Irrigation water quality of Al-Gharraf Canal, south of Iraq

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Abstract. To evaluate the water quality of Al-Gharraf Canal south of Iraq for irrigation purpose, analysis of 12 physiochemical parameters of water samples by standard methods was carried out at five stations during the year 2016 (water temperature, pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, calcium, magnesium, sulfate, nitrate, sodium, potassium).

Seven irrigation water quality indices were calculated like; sodium percentage (% Na), soluble sodium percentage (SSP), residual sodium bicarbonate (RSBC), Kelly’s ratio (KR), permeability index (PI), magnesium adsorption ratio (MAR), and sodium adsorption ratio (SAR).

The results represented as diagrams (Piper, Stiff, Schoeller, Durov, Gibbs, and Wilcox) using AquaChem and RockWork hydro-chemical software.

Chemical analysis for canal water demonstrates the calcic chlorinated water type, the dominance of alkalis water, the major cations was in the order of: Na+ > Ca2+ > K+ > Mg2+ and major anions was: Cl- > SO42- > HCO3- > NO3-, the mean values of the irrigation water quality indices were (in meq/l) were; SAR (2.37), % Na (43.4), PI (%) (52.3), SSP (%) (38.1), MAR (%) (34.5), KR (0.61), RSBC (-1.78).

The results indicate the suitability of canal water for irrigational purposes based on the calculated indices for the majority of crops under special management for salinity and permeability control.

The presentation of chemical analysis by diagrams and numbers makes understanding of complex water system too simpler and quicker. This study is a comprehensive assessment towards providing indicators and classification indices on irrigation water quality of the canal ecosystem, which will be the basis for future planning decisions on agricultural demand management measures and water quality monitoring to protect this principal water resource.
Key words: Al-Gharraf, irrigation water, Durov, Piper, SAR, Wilcox, Gibbs.

1. Introduction

Rivers are the main source of water in Iraq and some countries in the Middle East, the region that is known by its shortage of water resources and acute water scarcity problems [1].

The supply of freshwater is essential to the socio-economic development and agriculture is the largest consumer; therefore the water shortage and quality issues cannot be separated or studied in isolation of agriculture [2,3,4].

It is expected that Iraq and the region will suffer from drought caused by climate change with less rainfall and high temperatures affecting peoples and crop yields [5, 6].

Iraq which was considered rich in its water resources, now it is suffering from a water shortage due to the large number of dams and reservoirs constructed on the Euphrates and Tigris in Turkey, Syria, and Iran during the last decades [7, 8].

Salinization is a growing problem affects agriculture in the central and southern Iraq. It is evaluated that around 60% of the cultivated land has been genuinely influenced by saltiness; and 20-30% has been abandoned [9].

Al-Gharraf Canal is a main source of water for agriculture and public water supply in the south of Iraq. It branches from the Tigris upstream of Al-Kut Barrage and flows through Wasit and Dhi-Qar provinces. Its water is utilized for drinking, irrigation, raising livestock and fishing [11].

The major irrigation water quality problems are sodicity, salinity, and alkalinity caused by the presence of large amounts of ions in water, affecting soil’s chemical and physical properties causing reduce soil productivity [12].

The common indices used to assess the suitability of water for irrigation are; percent sodium (% Na), residual sodium bicarbonate (RSBC), soluble sodium percentage (SSP), Kelly’s ratio (KR), permeability index (PI), magnesium adsorption ratio (MAR), sodium adsorption ratio (SAR) [13, 14, 15, 16].

The hydrochemical classification diagrams of, Piper, Durov, Stiff, Schoeller, Gibbs, and Wilcox have been widely used in the world (but little used in Iraqi studies) to show the ionic concentration in water samples for best understanding of complex water system which becomes quicker and simpler when it presents in graphical forms. Previous studies on water quality in Al-Gharraf region [17, 10] focused only on the general physicochemical characteristics of the canal water. The objective of the present work is to discuss the hydrochemical characteristics of Al-Gharraf Canal water and assessing its suitability for irrigation by applying several quality parameters, classification indices, and diagrams.

