Evaluation of the Groundwater Quality for Irrigation: Case Study of Hilla district, Babylon Province, Iraq

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Abstract. A crisis of water scarcity in the world encouraged researchers, especially in the arid areas, to know the nature and quality of all its sources regardless of surface water. The groundwater evaluation for irrigation was suggested by using the model of Water Quality Index for Irrigation (WQIIR) in the ArcMap/GIS Software. This model was applied to 48 wells distributed throughout the Hilla district, Babylon, Iraq. The samples of EC, Ca++2, Mg++2, Cl-, Na+, HCO3-, and SAR for groundwater were collected from these wells during wet and dry seasons in 2016. The generated maps in GIS for the WQIIR model in both seasons were divided into categories based on restriction’s groundwater use for irrigation. These categories consisted of Severe Restriction (SR), High Restriction (HR), Moderate Restriction (MR), Low Restriction, and No Restriction. The areas values and their classification of restriction’s groundwater use for irrigation related to the five categories that resulted within the generated maps in GIS using the WQIIR model in the wet season (in km²) were: 42.79 (SR), 407.05 (HR), 377.77 (MR), 32.39 (LR) and 0.23 (NR) respectively and for the dry season were as follows: 42.79 (SR), 407.05 (HR), 377.77 (MR), 32.39 (LR) and 0.23 (NR) respectively. The areas and the classification categories of restriction groundwater for irrigation calculated based on the values resulted from the WQIIR model have shown variation in the dry and wet seasons.

1. Introduction
The shortage of main water resources represents globally anxiety factor which is related to human life and the environment. The main physio-chemical parameters are connected with the level of abundance of water and the concentrations of parameters in the water body have significant effects of evaluating the Water Quality Index (WQI). Nevertheless, studying these parameters separately doesn't give the complete vision for the Water Quality Index [1]. In any case, the parameters must meet pre-established standards for water use in a specific region or country, otherwise; treatment before use is required if the water does not meet the standard limits for water [1]. The spatial distribution maps of groundwater show well visualization of variations in the quality of water [2]. Many researchers adopted various physical and chemical parameters in the water resources to evaluate the water quality index for irrigation, where that the water quality is not restricted by one parameter or limited number parameters but should be included the most parameters in a water body as possible [3]. This process enables decision-makers to get and understand the results without complex and reduce the steps to evaluate the water quality and possible risk on a water body, depending on measured parameters [4]. Furthermore, this assists in implementing the comparison between various sampling sites and/or events [5]. The water quality for irrigation has to be evaluated to avoid or, at least, to minimize negative impacts on agriculture [5]. The water quality index for irrigation is calculated by a numerical or mathematical method that gives the scientists and specialists in the field of water resources a broad vision about the quality of groundwater in the regions that existing in them [5, 7]. the water quality index for irrigation method is a confident way contributes to decreasing the time and effort by avoiding drilling the wells of groundwater for...
agriculture purposes within the high contamination areas. Moreover, the WQI method determines the areas that have a good quality of groundwater for irrigation the agriculture lands and to establish the residential areas at the unoccupied areas within these areas. The attempts to develop water resources related to the indicators are not new. The quality of groundwater is directly related to the characteristics of the water source, which will influence its appropriateness for particular utilization. Consequently, the physical and chemical parameters in the groundwater should continuously be observed and to be under control so that the valuation of groundwater quality [8]. In the beginning, the general water quality index for irrigation has been established by [9] that used the weights of parameters separately [9]. [10] adopted the average weighting formula to assess the water quality index for irrigation. [10] was concerned that the arithmetic mean was less sensitive to the low variable value. Recently, many modifications were considered for the water quality index for the irrigation model through several researchers and experts [4, 11, 12].

The combining of the water quality index for irrigation and the Geographical Information System (GIS) was employed to produce changeability maps for water parameters. The model of water quality index for irrigation and the GIS showed high potential in the assessment of water for multi-purpose usage. The water quality index for irrigation model and spatial analysis tools in the GIS as well as remote sensing are considered excellent tools for summarizing overall water quality conditions in different regions and over the year. Moreover, they are providing relevant information for the specific water use that can be clearer for decision-makers.

Lately, the countries in the middle east suffer from a crisis of surface water shortage especially in Iraq due to many reasons such as climate change and construction of dams along the rivers outside the borders of Iraq that led to the decreasing water level in the Tigris and Euphrates rivers. The unsystematic use of the rivers' water-related to irrigation projects and wastewater and waste of war caused to change the concentrations of parameters in rivers to the worst. Thus, the population tends to invest the available groundwater in an area. This requires verifying the quality of the groundwater and its suitability for use in drinking and agriculture. This is done by creating maps in the GIS that depend on suitable parameters measured from wells separated in a specific area using a scientifically approved mathematical model. So, the objectives of the present study are to assess the quality of groundwater for irrigation in arid areas: a case study is the Hilla district, Babylon, Iraq using the model of water quality index for irrigation together with the GIS software. Producing the interpolation maps of groundwater quality for irrigation for the selected parameters which are entering into the selected mathematical model that will use to the groundwater into categories in the study area. Then, reclassifying the generated maps into categories based on restriction’s groundwater use for irrigation in the wet and dry seasons in 2016.

