Using of geographical information system and water quality index for evaluation of groundwater quality in the Dammam Zone, Faddak farm, Karbala, Iraq

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Abstract: This study aims to evaluate the groundwater quality for irrigation purpose in the Dammam formation, Faddak farm, Karbala governorate. Set of physical and chemical parameters included the concentrations of cations and anions were measured in the water samples taken from seven wells in the region under consideration. Results have been analyzed with aid of geographical information system (GIS) by application of “Inverse Distance Weighted, IDW” interpolation method. The plotted maps proved that the groundwater in the study area can classify as “slightly brackish water” because the total dissolved salts ranged from 1000 to 300 mg/L. Also, the sulfate and chloride ions have relatively very high values with arrangement of cations of Na⁺ > Ca²⁺ > K⁺ > Mg²⁺ and anions of SO₄²⁻ > Cl⁻ > HCO₃⁻ > NO₃⁻. The calculated values of Irrigation water quality index (IWQI) was greater than zero and less than 40; so, the water can identify as “severe restriction, SR”. Therefore, this water can’t be used for irrigation purpose and can be applied only for the soil with high hydraulic conductivity which popular property for study area.

1. Introduction

Water is considered the origin of life and it represents the most important agent of natural resources over the landscape. It reflects the continuation of life for all organisms and also is the important source of energy over the world. One of the vital natural resources for water is the “groundwater” especially two billion people depend directly on aquifers for drinking water, and forty percent of the food production in the world can achieve through using groundwater for irrigation [1]. Groundwater is water found beneath the ground surface and resulted from seepage of water in the downward direction from the surface through migration in the soil matrix and voids of geologic formations named an aquifer. [2] Bear (1979) defined aquifer as “a geological formation which is capable of storing and transmitting a significant quantity of water under ordinary field conditions.”

To assess water quality, traditional methods are required to compare of measured parameters with acceptable guidelines. The usage of such methodology gives suitable identification for limitations sources; however, this will not plot an overall vision of the temporal and spatial trend for overall water [3-5]. One approach of water quality classification is by using indices, where a set of variables can be combined in the single number, facilitating the explanation of extensive lists of indicators, supported this classification [5-7]. Water quality indices are
understandable and simple tool for decision maker to identify the quality of water and optimum use in the irrigation sector. The salinity of water usually develops progressively within a flow domain even if it is a single layer due to the dissolution of its salts content because of groundwater migration between discharge and recharge zones. The geological setting in Iraq permits such a quality profile with the sedimentary cover ranged from 4 to 13 km thick.

Previous studies are used the water quality index (WQI) with or without of GIS for evaluation and management of groundwater quality for domestic, irrigation and other uses. This index is a significant inductor and considered one of the best active tools to transfer the details of water resource to the policy-maker. For example, the investigation of the groundwater quality in the Dibdiba Aquifer, Kerbala City, Iraq for human consumption by using WQI was achieved. The results showed that the water was found to be severely contaminated and unsuitable for drinking purpose [8]. The study presented by [9] was concentrated on the assessment of water quality in the western region of Iraq and to find its suitability for drinking and irrigation purposes depending on WQI map created by ArcGIS Spatial Analyst tool. Also, the deep discussion for the quality of groundwater at Jazeera Al Najaf was implemented based on the calculations of WQI [10].

The present work aims to provide an overview of groundwater quality in the Dammam formation, Faddak farm, Karbala desert through plotting the spatial distribution of water quality parameters like concentrations of cations and anions with irrigation water quality index (IWQI) by application of GIS using IDW interpolation method.

2. Study area

To identify the properties of groundwater, several samples of this water were collected from certain site somewhere located at 19 km western south of Karbala Governorate center under the south coast of Al-Razzaza lake in Iraq. The site is located between latitudes (43° 52′ 44ʺN), and longitudes (32° 43′ 23ʺE) with gross area reached to 2000 dunam as shown in Figure 1(a-d). The main soil type of aquifer in this area is sediments of gravel, sand, and gravelly sand with presence of clayey lenses [11,12]. These lenses are taken the shape of compacted clayey balls interfered with small quantity of sand and gypsum working as agent material. This region can describe as smooth topographic features with an elevation ranged from 20 to 61 m above sea level as illustrated in Figure 1(e). This figure proves that the surface elevation of this area decreases from northeast to southwest and it contains ten wells as in Figure 1(f) that can be utilized to estimate the aquifer properties.