2. Materials and methods

2.1 The study area

Al-Gharrar Canal (Figure 1) is the major branch of Tigris River south of Baghdad; its water features are similar to the hydrological features of the Tigris in Al-Kut area. The canal yearly discharge has substantial yearly variance and experiences common and human issues, for example, pollution, salinity, a collection of mud, the growth of plants, misusing and lessening of water levels [18].

The canal passes through several towns and many villages in Wasit and Thi-Qar provinces until ends in the south Mesopotamian marshes [19]. The length of the primary canal is around 230 km, 50-80 m width and 3-7 m depth, irrigates an area of 700,000 hectares, the maximum capacity was about 622 m³/s, and the drainage area is 435,052 x10⁶ m². It's basin populated by more than million individuals and going through a farming zone of around 215019 h in the south-west of Iraq inside the sediment plain [20].
The canal lies between the north scope (32 ° 27’ - 31 ° 2’) and east longitude (45 ° 45’ - 46 ° 4’), this geographical position gives the region features like; the high rate of solar radiation, high temperature, few rain events, low dampness, and high rate of dissipation [19].

![Figure 1](image.png)

**Figure 1.** The study area and sampling stations [20].

### 2.2 Field sampling and water analysis

Water samples were collected monthly in pre-cleaned sterilized polyethylene bottles of two-liter capacity during January to December 2016 from five sampling stations on the canal (Figure 1). Samples were preserved and examined according to the standard methods of the American Public Health Association (APHA) [21].

Some variables were measured *in situ* including; water temperature (T) (°C), pH, and, electrical conductivity (EC) (μS/cm) by using the WTW multi-meter model Multi 340i. Total dissolved solids (TDS) measured by a temperature controlled oven. The concentrations of Ca\(^{2+}\), Mg\(^{2+}\) were measured by EDTA complex metric titration, K\(^+\) and Na\(^+\) by flame photometer model M410, UK, and Cl\(^-\) by silver nitrate titration method. Sulfate (SO\(_4^{2-}\)) was analyzed spectrophotometrically by BaSO\(_4\) turbidity method. Nitrate (NO\(_3^-\)) concentration was analyzed by cadmium reduction method and HCO\(_3^-\) by acid-base titration method. Determination of the study stations positions by the Global Positioning System (GPS). The concentration values expressed in milligram per liter (mg/l) unless otherwise indicated.

### 2.3 Irrigation water quality indices

The irrigation water quality indices, like (% Na), (SSP), (KR), (RSBC), (PI), (SAR), and (MAR) were calculated using the result values of water samples analysis and the suitable equations (Table 1).
Table 1. Equations used to calculate the water quality indices and criteria used for classifying irrigation water quality of the study area (concentrations in mill equivalents/liter; meq/l).

| Water quality indices                     | Equations                                                                 | Water quality criteria                                                                 | Reference |
|-------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-----------|
| Sodium Percentage (% Na)                  | \( \text{Na} = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \) | < 20 excellent, 20–40 good, 40–60 permissible, 60–80 doubtful, >80 unsuitable.         | [14]      |
| Soluble Sodium Percentage (SSP) (%)       | \( \text{SSP} = \frac{\text{Na}^+ \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \) | < 50 good, > 50 bad                                                                     | [22]      |
| Residual Sodium bicarbonate (RSBC)        | \( \text{RSBC} = \text{HCO}_3^- - \text{Ca}^{2+} \)                        | < 1.25 Safe                                                                             | [23]      |
| Kelly ratio (KR)                          | \( \text{KR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \)     | < 1 good, > 1 bad.                                                                     | [24]      |
| Sodium Adsorption Ratio (SAR)             | \( \text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{\frac{1}{2}}} \)     | < 10, excellent (S1), 10–18 good (S2), 18–26 doubtful (S3), > 26 unsuitable            | [13]      |
| Permeability index (PI) (%)               | \( \text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100 \) | < 20 excellent, 20–40 good, 40–80 injurious, > 80 unsatisfactory                     | [25]      |
| Magnesium Adsorption Ratio (MAR) (%)      | \( \text{MAR} = \frac{\text{Mg}^{2+} \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \)     | < 50 suitable, > 50 unsuitable.                                                        | [26]      |

2.4 Graphical diagrams
The overall hydrochemical components of irrigation water explained with the most widely utilized graphical diagrams; Piper [27], Durov [28], Stiff [29], Wilcox [14], Schoeller [30], and Gibbs [31] to better explain of the classification and water composition using the analysis result values of the dissolved ions by meq/l. The hydrochemical software, RockWork version 16 and AquaChem 2014.2 software were used to plot these diagrams.