2. Methodology

2.1 Study area

Hilla district is considered to be the most important district in Babylon Province in terms of the administrative function. This district includes Hilla center, the administrative, political, and financial capital of Babylon Province. The district also includes Kifill and AbiGhraq. The district is situated between latitude 32° 15' 0" N and 32° 30' 0" N, and longitude 44° 15' 0" E and 44° 30' 0" E (Figure 1). The Hilla district is located in the arid area and occupies an area of 860 km², which constitutes 16.1% of the total area of Babylon Province. In 2017, the official population of Hilla district was approximately 909,000 inhabitants [13]. This district has the highest population among other districts in Babylon province. The Hilla district is located in the arid region and the climate in the district varies always with the changes of seasons and daily. The yearly wind prevails in the district blows from the northwest, with yearly mean of wind speed is 7.2 km/h. The summer season is hot and dry without rainfall and temperature can reach above 50 °C. Rainfall in the district is characterized by less than 100 mm/year, and the average annual relative humidity is 46%. Temperatures during winter are moderate (above 0 °C). The average rainfall is 102 mm/year, and the mean annual percentage of relative humidity is about 46 [14, 15, 16, 17].
For irrigation purposes, surface water was used to irrigate about 94% of the total lands in Iraq, and the remaining lands were irrigated by the groundwater in 1990 [18]. Surface water is considered the main source for irrigation purposes in Iraq, where approximately 78% of all withdrawal water is used for irrigation purposes in 2000 [18].

Figure 1. Map of study and sampling sites.

2.2 Geology and hydrology of the study area

The Hydrogeology conditions inside Babylon province are relating to the geology of Iraq. Iraqi lands are divided into seven zones according to their morphology and hydrogeological conditions. They are the Thrust zone [TZ]; High folded zone [HF]; Low folded zone [LF]; Al-Jazira zone [JZ]; Mesopotamia zone [MZ]; Western Desert zone [WD]; and Southern desert zone. The study area located in Aquifer of MZ in the middle of Iraq [19, 20, 21], in a vast flat plain. The highest elevation of MZ is about 200 m above sea level (a.m.s.l.) nearby Makhoul Mountain in the north. While the lowest point is about 1 m (a.m.s.l.) at Arabian Gulf [20].

The Quaternary sediments cover most of the Mesopotamia region, which are eroded by the fluvial system. The sedimentary plain is mostly covered by the Holocene Sequence, which is about 15–20 m of thickness, and it is composed mainly of silty clay, loamy sand, and sandy loam soil [4]. More details can be found in [22]. According to Jassim and Goff (2006) [23], the Hilla district is located within the Mesopotamia plan silt zone where they geologically divided Iraq into fourteen zones.

Despite the flatness of MZ, but this zone has a gentle slope from the northwest toward the southeast, and the groundwater flows the same trend of surface drainage in this area [19]. The groundwater level throughout the MZ depends on natural and artificial circumstances. The natural circumstances are based on rainfall distribution, and the rate of evaporation, so the groundwater level rise during the winter and spring season where the rainfall increase and the evaporation decrease. The artificial circumstances are limited especially close to an urban and rural area, where the groundwater withdrawal through wells and excess of irrigation.

The Tigris and Euphrates rivers are the main sources for groundwater in the Mesopotamia plain. The groundwater in this area is generally found within the recent alluvial deposits, and it is quantitatively promising [19, 20, 21, 22]. However, salinity is considered as a major groundwater quality issue in this region [19].

According to [19], the salinity increases generally from the recharge areas towards discharges areas (from the north and northwest towards south and southeast) within the plain. Moreover, the groundwater
type changes from sulfate to chloride type, according to groundwater variation from recharge to discharge areas, respectively [19]. However, the groundwater, which is nearby the rivers, streams, and main irrigation channels, has a better quality for exploitation, where, the seepage of freshwater exists continually.

2.3 Collection and Analytical Samples
In the study, 48 samples were collected during the wet season (from January to April and from November to December) and the dry season (May - October) in 2016 throughout Hilla district, Babylon, Iraq, as shown in Tables 1 and 2. The location of collected samples for the physical and chemical parameters can be seen in Figure 1. These samples were analyzed in the laboratory of the General Commission for Groundwater [24]. In both seasons, the accuracy of water analysis for the measured parameters at each well in the study area was computed according to [25] using the following equation:

\[
\% \text{ different} = \frac{\sqrt{\text{cation}} - \sqrt{\text{anions}}}{\sqrt{\text{cation}} + \sqrt{\text{anions}}} \times 100
\]

