ensure that soil quality and crops are not harmed, and to preserve groundwater resources, which may be non-renewable or limited.

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تقييم ملائمة المياه الجوفية ومستجمعات مياه نهر الفرات في وادي جروة/القائم في غرب العراق للاستخدام الزراعي

حارث فرحان خلف[1]
H96ero@gmail.com

عبدالكريم احمد مخيلف[2]
ds.dr.abdalkareem@uoanbar.edu.iq

ميس طه يعقوب الهيتي[1]
g.mais.taha@uoanbar.edu.iq

الملخص

تعد المياه الجوفية ضمن المناطق الجافة مورد أساسي للري في منطقة مستجمعات مياه وادي جروة، القائم – غرب العراق، ان معرفة نوعية المياه الجوفية مهمة للتنمية لزراعية المستدامة، تم استخدام المعلومات من اربعة ابار فضلاً عن مياه نهر الفرات في المنطقة الغربية من العراق، حللت هذه العينات المائية للموسمين (2024-2025) كيميائياً لبيان نوعيتها ومدى ملائمتها لعمليات الري في منطقة زراعية واعدة، تم قياس الموصلية الكهربائية (EC)، نسبة امدصاص الصوديوم (SAR)، نسبة الصوديوم ٪ Na، نسبة المغنيسيوم، تم اختيار مؤشر النفاذية (PI) وكربونات الصوديوم المتبقية (RSC) من أجل تقدير ملاءمة المياه الجوفية للري، اشارت النتائج للعينات بان قيم حوالي23.38 ٪،51.45 ٪،26.06 ٪،57.91 ٪،52 ٪، و44.32 ٪ من المياه الجوفية تجاوزت الحد المسموح به لـ EC و SAR و٪ Naو PI على التوالي.

تحدد هذه المؤشرات أن عينات المياه الجوفية القليلة ذات نوعية رديئة، فضلا عن استخدام أداة ArcGIS لتعيين مواقع أخذ عينات المياه الجوفية ورسم التوزيع المكاني لصفات مياه الري، تشير النتائج إلى أن عينات المياه الجوفية التي تم جمعها بشكل أساسي من تجاوز قيم حدود الري المسموح بها، النتائج توصي بالإدارة السليمة للمياه الجوفية من موقع الدراسة قبل استخدامها في الري ، للمحتوى الملحي المرتفع في مياه الآبار المدروسة، يُنصح باللجوء إلى تقنيات إدارية لترشيد استخدامها، وتفضيل نقل واستخدام مياه نهر الفرات للاستخدامات الزراعية، لضمان عدم الإضرار بنوعية التربة والمحاصيل الزراعية، وللحفاظ على الموارد المائية الجوفية التي قد تكون غير متجددة أو محدودة.

الكلمات الدالة: الموارد المائية، وادي جروة، الزراعة المستدامة، تحليلها كيميائياً، الري.

[1]**جامعة الانبار، كلية الزراعة، الانبار، العراق.**
[2]**جامعة الانبار، مركز دراسات الصحراء، الانبار، العراق.**

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