In Piper diagram (Figure 2) the percentage concentration values in meq/l of the main anions (Cl\(^-\), SO\(_4^{2-}\), and HCO\(_3^-\)) and cations (Ca\(^{2+}\), Na\(^+\), K\(^+\), and Mg\(^{2+}\)) are plotted in two triangles, which were then anticipated further into a diamond-like field and inference is drawn for the chemical composition of water [27].

Durov diagram (Figure 3) is consisting of two ternary diagrams and the percentages of the anions are plotted against that of cations; sides shape the central rectangular, two-fold plot of total anion vs. the total concentrations of the cation [28].

Both the diagrams (Piper and Durov) show differences and similarities because the water samples which have the same qualities will plot together as groups, in the first diagram, the information plotted on the diamond-shaped field will decide the water type. Complexity to this, crossing point of lines reached out from the points in ternary outlines and anticipated on the sub-divisions of paired plot of Durov diagram show the hydrochemical forms required alongside water sort [22].

The canal water quality for irrigation purpose was assessed by Gibbs diagram (Figure 7) which is widely used to explain the relationship of water composition and characteristics [31].

Gibbs suggested that a simple plot of TDS versus the weight ratio of Na\(^+\) / (Na\(^+\) + Ca\(^{2+}\)) would provide meaningful information on the relative importance of three major natural mechanisms.
controlling surface water chemistry: (1) rock weathering dominance, (2) atmospheric precipitation dominance, and (3) evaporation and fractional crystallization dominance [32, 33].

These two equations are used, the ionic concentration is in meq/l:
- Gibbs ratio I (for anion) = [Cl⁻]/[Cl⁻+HCO₃⁻]
- Gibbs ratio II (for cation) = [Na⁺+K⁺]/[Na⁺ + K⁺+Ca²⁺]

### 2.5 Stiff Diagram

Stiff diagrams 'Figure 5' are a typical method for showing concoction attributes for individual water tests. A stiff diagram utilizes four parallel, horizontal axes reaching out on each side of a vertical zero axis. Anions and cations are plotted on the left and right of the vertical axis in meq/l. These shapes are frequently included specifically on the site map for quick comparison of all the samples on a single page. Major ion concentrations are appeared to the left and right of the plot centerline and present the graph its shape and size [29].

### 3. Results and discussion

The results of the physicochemical parameters measured, water quality indices calculated, and diagrams plotted for the canal water samples in the study area are summarized in Tables 2, 3, 4, Figures 2, 3, 4, 5, 6, and discussed as follows:

#### 3.1 General water physiochemical parameters

The temperature variation of the canal water in the study area ranged from 17 to 33°C. Hydrogen ion concentration (pH) was ranging from 7.0 to 8.3; EC value ranging from 1.19 to 1.925 ds/m. The TDS in the canal water ranged between 760 and 1232 mg/l. Cl⁻, SO₄²⁻, HCO₃⁻, and NO₃⁻ were ranging from 187 to 288, 147 to 210, 102 to 327, and 2.2 to 7.2 respectively. The concentration of Na⁺ ranged from 80 to 125 mg/l, Ca²⁺ from 80 to 125 mg/l, Mg²⁺ from 23 to 43 mg/l, and K⁺ from 34 to 77 mg/l. From this it was clear that hydrochemistry was dominated by sodium, calcium, chloride and sulfate ions. The relative abundance (in mg/l) of major cations was in the order of: Na⁺ > Ca²⁺ > K⁺ > Mg²⁺ and major anions was: Cl⁻ > SO₄²⁻ > HCO₃⁻ > NO₃⁻, Table 2 and Table 3.