**Table 1.** Physical-chemical properties of water quality for groundwater (wet season).

| Well No. | X        | Y        | HCO₃ (mg/L) | Cl (mg/L) | EC (µs/cm) | Na (mg/L) | SAR (meq/cm) |
|---------|----------|----------|-------------|-----------|------------|------------|-------------|
| W1      | 429963.627 | 3600115.416 | 300 | 680 | 3010 | 72 | 0.885 |
| W2      | 431445.296 | 3602549.588 | 1000 | 2600 | 24400 | 4084 | 28.880 |
| W3      | 436793.619 | 3603408.950 | 76 | 230 | 1304 | 212 | 3.776 |
| W4      | 432926.966 | 3598633.747 | 115 | 1010 | 5066 | 700 | 8.589 |
| W5      | 437371.975 | 3600421.472 | 88 | 333 | 1958 | 211 | 2.688 |
| W6      | 433879.468 | 3595458.740 | 406 | 358 | 1811 | 232 | 4.356 |
| W7      | 440017.814 | 3598633.747 | 300 | 995 | 6415 | 838 | 7.751 |
| W8      | 444784.051 | 3600763.112 | 483 | 132 | 1113 | 72 | 1.393 |
| W9      | 435466.971 | 3592601.235 | 166 | 642 | 3200 | 436 | 4.600 |
| W10     | 438536.144 | 3593977.071 | 228 | 80 | 728 | 36 | 0.810 |
| W11     | 442366.152 | 3596622.909 | 130 | 172 | 1265 | 179 | 5.421 |
| W12     | 446473.660 | 3597787.078 | 72 | 220 | 1200 | 207 | 3.837 |
| W13     | 450177.834 | 3597998.078 | 214 | 248 | 2417 | 237 | 4.452 |
| W14     | 436207.806 | 3588791.227 | 622 | 1785 | 19960 | 2966 | 26.108 |
| W15     | 440652.815 | 3592072.067 | 215 | 300 | 3570 | 266 | 4.685 |
| W16     | 443616.154 | 3593553.736 | 256 | 929 | 5578 | 730 | 7.187 |
| W17     | 448726.351 | 3594677.683 | 99 | 240 | 1502 | 190 | 2.930 |
| W18     | 435466.971 | 3584785.386 | 599 | 1950 | 8405 | 1362 | 14.062 |
| W19     | 441922.817 | 3588262.059 | 52 | 180 | 992 | 172 | 3.567 |
| W20     | 445591.980 | 3589059.397 | 159 | 219 | 1770 | 191 | 4.324 |
| W21     | 449013.665 | 3591648.733 | 68 | 185 | 1111 | 181 | 3.443 |
| W22     | 454199.509 | 3593553.736 | 128 | 132 | 1532 | 175 | 6.088 |
| W23     | 452721.567 | 3590206.216 | 121 | 175 | 1990 | 220 | 4.305 |
| W24     | 448038.433 | 3587639.752 | 188 | 3310 | 12000 | 3241 | 31.950 |
| W25     | 442451.981 | 3584557.885 | 471 | 123 | 1042 | 70 | 1.343 |
| W26     | 437054.474 | 3581594.546 | 1006 | 1159 | 9060 | 1079 | 10.613 |
| W27     | 448378.664 | 3584134.551 | 87 | 260 | 1455 | 240 | 3.992 |
| W28     | 451977.004 | 3582441.214 | 83 | 255 | 1400 | 232 | 3.931 |
| W29     | 437371.975 | 3578631.207 | 302 | 496 | 3715 | 361 | 4.070 |
| W30     | 444462.823 | 3579795.376 | 426 | 133 | 1362 | 196 | 4.692 |
| W31     | 438536.144 | 3575032.866 | 416 | 136 | 1748 | 197 | 2.909 |
| W32     | 445626.992 | 3576091.202 | 197 | 2596 | 9696 | 2412 | 23.769 |
| W33     | 452400.338 | 3578737.000 | 292 | 80 | 870 | 77 | 2.115 |
| W34     | 439171.145 | 3571011.191 | 74 | 592 | 3482 | 769 | 9.535 |
| W35     | 444356.989 | 3571752.026 | 158 | 43 | 4448 | 72 | 0.711 |
| Well No. | X     | Y     | HCO₃  (mg/L) | Cl (mg/L) | EC (μs/cm) | Na (mg/L) | SAR (meq/cm) |
|---------|-------|-------|-------------|-----------|------------|-----------|--------------|
| W1      | 3600115.416 | 280 | 740 | 3190 | 74 | 0.895 |
| W2      | 3602549.588  | 866 | 3082 | 26000 | 4196 | 29.129 |
| W3      | 3603408.950  | 70  | 260 | 1376 | 240 | 4.183 |
| W4      | 3598633.747  | 105 | 1048 | 5514 | 726 | 8.743 |
| W5      | 3600421.472  | 82  | 353 | 2122 | 225 | 2.827 |
| W6      | 3595458.740  | 374 | 382 | 1989 | 248 | 4.513 |
| W7      | 3598633.747  | 188 | 1135 | 6785 | 864 | 7.855 |
| W8      | 3600763.112  | 467 | 142 | 1183 | 78 | 1.483 |
| W9      | 3592601.235  | 154 | 694 | 3400 | 458 | 4.727 |
| W10     | 3593977.071  | 212 | 90  | 772  | 36  | 0.791 |
| W11     | 3596622.909  | 114 | 194 | 1399 | 193 | 5.666 |
| W12     | 3597787.078  | 64  | 248 | 1300 | 219 | 3.976 |
| W13     | 3597998.078  | 204 | 272 | 2583 | 267 | 4.910 |
| W14     | 3588791.227  | 610 | 1907 | 21240 | 3034 | 25.978 |
| W15     | 3592072.067  | 201 | 322 | 3690 | 286 | 4.944 |
| W16     | 3593535.736  | 232 | 989 | 5822 | 766 | 7.361 |
| W17     | 3594677.683  | 91  | 260 | 1538 | 208 | 3.172 |
| W18     | 3584875.386  | 581 | 2096 | 8595 | 1398 | 14.072 |
| W19     | 3588262.059  | 48  | 200 | 1068 | 188 | 3.821 |
| W20     | 3590590.397  | 145 | 241 | 1944 | 205 | 4.559 |
| W21     | 3591648.733  | 62  | 215 | 1249 | 193 | 3.609 |
| W22     | 3593553.736  | 116 | 152 | 1678 | 189 | 6.472 |
| W23     | 3590206.216  | 109 | 199 | 2110 | 232 | 4.416 |
| W24     | 3587639.752  | 172 | 3494 | 12760 | 3361 | 32.478 |
| W25     | 3584577.885  | 449 | 137 | 1138 | 70  | 1.306 |
| W26     | 3581594.546  | 894 | 1279 | 9300 | 1179 | 11.237 |
| W27     | 3584134.551  | 83  | 278 | 1545 | 254 | 4.140 |
| W28     | 3582441.214  | 77  | 267 | 1500 | 248 | 4.115 |
| W29     | 3578631.207  | 284 | 562 | 3765 | 383 | 4.212 |
| W30     | 3579795.376  | 404 | 143 | 1438 | 208 | 4.882 |
| W31     | 3575032.866  | 388 | 148 | 1852 | 203 | 2.910 |
| W32     | 3576091.202  | 183 | 2752 | 9944 | 2538 | 24.516 |
| W33     | 3578737.000  | 268 | 86  | 910  | 79  | 2.115 |
| W34     | 3575011.191  | 72  | 628 | 3578 | 793 | 9.634 |