Geologically, this area is with plain-like to slightly expressed hilly character and formed a part of Karbala-Najaf plateau, which belongs to the Mesopotamia zone, and situated in the center of Iraq [13-16]. The stratigraphic column for region under consideration composed of the following formations arranged from oldest to newest [17]:

- Tayarat formation (Cretaceous): It is composed of clayey, limestone, dolostone and dolomitic limestone. This formation characterizes by the existing of cavities and Karstification in most areas [18-20]. This formation is the most important for the upper chalky period of sedimentation, which extends over a wide area of the western desert.
- Umm Er Radhuma formation (Upper Paleocene): This formation is consisted of dolomite and dolomitic limestone with thin layers of gypsum and anhydrite. The presence of fractures, fissures and cavities can be observed in this formation; so, it is identified as a good water bearing formation within the Southern Desert [21,22]. It is a complex hydrogeological unit with Dammam formation, due to the presence of hydraulic connection between these formations [23-25].
- Dammam formation (Eocene): It is most important aquifer in South West of Iraq. This formation contains of different types of carbonate rocks like dolomite, dolomitic limestone and limestone. Observations proved that there are cavities, karstified canals, fractures, fissures and joints in this formation; accordingly, it has highest hydraulic conductivity and transmissivity [20].
Euphrates formation (Early Miocene): It considers one of the widespread formations in Iraq and belongs to the early Miocene sequence. This formation includes of limestone with texture varied from olitic to chalky limestone which locally contain corals and shell coquinas.

Nfayil formation (Middle Miocene): It generally consists of green, partly reddish in places sandy, dolomitic and gypseous marl with interbedded calcareous, partly sandy claystone and fossiliferous limestone. The gypsum can occur as selenite veins and as crystals within the rocks [26,27].

Fat'ha formation (Middle Miocene): It is one of the most aerially widespread and economically important formations in Iraq. This formation has been developed in the southern direction and along the eastern bank of Al-Razzaza Lake. It consists of lenticular sequence of reddish sandy calcareous claystone and brownish coarse grained sandstone, with limestone intercalations. The limestone beds are often whitish, porous, chalky and partly sandy [28].

Injana formation (Late Miocene): This formation is exposed along both ridges of Tar Al-Sayid and Tar Al-Najaf and in the eastern bank of Al-Razzaza Lake. It is consisted of sandy calcareous claystone and lentics of grey, partly greenish silty, brownish, greenish and yellowish sandstone [28]. The lower contact with the Fat'ha formation is conformable and represented by admixture of pebbles, sands and silts cemented by grey marl. The upper contact with the overlying formation (Dibdibba formation) starts with the first whitish, grey, friable and pebbly sandstone.

Dibdibba formation (Pliocene – Pleistocene): It is formed of pebbly sandstone and sandstone with some claystone, siltstone, and marl associated with secondary gypsum [29]. The formation is well exposed along both ridges of Tar Al-Sayed and Tar Al-Najaf, occupying the top part of the exposed sequence, hence making up the bed rock of the desert plain between Najaf and Karbala.

The hydrogeological investigations signified that the Dammam formation contains huge quantities of water [30]. The transmissivity value of this formation varies from 3.1 to 4752 m²/day which reflects the heterogeneity of aquifer due to the variation of fractures and porosity [25]. The value of storage coefficient for confined aquifer may equal to 1.2 × 10⁻⁴ while the specific yield for unconfined aquifer can equivalent to 2.45 × 10⁻² [17]. The piezometric head in the Dammam aquifer is approximately equal to 41.97 m which very close to the head in Umm Er Radhumu aquifer where this head can cause a vertical recharge from Umm Er Radhumu (the lower aquifer) to Dammam (the upper aquifer) [31]. The movement of groundwater in the western desert is directed to the east and the north-east. However, the groundwater flow takes different pathways through the local region based on topographic, geological and structural features [26]. Direction of flow in the Dammam aquifer was generally from south-west to north-east (i.e., towards Euphrates River) which represents the regional groundwater flow direction of Iraq [32].
Figure 1. (a-d) Geographical location, (e) topography and (f) locations of the wells for the study area.
3. Groundwater quality analysis
The quality of groundwater is of nearly equal importance to quantity. The assessment of groundwater quality is very important to ensure the optimum and sustain usage of this resource. The required quality of groundwater supply depends upon its purpose [33]. The quality of deep groundwater in the Faddak farm was evaluated by taking samples from seven of the wells within the study area in December 2019. To withdraw of samples, the wells were pumped until the temperature, and pH were stabilized. Clean polyethylene bottles were used for the collection of these samples and the analyses have been conducted at the holy Karbala Province - Karbala Sewage directorate. However, the pH, EC, TDS and temperature were measured in the site of the study area. Laboratory tests were carried out to find TSS, COD and the concentrations of SO42-, HCO3-, Cl-, PO43-, NO3-, NO2-, NH3, H2S, Ca2+, Mg2+, K+, Na+, Pb2+, Cd2+, Cu2+, Ni2+ ions. ArcGIS 10.4.1 was applied to generate of different thematic maps and ArcGIS Spatial Analyst to obtain the distribution maps for measured parameters and irrigation water quality index (IWQI).