#### Table 2. Annual range and mean values of chemical and physical parameters of water samples during the study period. The temperature in °C, EC in (ds/m) and the rest in mg/L.

| 1st Station (Kut) | 2nd Station (Hai) | 3rd St. (Qalaa) | 4th St. (Badaa) | 5th St. (Shatra) |
|-------------------|-------------------|-----------------|-----------------|-----------------|
| **Range**         | **Mean**          | **Range**       | **Mean**        | **Range**       |
| Temp.             | 17 31             | 23.7            | 18 32           | 24.5            | 18 32           | 23             | 18 33           | 24             |
| pH                | 7.2 7.6           | 7.3             | 7.2 7.6         | 7.4             | 7 8.3          | 7.5            | 7.2 8.2        | 7.6            |
| EC                | 1.19 1.6          | 1.37            | 1.29 1.72       | 1.51            | 1.35 1.67      | 1.61           | 1.42 1.88      | 1.651          |
| TDS               | 760 1023          | 877             | 828 1101        | 967             | 864 1069       | 1041           | 911 1206       | 1057           |
| HCO₃⁻             | 102 140           | 118             | 192 270         | 223             | 186 327        | 235            | 198 324        | 240            |
| Cl⁻               | 205 275           | 251             | 187 216         | 228             | 204 282        | 232            | 192 282        | 232            |
| Ca²⁺              | 82 114            | 96              | 80 120          | 103             | 90 125         | 107            | 92 107         | 98             |
| Mg²⁺              | 29 43             | 35              | 26 41           | 32              | 25 27          | 34             | 23 39          | 31             |
| SO₄²⁻             | 150 193           | 171             | 168 190         | 175             | 147 198        | 181            | 170 210        | 190            |
| NO₃⁻              | 2.8 7             | 4.1             | 2.8 7.2         | 4.8             | 3.3 6.6        | 4.8            | 2.8 6.2        | 4.85           |
| Na⁺               | 91 144            | 108             | 88 150          | 107             | 96 143         | 120            | 104 121        | 106            |
| K⁺                | 37 57             | 44              | 34 57           | 44              | 42 63          | 47             | 39 67          | 55             |

The major anions was: Cl⁻ > SO₄²⁻ > HCO₃⁻ > NO₃⁻, Table 2 and Table 3.
Table 3. Annual mean values of major ions concentration in water samples by meq/l unit.

| Stations | Ca$^{+2}$ | Mg$^{+2}$ | Na$^{+}$ | K$^{+}$ | Cl$^{-}$ | SO$_4^{2-}$ | HCO$_3^{-}$ |
|----------|-----------|-----------|----------|---------|---------|-----------|-------------|
| Kut      | 4.79      | 2.88      | 4.7      | 1.13    | 7.07    | 3.56      | 1.93        |
| Hai      | 5.14      | 2.63      | 4.65     | 1.13    | 6.42    | 3.64      | 3.66        |
| Qalaa    | 5.34      | 2.8      | 5.22     | 1.07    | 6.54    | 3.76      | 3.85        |
| Badaa    | 4.89      | 2.55      | 4.61     | 1.41    | 6.54    | 3.95      | 3.93        |
| Shatra   | 5.49      | 2.63      | 4.78     | 1.3     | 6.93    | 3.74      | 2.97        |

3.2 Water quality indices

Table 4 shows the annual means of water quality indices including: (%Na), (RSBC), (SSP), (KI), (PI), (MAR) and (SAR) in the canal water samples during the study.