Table 2. Physical-chemical properties of water quality for groundwater (dry season).
Maps for Physical and Chemical Parameters

The interpolation method of kriging was used to generate the maps in ArcMap/GIS Software 10.5 for the selected parameters of groundwater for irrigation purposes in the Hilla district during the wet and dry seasons in 2016.

Model of Assessment the Groundwater Quality Index for Irrigation

The method of calculating the groundwater quality index for irrigation (WQIIR) was developed by Meireles et al. (2010) [27], and this method was applied in the current study area (Hilla district). The water quality index for the irrigation (WQIIR) method was computed based on the following Equation (2) as similar to [6, 26]. This equation includes two parts are: WQi and Wi:

\[
WQIIR = \sum_{i}^{m} WQi \times Wi
\]

where,

WQIIR: non-dimensional parameter variation from 0 to 100; WQi: the quality of each parameter which is representing the function of its concentration and ranging from 0 to 100; Wi: the normalized weight for each parameter that expresses on water quality in the explaining of global variability.

The significant parameters that contributing to the determination of the water quality for agriculture are EC, Na\(^+\), Cl\(^-\), and HCO\(_3\)^- and SAR. For each parameter, the values of WQi were calculated according to [27] based on the following equation introduced by [28]. Limiting the range for each parameter for water quality (WQi) was computed based on the values in Table 3, using the collected data in Tables 1 and 2 during wet and dry seasons.

\[
WQi = q_{max} - \left( \frac{(X_{ij} - X_{in}) \times X^2 \times q_{imap}}{X_{amp}} \right)
\]

According to Criteria of the University of California Committee of Consultants and the relative weight for each parameter was arranged according to its importance of the water quality for irrigation [26, 28] (Table 4).

Table 3. Limiting values for each parameter for computing water quality (WQi) [27].

| Parameter     | Limiting Values |
|---------------|-----------------|
| HCO\(_3\) (meqL\(^{-1}\)) | (1.0 - 1.5)     |
| Cl (meqL\(^{-1}\))       | (1 - 4)         |
| Na (meqL\(^{-1}\))       | (2.3)           |
| SAR (mmolL\(^{-1}\))     | (2.3)           |
| EC (uscm\(^{-1}\))       | (200 - 750)     |
| WQi              | 85 - 100        |
| HCO\(_3\) > 8.5       | 1 > Cl = 10     |
| Na > 9            | 2 > SAR = 12    |
| EC > 3000         |                 |
| WQi              | 0 - 35          |
Table 4. Weights of parameters applied in the (WQIIR) model for irrigation [27].

| Wi   | Parameters                        |
|------|-----------------------------------|
| 0.211| Electrical Conductivity (EC)      |
| 0.204| Sodium (Na)                       |
| 0.202| Bicarbonate (HCO₃⁻)               |
| 0.194| Chloride (Cl)                     |
| 0.189| Sodium Adsorption Ratio (SAR)     |

The indexes of existing water quality were divided into categories based on the suggested water quality index. These categories were taken into consideration the salinity problems risk, reduction of water infiltration into the soil as well as toxicity to plants, where [29] presented this classification [26, 29]. Table 5 shows water use restriction and recommendation of using water for plants and soil based on ranges values of water quality index for irrigation.