4. Results and discussion
4.1 Spatial analysis of groundwater quality
The water quality variables like pH, TDS, EC, Ca2+, Na+, SAR, K+, Cl-, SO42- and others mentioned previously were listed in Table 1 and their respective maps have been prepared using point data spatial analysis of GIS. According to Figure 2(a and b) in combination with this table, the values of pH are ranged from 5.5 to 8.5 while the electrical conductivity (EC) of water at 25°C varies widely from 4060 and 5370 μS/cm. In addition, the TDS values are changed from 1770 to 2850 mg/L and according to classification of Altoviski (1962) for TDS [34], all groundwater samples can classify as slightly brackish water (TDS > 1,000 mg/L). Figure 2(c) signifies that the magnitudes of TDS increased spatially from the north-west to the south-east for study area.

The predominant cations trend in aquifer under consideration is Na+ > Ca2+ > K+ > Mg2+. This means that the sodium is the most ions presented in the groundwater of the study area with concentration range of (290.8-395.9 mg/L); however, the spatial distribution of this ion can be observed in Figure 2(d). The maximum and minimum values of remaining cations (i.e., calcium, potassium and magnesium) are listed in Table 1 where the spatial distribution of calcium and potassium can be explained in Figure 3(a and b) respectively. Combination of relative concentrations for magnesium, sodium and calcium ions represents the most familiar factor for water quality affected on the water infiltration rate. This factor is known as the “sodium adsorption ratio, SAR” measured in mg/L and calculated by following equation [35]:

\[
\text{SAR} = \frac{\text{Na}^+}{\sqrt{\text{Ca}^{2+}\times\text{Mg}^{2+}}} 
\]

(1)