Table 4. Annual mean values and results of irrigational water quality indices from the five stations during the study.

| Station | SAR | % Na | PI (%) | SSP (%) | MAR (%) | KR | RSBC |
|---------|-----|------|--------|---------|---------|----|------|
| Kut     | 2.4 | 43.2 | 49.2   | 38.9    | 37.55   | 0.61| -2.86|
| Hai     | 2.36| 42.6 | 52.8   | 37.4    | 33.85   | 0.60| -1.48|
| Qalaa   | 2.4 | 43.6 | 53.7   | 39.07   | 34.4    | 0.64| -1.49|
| Badaa   | 2.5 | 44.9 | 54.7   | 38.3    | 34.3    | 0.62| -0.96|
| Shatra  | 2.23| 42.8 | 50.4   | 37.05   | 32.4    | 0.59| -2.52|
| Mean    | 2.37| 43.4 | 52.3   | 38.1    | 34.5    | 0.61| -1.78|
| Result  | Excellent | Permissible | Injurious | Good | Suitable | Good | Safe |
| References | [13] | [14] | [25] | [22] | [26] | [35] | [34] |

A. Sodium adsorption ratio (SAR)

The classification of the canal water samples with respect to SAR showed that its mean value is 2.37, all of the samples were <10 and fall under excellent category [13, 39]. SAR calculates the degree to which dissolved cations tend to enter into cation exchange sites in the soil. The high Na concentrations relative to the Ca and Mg affects the soil permeability, contributes to total salinity and toxic to sensitive plants [13, 40].

B. Sodium percentage (% Na)

High percentage of sodium in water decreases plant growth and soil penetrability. Results for Na % ranged from 42.6 % to 44.9 % with a mean of 43.4 %, as shown in Table 4, based on % Na, the canal water was not excellent nor good but permissible for irrigation [14].

C. Permeability index (PI)

In the present study, its values ranged from 49.2 meq/l to 54.7 meq/l with a mean of 52.3. This result suggests that all water samples can be categorized as injurious irrigation water [38]. As proposed by Doneen [25], soil permeability is influenced by a long-term utilization of irrigation water, depending on soil sort and the water content of (Na$^+$, Ca$^{2+}$, Mg$^{2+}$ and HCO$_3^-$).

D. Soluble sodium percentage (SSP)
It is a vital factor to study sodium hazard and for adjudging the quality of water for irrigation. The high rate of sodium in water may decrease plant growth and soil penetrability [14].

The soluble sodium percentage values range between 37.05 meq/l to 39.07 meq/l with a mean of 38.1. According to SSP, all of the canal water was good for irrigation [22].

E. Magnesium adsorption ratio (MAR) (%)

It was proposed by Szaboles and Barab [36] for classifying irrigation water quality. MAR values of all the samples varied from 32.4 to 37.55 % with a mean of 34.5 % which was less than 50.0 indicating that water is suitable for irrigation uses. Crops are harmfully affected and the soil becomes more saline if MAR exceeds 50% [15, 26, 37].

F. Kelly Ratio (KR)

The Kelly Ratio values of the study area ranged between 0.59 meq/l to 0.64 meq/l with a mean of 0.61. This indicates that all of the water samples fall within the limit of <1.0 and are considered good for irrigation [35]. When the concentration of Na+ increases, it will replace Ca2+ and cause soil dispersion, where Ca2+ has a vital role in the nutrition of plants. In like manner, the take-up of K+ is stimulated, while the absorption of Na+ is repressed, by Ca2+, notwithstanding when the concentration of Ca2+ is low [24].

G. Residual sodium bicarbonate (RSBC)

Water with high RSBC has high sodium hazard and high pH makes land infertile attributable to deposition of sodium carbonate. Carbonate and bicarbonate are combined with Na+ when Ca2+ and Mg2+ precipitated by plant uptake and evaporation to represents a loss of fertility [23].

In this study RSBC values (Table 4) ranged from -2.86 meq/l to -0.96 meq/l with a mean of -1.78, it was less than the critical value of 1.25 meq/l and consider safe for irrigation (Gupta, 1989). The negative values indicated that dissolved ions content of Ca2+ and Mg2+ > HCO3- [23].

3.3 Graphical Diagrams

3.3.1 Piper Diagram

The concentrations of the main cations and anions found in the canal water of the study area are plotted from the available data in Piper’s diagram to reveal the analogies, dissimilarities, and type of water (Figure 2). The Piper diagram of water classification showed that all canal water samples were in the Na+, Ca2+, K+, Mg2+ and Cl-, SO42-, HCO3-, NO3- facies, the alkali elements (Na+ + K+) exceeded alkali-earth (Ca2+ + Mg2+), the strong acidic anions (Cl- + SO42-) exceeded the weak acidic anion HCO3-, calcium chloride type of water were predominant in all samples.