Table 5. Characteristics of Water Quality Index of Irrigation [27].

| WQIIR | Water usage Restrictions | Soil Restriction | Recommendation |
|-------|--------------------------|------------------|----------------|
| 85 - 100 | No Restriction (NR) | No toxicity risk for most plants |                |
| 70 - 85 | Low Restriction (LR) | Elevated risks for salt sensitive plants |                |
| 55 - 70 | Moderate Restriction (MR) | Plants with moderate tolerance to salts may be grow |                |
| 40 - 55 | High Restriction (HR) | Suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO₃⁻ values. |                |
| 0 - 40 | Severe Restriction (SR) | Only plants with high salt tolerance, except for Waters with extremely low values of Na, Cl and HCO₃⁻ |                |

2.6 Generating Maps of Quality Index for the measured parameters

The model of water quality index for Irrigation for the groundwater in the Hilla district was applied using the parameters in the selected wells are EC, Cl, Na, HCO₃⁻, and SAR. The values of the WQIIR of groundwater in both seasons resulted from the summation of the multiplying of water quality (WQi) by the weight (Wi) of each parameter measured.

2.7 Classified Maps of Groundwater for Irrigation Using the WQIIR Model

The maps Water Quality Index for irrigation (WQIIR) were generated in the GIS. The spatial analysis tools in the GIS were used by sum the maps of the WQiWi with their categories for each parameter (EC, Cl, HCO₃⁻, Na, and SAR) for each season (wet and dry). The prediction maps of the WQiWi for parameters generated using the interpolation method kriging in the GIS environment.
3. Results

3.1 Prediction Maps for the Selected Parameters
For the selected parameters of groundwater in the study area, the prediction maps during the wet and dry seasons in 2016 for the electrical conductivity (EC), adsorption ratio (SAR), bicarbonates (HCO$_3^-$) sodium (Na$^+$) and chloride (Cl$^-$) can be seen in Figures 2 and 3.

![Image of interpolation maps using the kriging method in the GIS of (a): EC-wet season; (b): EC-dry season; (c): SAR-wet season; (d): SAR-dry season.](image)

**Figure 2.** Interpolation maps using the kriging method in the GIS of (a): EC-wet season; (b): EC-dry season; (c): SAR-wet season; (d): SAR-dry season.
Figure 3. The interpolation maps using the kriging method in the GIS of (a): HCO$_3$-wet season; (b): HCO$_3$-dry season; (c): Na-wet season; (d): Na-dry season; (e): Cl-wet season; (f): Cl-dry season.
3.2 Generating Maps of Quality Index for the measured parameters

After generating the interpolation maps of multiplying WQi by Wi for each parameter, the values of the electrical conductivity (EC) were ranged from 7.426 to 16.287 (Figure 4a) and from 7.438 to 15.010 (Figure 4b) in the wet and dry seasons respectively. For chloride (Cl⁻), the values of the WQiWi during the wet season were ranged from 7.000 mg/L to 14.533 mg/L (see Figure 4c) and from 7.000 mg/L to 12.986 mg/L in the dry season (see Figure 4d). From the prediction maps of the WQiWi for the bicarbonates (HCO₃⁻), the range values in the wet season were varied from 7.612 to 18.922 mg/L (Figure 5a) and from 7.074 to 20.100 mg/L (Figure 5b) in the wet and dry seasons respectively. The range values of the WQiWi resulted from the prediction maps for sodium (Na) in the wet season were (7.262 – 7.360) mg/L (Figure 5c), while in the dry season the range values were (7.200 – 7.380) mg/L respectively (Figure 5d).

The values of the WQiWi for the Specific Absorption Rate (SAR) in the wet and dry seasons were ranged (respectively) from 6.797 to 17.896 mg/L (Figure 5e), and from 7.129 to 16.868 mg/L (Figure 5f). Summary, the values of the WQiWi and the WQIIR for each parameter measured in the selected wells are tabulated in Table 6.

![Figure 4. Interpolation maps of WQiWi during the season of (a): EC-wet; (b): EC-dry; (c): Cl-wet; (d): Cl-dry.](image-url)
Figure 5. Interpolation maps of WQiWi during the season of (a): HCO₃-wet; (b): HCO₃-dry; (c): Na-wet; (d): Na-dry; (e): SAR-wet; (f): SAR-dry.
Table 6. The WQIIR values resulted from multiplying the WQi by the Wi for measured parameters in the selected wells during the wet and dry seasons in 2016.