The SAR values increase spatially from the north-west to the south-east following the aquifer flow direction as shown in Figure 3(c). The abundance of the major anions is arranged in the following order: SO42-> Cl-> HCO3-> NO3-. The aquifer characterizes by a high sulfate ion concentration which varied from 409 to 2015 mg/L. Figure 3(d) presents the spatial variation of sulfate ion (SO42-) concentration in the study area. Chloride is also presented in irrigation water which in spite of required for crops at low concentrations but high levels may be harmful for sensitive crops. Water with chloride less than 140 mg/L (or 4 meq/L) can classify to be good quality for irrigation [36]. Accordingly, the chemical analysis of water samples showed that the chloride ion concentrations are relatively very high as in Table 1 and Figure 4(a). The HCO3- concentration is relatively low in comparison with sulfate and chloride ions in the range from 195.2 to 567.3 mg/L (Table 1 and Figure 4(b)).
| Parameter | Well designation | Drainage | Maximum | Minimum |
|-----------|------------------|----------|---------|---------|
| pH        | Well 1 | 6.6 | 8.5 | 5.5 |
|           | Well 2 | 8.5 | 6.9 | 5.5 |
|           | Well 3 | 6.9 | 7 | 5.5 |
|           | Well 4 | 7 | 6.4 | 5.5 |
|           | Well 6 | 24 | 6.5 | 5.5 |
|           | Well 8 | 24 | 6.5 | 5.5 |
|           | Well 10 | 24 | 6.5 | 5.5 |
| Temp.     | Drainage | 30.8 | 26.7 | 15 |
|           | Maximum | 29.1 | 29.5 | 15 |
|           | Minimum | 25.1 | 24.5 | 15 |
| EC        | Drainage | 48.20 | 42.30 | 41.10 |
|           | Maximum | 40.60 | 37.40 | 53.70 |
|           | Minimum | 53.70 | 44.10 | 44.60 |
| TDS       | Drainage | 2850 | 1920 | 1929 |
|           | Maximum | 2400 | 1770 | 2850 |
|           | Minimum | 2060 | 1600 | 1770 |
| TSS       | Drainage | 5 | 24 | 73 |
|           | Maximum | 917 | 39 | 917 |
|           | Minimum | 917 | 2 | 2 |
| COD       | Drainage | 99 | 24 | 7 |
|           | Maximum | 213 | 2 | 99 |
|           | Minimum | 87 | 31 | 31 |
| SO4       | Drainage | 980 | 409 | 1277 |
|           | Maximum | 832 | 1115 | 2105 |
|           | Minimum | 795 | 240 | 1233 |
| HCO3      | Drainage | 567.3 | 195.2 | 341.6 |
|           | Maximum | 222 | 268.4 | 567.3 |
|           | Minimum | 115 | 231.8 | 195.2 |
| Cl-       | Drainage | 1004 | 976 | 1900 |
|           | Maximum | 976 | 852 | 1900 |
|           | Minimum | 920 | 980 | 852 |
| NO3       | Drainage | 4.06 | 0.07 | 2.09 |
|           | Maximum | 0.21 | 0.07 | 0.21 |
|           | Minimum | 0.05 | 0.07 | 0.05 |
| NH4       | Drainage | 0.2 | 0.17 | 0.13 |
|           | Maximum | 0.2 | 0.2 | 0.13 |
|           | Minimum | 0.17 | 0.2 | 0.13 |
| H2S       | Drainage | 42 | 81 | 81 |
|           | Maximum | 81 | 81 | 2 |
|           | Minimum | 2 | 2 | 2 |
| Ca2+      | Drainage | 204.4 | 180.36 | 160.3 |
|           | Maximum | 140.23 | 1320.64 | 160.3 |
|           | Minimum | 124.34 | 1240.48 | 160.3 |
| Mg2+      | Drainage | 33.67 | 31.72 | 34.88 |
|           | Maximum | 39.04 | 29.28 | 53.68 |
|           | Minimum | 29.28 | 29.28 | 26.84 |
| K+        | Drainage | 41.9 | 38.2 | 30.4 |
|           | Maximum | 37.9 | 45 | 30.4 |
|           | Minimum | 39.3 | 39.3 | 30.4 |
| Na+       | Drainage | 325.5 | 324.5 | 350 |
|           | Maximum | 395.9 | 350 | 350 |
|           | Minimum | 350 | 350 | 350 |
| Pb2+      | Drainage | 0.46 | 0.18 | 0.88 |
|           | Maximum | 1.42 | 0.61 | 1.42 |
|           | Minimum | 0.61 | 0.06 | 0.3 |
| Cd2+      | Drainage | 0.1 | 0.104 | 0.18 |
|           | Maximum | 0.192 | 0.15 | 0.265 |
|           | Minimum | 0.138 | 0.015 | 0.14 |
| Cu2+      | Drainage | 0.06 | 0.29 | 0.06 |
|           | Maximum | 0.34 | 0.34 | 0.06 |
|           | Minimum | 0.06 | 0.29 | 0.06 |
| Ni2+      | Drainage | 5 | 0.2 | 0.4 |
|           | Maximum | 7 | 6.5 | 6.5 |
|           | Minimum | 0.2 | 4.12 | 0.3 |
| SAR       | Drainage | 29.83 | 31.51 | 34.2 |
|           | Maximum | 43.32 | 26.37 | 23.98 |
|           | Minimum | 30.15 | 27.71 | 23.98 |
Figure 2. Distribution of a) pH, b) EC, c) TDS and d) sodium ion in the study area.
Figure 3. Distribution of (a) $\text{Ca}^{2+}$, (b) $\text{K}^+$, (c) SAR and (d) $\text{SO}_4^{2-}$ parameters in the study area.
Figure 4. Distribution of a) chloride and b) bicarbonate ions in the study area.

4.2 Irrigation water quality index (IWQI)
In order to assess the groundwater quality for irrigation purpose in more accuracy, the IWQI will be determined. This index reflects the overall water quality by single number for certain time and location depended on the specific variables of water quality. This number can’t give the whole vision of water quality because several other variables have not included in this index. This means that the IWQI depends on number of significant variables which provided a clear indicator for status of water.
Regional soil, cultivated crop pattern and climatologic conditions are most parameters that must be adopted to specify the quality of water required for irrigation. In this regard, GIS can
draw spatial distribution maps for individual water quality variables and these maps are able to introduce comparative evaluations. Collective of quality variables in IWQI can utilize to specify the suitability of groundwater for drinking and irrigation uses. IWQI model developed by [37] was applied to the measured data for study area. This required to; 1) identify the relevant parameters for irrigation use and 2) establish the quality measurements (qi) with aggregation weights (wi). Eq.1 in combination with criteria mentioned in Table 2 established by [38] can be applied to estimate the values of qi.