3.3.2 Durov Diagram

Durov diagram shows that the type of water samples of the canal from the five stations in all seasons is calcium chloride type demonstrates the dominance of alkaline water with increased portions of earth alkaline, the prevailing anions are chloride and sulfate, cations are sodium and calcium. In general, water chemistry of the study area was dominated by alkaline elements and strong acids 'Figure 3'.
Figure 2. Piper’s Diagram showing the major chemical compositions of the canal water samples.

Figure 3. Durov’s Diagram showing the chemistry of water samples.
3.3.3 Wilcox Diagram
SAR and EC plotted to get Wilcox diagram which divides waters into C1, C2, C3, and C4 categories on the basis of salinity hazard (EC) and S1, S2, S3 and S4 categories on the basis of sodium hazard (SAR). The results of this study indicate that all samples of the canal were in a C3S1 category with high salinity and low sodium (alkalinity) hazards as shown in 'Figure 4' [14, 41].

The canal water of these samples can be used for irrigation with most crops under special management for salinity control due to high salinity hazards.

When the concentration of chloride ions higher than 4 meq/l, toxicity problems can occur for sensitive crops according to [42]. Waters of Al-Gharraf (Table 3) have more than 4 meq/l and a high risk of salinity, it is fresh brackish water based on Stuyfzand classification [43].

![Figure 4. The site of the water samples on the Wilcox Diagram.](image)

3.3.4 Stiff Diagram
The stiff system is a method for showing similarities or differences and changes in water composition explaining the chemical composition in hydrological cross-section. The width of the pattern could be used as an approximate indication of total ionic content [44].

'Figure 5' shows a stiff diagram for one of the study stations, there were little differences in the concentrations of the major dissolved ions (Ca\(^{2+}\), Na\(^{+}\), Mg\(^{2+}\), K\(^{+}\), Cl\(^{-}\), SO\(_4\)^{2-}\), and HCO\(_3^-\)) among stations and seasons.
3.3.5 Schoeller Diagram

The Schoeller diagram is used to study the chemical composition of the canal water, ions concentrations (meq/l) are plotted as shown in Figure 6.

Results specify that lines of similar slope connecting concentrations of different parameters are indicative of water from a similar source. The most water type of high sodium content also has a high concentration of chloride [30].

Schoeller index revealed that base exchange reactions were more predominant than cation-anion exchange reaction. In this area, water samples had higher HCO$_3^-$ values than alkali-earth indicating that water of the study area was of base exchange-softened type [45].

Figure 5. Stiff diagram for one of the study stations shows the water ionic composition.

Figure 6. The position of the canal water samples on the Schoeller’s diagram.
3.3.6 Gibbs diagram

According to Gibbs diagram, the predominant of all the canal water samples in the study area fall in the evaporation and fractional crystallization dominance field of the diagram and evaporation is the main responsible process for changing the chemistry of the canal water, 'Figure 7' [31].

Figure 7. Gibb’s diagram plot of the canal water samples.

4. Conclusions

Chemical composition of Al-Gharraf Canal water indicated that the cationic concentrations ranged in the order of Na$^+$ > Ca$^{2+}$ > K$^+$ > Mg$^{2+}$, while it is Cl$^-$ > SO$_4^{2-}$ > HCO$_3^-$ > NO$_3^-$ for anions.

The Piper and Durov diagrams showed the predominance of calcic chlorinated (Ca$^{2+}$- Cl$^-$) type.

The Gibbs plotting suggesting that evaporation and fractional crystallization is the prime process for contributing the ions into the water.

Wilcox diagram reveals that the water quality class is C3–S1 has a high risk of salinization and a low risk of alkalization with low SAR.

RSBC values of the canal water samples belong to good class; the irrigation water does not present any risk of sodicity but has a high risk of salinization, especially for sensitive crops.

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