| Well No. | HCO₃ | Cl  | EC  | Na  | SAR | WQIWI-Wet | WQIWI-Dry |
|----------|------|-----|-----|-----|-----|-----------|-----------|
| W1       | 11.59| 6.79| 7.39| 17.12| 6.62| 6.62      | 12.00     |
| W2       | 7.07 | 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W3       | 18.71| 12.47| 14.04| 7.14 | 14.84| 6.62      | 12.00     |
| W4       | 16.52| 6.79| 7.39| 7.14 | 9.30| 6.62      | 12.00     |
| W5       | 17.52| 7.77| 11.05| 7.14 | 16.95| 6.62      | 12.00     |
| W6       | 9.40 | 6.79| 11.57| 7.14 | 13.93| 6.62      | 12.00     |
| W7       | 11.59| 6.79| 7.39| 7.14 | 9.96| 6.62      | 12.00     |
| W8       | 7.81 | 6.79| 11.57| 7.14 | 13.93| 6.62      | 12.00     |
| W9       | 15.11| 6.79| 7.39| 7.14 | 13.55| 6.62      | 12.00     |
| W10      | 13.40| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W11      | 16.11| 15.11| 14.31| 7.14 | 12.25| 6.62      | 12.00     |
| W12      | 19.11| 6.79| 11.57| 7.14 | 16.95| 6.62      | 12.00     |
| W13      | 13.79| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W14      | 7.07 | 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W15      | 13.76| 9.28| 7.39| 7.14 | 13.41| 6.62      | 12.00     |
| W16      | 12.63| 6.79| 7.39| 7.14 | 10.40| 6.62      | 12.00     |
| W17      | 16.96| 12.00| 12.65| 8.4  | 16.26| 6.62      | 12.00     |
| W18      | 7.07 | 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W19      | 7.07 | 14.75| 16.23| 9.73 | 15.17| 6.62      | 12.00     |
| W20      | 15.31| 12.97| 11.71| 8.32 | 13.98| 6.62      | 12.00     |
| W21      | 19.51| 14.52| 15.4  | 9.06 | 15.37| 6.62      | 12.00     |
| W22      | 16.16| 16.76| 12.43| 9.51 | 11.27| 6.62      | 12.00     |
| W23      | 16.36| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W24      | 14.51| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W25      | 8.05 | 17.00| 15.88| 17.27| 6.62| 6.62      | 12.00     |
| W26      | 7.07 | 6.79| 7.39| 7.14 | 7.71| 6.62      | 12.00     |
| W27      | 17.62| 11.1| 12.98| 7.14 | 14.5| 6.62      | 12.00     |
| W28      | 18.01| 11.33| 13.36| 7.14 | 14.6| 6.62      | 12.00     |
| W29      | 11.55| 6.79| 7.39| 7.14 | 14.38| 6.62      | 12.00     |
| W30      | 8.98 | 16.73| 13.63| 7.95 | 13.4| 6.62      | 12.00     |
| W31      | 9.19 | 16.65| 11.79| 7.88 | 16.32| 6.62      | 12.00     |
| W32      | 14.26| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W33      | 11.76| 18.18| 17.09| 16.75| 18.58| 6.62      | 12.00     |
| W34      | 18.91| 6.79| 7.39| 7.14 | 8.56| 6.62      | 12.00     |
| W35      | 15.34| 19.19| 7.39| 11.57| 6.62| 6.62      | 12.00     |
| W36      | 12.27| 6.79| 7.39| 7.14 | 13.28| 6.62      | 12.00     |
| W37      | 15.56| 6.79| 7.39| 7.14 | 7.06| 6.62      | 12.00     |
| W38      | 13.24| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W39      | 16.05| 18.4| 19.1| 17.27| 18.32| 6.62      | 12.00     |
| W40      | 16.72| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W41      | 11.69| 6.79| 7.39| 7.14 | 15.04| 6.62      | 12.00     |
| W42      | 19.80| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W43      | 19.01| 12.33| 14.17| 7.14 | 14.59| 6.62      | 12.00     |
| W44      | 13.85| 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W45      | 17.72| 6.79| 7.39| 7.14 | 7.38| 6.62      | 12.00     |
| W46      | 7.07 | 6.79| 7.39| 7.14 | 6.62| 6.62      | 12.00     |
| W47      | 16.25| 6.79| 11.16| 7.14 | 14.39| 6.62      | 12.00     |
| W48      | 18.31| 6.79| 16.00| 12.37| 18.84| 6.62      | 12.00     |
3.3 Classified Maps of Groundwater for Irrigation Using the WQIIR Model
The final prediction maps of the WQIIR model in the wet and dry seasons were divided into categories according to the classifications of [27] (see Figure 6).

Figure 6. Interpolation maps of water quality index for irrigation for groundwater (WQIIR) in Hilla district, Babylon, Iraq in the season of (a): wet; (b): dry.

3.4 Reclassified predicted maps of Groundwater for Irrigation
According to the classification ranges of Meireles et al. (2010) [27], each category within final maps (Figures 7a and 7b) in both seasons were given the symbol of restriction of water use in the groundwater in the study area that mentioned in Table 5.

Figure 7. Reclassified maps of groundwater quality index for irrigation in the Hilla district, Babylon, Iraq in the seasons of (a): wet; (b): dry.
4. Discussion

4.1 Prediction Maps for the selected Parameters

Electrical conductivity is associating with total dissolved solids (TDS). During the wet season, the Electrical conductivity (EC) concentration was ranged from 24400 μS/cm to 392 μS/cm with an average value of 4947 μS/cm (Figure 2a). The concentration of EC during the dry season was ranged from 26000 μS/cm to 408 μS/cm with an average value of 5173 μS/cm (Figure 2b).

The common chemical agent which is controlled on the water infiltration rate is the proportional concentrations for ions of sodium, calcium, and magnesium in water and it defines Sodium Adsorption Ratio (SAR) (Abdullah et al., 2016). The readings of SAR during the wet season were variated from 41.97 to 0.71 meq/L with the mean value of 8.84 meq/L (Figure 2c). In the dry season, the maximum and minimum values (in meq/L) were 42.65 and 0.72 respectively with the mean value of 9.06 meq/L (Figure 2d).