\[
q_i = q_{i\text{max}} - \left( \frac{(x_{ij} - x_{\text{inf}}) \times q_{i\text{amp}}}{x_{\text{amp}}} \right)
\]

where \(q_{i\text{max}}\) is the maximum magnitude of qi for specific class, \(x_{ij}\) is the measured value of the variable, \(x_{\text{inf}}\) is the value corresponded to the lower limit of the class to which the variable belongs, \(x_{\text{amp}}\) is class amplitude to which the variable belongs, and \(q_{i\text{amp}}\) is the class amplitude. For the last class of each variable, the \(x_{\text{amp}}\) can evaluate by taking the highest value calculated from chemical-physical analysis of water samples as the upper limit. The weight of each variable utilized in the determination of IWQI was taken from [37] as listed in Table 3. Eq.3 can apply to find the value of IWQI.

\[
\text{IWQI} = \sum_{i=1}^{n} q_i w_i
\]

Table 2. Parameters limiting values for calculation of qi [38].

| qi   | EC (µS/cm) | SAR (meq/L)\(^{1/2}\) | Na\(^+\) | Cl\(^-\) | HCO\(_3\)\(^-\) |
|------|------------|------------------------|----------|----------|----------------|
| 85-100 | 200-750    | <3                     | 2-3      | <4       | 1-1.5         |
| 60-85  | 750-1500   | 3-6                    | 3-6      | 4-7      | 1.5-4.5       |
| 35-60  | 1500-3000  | 6-12                   | 6-9      | 7-10     | 4.5-8.5       |
| 0-35   | <200 or ≥3000 | ≥12                 | <2 or ≥9 | ≥10      | <1 or ≥8.5    |

* meq/L

Table 3. Weights used for calculation of IWQI [37].

| Variable | Weight (\(w_i\)) | SAR | Na\\(^+\) | Cl\\(^-\) | HCO\(_3\)\\(^-\) | EC | Total |
|----------|------------------|-----|-----------|-----------|----------------|----|-------|
|          |                  | 0.189 | 0.204     | 0.194     | 0.202          | 0.211 | 1.000 |

Certain classifications for quality of water were presented by [39] and [40] based on the values of IWQI; however, these classes are identified the risks associated with usage such water for soil and plant. According to these classifications, the water considers “No Restriction, NR”, “Low Restriction, LR”, “Moderate Restriction, MR”, “High Restriction, HR” and “Severe Restriction, SR” when the values of IWQI of “85-100”, “70-85”, “55-70”, “40-55” and “0-40” respectively. For example, the “Recommendation” for usage of water classified as SR for “Soil” will be “Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water, soils must have high permeability, and excess water should be applied to avoid salt accumulation” while for plant can be taken the following form “Only plants with high salt tolerance, except for waters with extremely low values of Na\(^+\), Cl\(^-\) and HCO\(_3\)\(^-\)”.

Figure 5 shows the final IWQI map which resulted from overlapping of the thematic maps for SAR, Na\(^+\), Cl\(^-\), HCO\(_3\)\(^-\) and EC due to geo-statistical analysis. The spatial integration of groundwater quality mapping was implemented by ArcGIS Spatial Analyst extension using Eq. 3. This figure represents the spatial distribution of IWQ values for study area to describe the suitability of water for irrigation. So, this will be efficient tool for decision maker to specify the suitable locations of drilling wells that can be using for irrigation. The water in the study area can be classified as “severe restriction, SR”. This means that the water of the
studied aquifer should be avoided its use for irrigation under normal conditions; however, the water can be applied for the soil having high permeability. Fortunately, the study area in Karbala desert could use for groundwater.

Figure 5. Spatial distribution of irrigation water quality index in the study area.

5. Conclusions
Geographical information system in combination with IWQI can give clear vision for quality of groundwater in the Dammam formation, Faddak farm, Karbala governorate especially through plotting spatial distribution thematic maps for water quality indices. These maps certified that TDS values are varied from 1770 to 2850 mg/L and; therefore, this water can classify as “slightly brackish water”. Measurements proved that the predominant cations are arranged in the form of: Na\(^+\) > Ca\(^{2+}\) > K\(^+\) > Mg\(^{2+}\) while anions take the order of: SO\(_4^{2-}\) > Cl\(^-\) > HCO\(_3^-\) > NO\(_3^-\). The chemical analysis reported that the concentrations of chloride and sulfate ions are relatively very high. Also, the determined values of IWQI demonstrated that the groundwater in the Dammam formation is not suitable for irrigation purpose under normal
conditions because this water can identify as “severe restriction, SR”. However, the soils with high value of hydraulic conductivity can be irrigated with this type of groundwater especially the study area characterized by its high permeability.

6. References
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