For the wet and dry seasons, the values of bicarbonates ($HCO_3^{-1}$) was ranged from 1010 to 52 mg/L (Figure 2e) and from 970 to 48 mg/L (Figure 2f) respectively. The mean value was 259 mg/L during the wet season and 238 mg/L during the dry season.

The concentration of Sodium ion ($Na^{+1}$) is used to describes the toxicity in the water (Abdullah et al., 2016). The variation of Sodium concentrations during the wet season was (36 – 4344) mg/L with a mean value of 813 mg/L (Figure 3a). The concentration of Sodium during the dry season were ranged from 40 to 4534 mg/L, and the mean value of Sodium was 850 mg/L (Figure 3b).

The mean, maximum and minimum readings of chloride concentration ($Cl^{-1}$) (respectively) in the groundwater in Hilla district were 748, 3310, and 43 mg/L during the wet season (Figures 3c) and 815, 3494 and 47 during the dry season (Figures 3d).

4.2 Generating Maps of multiplying the WQi by the Wi for the measured parameters

The groundwater quality index for the Irrigation model in Hilla district, Babylon, Iraq was applied using five parameters are EC, Cl, Na, $HCO_3^{-1}$, and SAR. This model comprises three parts. In the first part, the weights (Wi) of parameters that were listed in Table 4, where each parameter was given the weight that deserves.

In the second part, the values of water quality (WQi) for each parameter, as shown in Tables 1 and 2, were calculated using Equation 3. In this part, the unit of each parameter converted to the required unit based on the values in Table 3, where that the values of $HCO_3^{-1}$, $Cl^{-1}$, $Na^{+1}$, $Ca^{+2}$, and $Mg^{+2}$ in mg/L were changed to equivalent values of meq/L [30]. Then, in the third part, the model of Water Quality Index for irrigation (WQIIIR) was applied on the study area (Hilla district) through multiplying the water quality (WQi) by the weights of parameters (Wi) for all samples based on Equation (2) during wet and dry seasons in 2016 (Table 6). Finally, the maps for groundwater of multiplying Wqi by Wi that resulted from using the interpolation method Kriging in the GIS environment were generated and applied in the study area (see Figures 4 and 5).

4.3 Classifying Maps of Groundwater for Irrigation using the WQIIIR Model

In the wet season, the final map of WQIIIR was divided into five categories with ranges of (34 - 55), (55 - 70), (70 - 85), and (85 – 89) (Figure 6a). The final map of WQIIIR in the dry season was divided into five categories and the ranges of this map are (35 - 40), (40 - 55), (55 – 70), (70 – 85), and (85 – 85.8) (Figure 6b).

The categories within the final maps in both seasons were reclassified based on the classification adopted by Meireles et al. (2010). In the study area, the areas of the category of severe restriction (SR) within Figures 6a and 6b were 54.12 km² and 42.79 km² in the dry and wet seasons respectively. The categories of high restriction (HR) in wet and dry seasons were occupied an area of 407.05 km² and 391.08 km² from which were represented 45.46% and 47.32 of the total of Hilla district in both seasons respectively. The moderate restriction (MR) category has defined the areas with a range of (55 – 70) of WQIIIR, where the area of the moderate restriction (MR) in the wet season was 377.77 km² (43.92%)
and 391.14 km (45.47%) in the dry season. The areas of 32.39 km² and 23.88 km² were represented the category of the low restriction (LR) of groundwater for irrigation use in the study area. The calculated areas of no restriction (NR) category of groundwater for irrigation use were very small, where the computed areas in the wet and dry seasons were 0.23 km and 0.01 km respectively (see Table 7). The area of the final produced map for each season was divided into categories according to the classifications by Meireles et al. (2010).

Table 7. Calculated area for the categories resulted from using the (WQIIR) model for Irrigation, and their symbols of restriction groundwater use for irrigation in the wet and dry seasons in 2016.

| No. | Restriction symbol | Range [27] | Wet | Category's area km | Dry | Category's area km |
|-----|--------------------|------------|-----|---------------------|-----|---------------------|
| 1   | SR                 | (0 – 40)   | 42.79 |                      | 54.12 |                      |
| 2   | HR                 | (40 – 55)  | 407.05 |                      | 391.08 |                      |
| 3   | MR                 | (55 – 70)  | 377.77 |                      | 391.14 |                      |
| 4   | LR                 | (70 – 85)  | 32.39  |                      | 23.88  |                      |
| 5   | NR                 | (85 – 100) | 0.23   |                      | 0.01   |                      |

In this study, the results showed wide differences in the calculated area's values in GIS between categories of restriction groundwater use for irrigation in the wet and dry seasons. The area values of categories of HR, LR, and NR in the wet season were higher the values in the dry season because the calculated values of WQIIR were bigger due to water dilution by rainfall. Otherwise, the computed areas in GIS for the categories SR and MR in the dry season were more than the areas in the wet season due to excessive usage to irrigate agricultural lands by water (see Table 7 as well as Figures 6 and 7).

Table 8 shows the WQIIR values using the model of groundwater quality index for irrigation during the wet and dry seasons in the Hilla district. Moreover, this table shows the classification symbols of restriction groundwater use for irrigation that was given for each well in the study area.

Table 8. Calculated area for the categories resulted from using the (WQIIR) model for Irrigation, and their symbols of restriction groundwater use for irrigation in the wet and dry seasons in 2016.

| Well No. | WQIIR dry | Restriction symbol | WQIIR wet | Restriction symbol | WQIIR dry | Restriction symbol | WQIIR wet | Restriction symbol |
|----------|-----------|--------------------|-----------|--------------------|-----------|--------------------|-----------|--------------------|
| W1       | 49.77     | HR                 | 49.51     | HR                 | W25       | 64.23              | HR         | 64.82              |
| W2       | 35.01     | SR                 | 35.01     | SR                 | W26       | 35.61              | SR         | 36.1               |
| W3       | 65.28     | MR                 | 67.2      | MR                 | W27       | 62.2               | MR         | 63.34              |
| W4       | 47.3      | HR                 | 47.14     | HR                 | W28       | 63.5               | MR         | 64.44              |
| W5       | 59.14     | MR                 | 60.43     | MR                 | W29       | 47.4               | HR         | 47.25              |
| W6       | 48.61     | HR                 | 48.83     | HR                 | W30       | 59.15              | MR         | 60.69              |
| W7       | 45.71     | HR                 | 42.87     | HR                 | W31       | 61.16              | MR         | 61.83              |
| W8       | 62.8      | MR                 | 63.69     | MR                 | W32       | 42.59              | HR         | 42.20              |
| W9       | 50.11     | HR                 | 49.98     | HR                 | W33       | 82.31              | LR         | 82.35              |
| W10      | 63.32     | MR                 | 63.40     | MR                 | W34       | 48.91              | HR         | 48.78              |
| W11      | 63.04     | MR                 | 66.99     | MR                 | W35       | 65.84              | MR         | 60.11              |
| W12      | 67.29     | MR                 | 68.69     | MR                 | W36       | 47.06              | HR         | 46.87              |
| W13      | 53.67     | HR                 | 55.80     | HR                 | W37       | 48.28              | HR         | 49.29              |
| W14      | 35.01     | SR                 | 35.01     | SR                 | W38       | 41.95              | HR         | 41.18              |
| W15      | 49.95     | HR                 | 50.98     | HR                 | W39       | 78.55              | LR         | 89.14              |
| W16      | 44.88     | HR                 | 44.35     | HR                 | W40       | 45.04              | HR         | 44.66              |
| W17      | 63.72     | MR                 | 66.27     | MR                 | W41       | 48.44              | HR         | 48.10              |
| W18      | 35.01     | SR                 | 35.01     | SR                 | W42       | 35.01              | SR         | 47.74              |
| W19      | 59.92     | MR                 | 62.95     | MR                 | W43       | 66.65              | MR         | 67.24              |
| W20      | 59.66     | MR                 | 62.29     | MR                 | W44       | 42.45              | HR         | 41.78              |
5. Conclusions
The Water Quality Index for Irrigation (WQIIIR) model and the ArcMap/GIS Software were combined to evaluate the groundwater for irrigation in the Hilla district, Babylon, Iraq. Six essential parameters for this model (EC, Ca$^{2+}$, Mg$^{2+}$, Cl$^{-1}$, Na$^{+1}$, HCO$_3^{-1}$, and SAR) were measured from 48 wells distributed throughout the study area during the wet and dry seasons in 2016. The interpolation maps in the GIS environment using the kriging method were generated for the selected parameters in the current study to provide a clear idea about the concentrations level for these parameters in the whole study area. The interpolation maps resulted from applying the WQIIIR model in the GIS software were generated, where that the WQIIIR values for each well were as result from multiplying the water quality indexes (WQi) by the weights (Wi) for the selected parameters. Then, these maps were classified into five categories based on restrictions groundwater use for irrigation in both seasons. These categories were defined as the following (a): Severe Restriction (SR), (b): High Restriction (HR), (c): Moderate Restriction (MR), (d): Low Restriction and (e): No Restriction. The area value for each category and its classification of restrictions groundwater use for irrigation in the Hilla district in the dry season were calculated and reclassified as follows: 42.79 (SR), 407.05 (HR), 377.77 (MR), 32.39 (LR) and 0.23 (NR) respectively, while in the wet season (in km$^2$) were: 42.79 (SR), 407.05 (HR), 377.77 (MR), 32.39 (LR) and 0.23 (NR) respectively.

The results displayed high differences for the calculated values of categories' areas that are calculated in the GIS for the restriction groundwater use for irrigation in the wet and dry seasons in 2016. In the wet season, in the classified final maps of groundwater for irrigation, the calculated areas' categories of high restriction (HR), low restriction (LR), and no restriction (NR) were more than the values of these categories in the dry season. The concentrations of measured parameters of LR and NR categories were exposed to dilution due to reducing the discharge from the aquifer by the population for different purposes and to increase the recharges the aquifer by rainfall. The increased values of the category of high restriction (HR) in the wet season compared with the dry season this is due to original high concentrations for the measured parameters for the wells located within the HR category.

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