# Evaluating Groundwater Quality for Sustainable Drinking and Irrigation Purposes and Assessing Nitrate Risks on Human Health in Rural Areas

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**Research**

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# Evaluating Groundwater Quality for Sustainable Drinking and Irrigation Purposes and Assessing Nitrate Risks on Human Health in rural areas

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## Abstract

Groundwater quality has specific importance for domestic, agricultural, and drinking water supply. Therefore, the objective of the current paper is to investigate groundwater quality for drinking and irrigation purposes, as well as studying health hazard effects of nitrate-containing groundwater on age groups living in rural areas. Two water quality indices were used for checking groundwater suitability for drinking and irrigation purposes. For drinking water quality index (DWQI), 88% of groundwater wells were poor water, whereas 12% were good water for drinking. The values of irrigation water quality index (IWQI) showed that the suitability of groundwater for irrigation uses was ranged from high to medium. In addition, this paper also included a risk assessment of nitrate-containing groundwater on rural resident's health. calculating oral hazard quotient ($HQ_{oral}$) for nitrates showed that 94% of the groundwater wells of the study area were less than 1, indicating no adverse health hazards on infants and children, whereas 6% of total wells were above 1, suggesting there are health risks. Regarding health effects on adults, all $HQ_{oral}$ values were less than 1, indicating no adverse health hazards. The Hazard Quotient via dermal contact ($HQ_{dermal}$) for nitrates was much less than the safety factor 1, indicating no health hazards on age groups via bathing.

Keywords: drinking water quality index, irrigation water quality index, health risk assessment.

## 1.1 Introduction

Groundwater plays a critical role as an important source of drinking water for millions of inhabitants in rural and urban areas, besides accomplishing the irrigation needs [1]. The contamination problems of groundwater are emerging in different parts of the earth because of climate change, increasing population, civilization, and manufacturing [2]. Groundwater quality is influenced by natural sources or a lot of types of human activity [3]. Both of point and non-point pollution sources like fertilizers, effluent from industries, and domestic sewage bring about groundwater to become polluted and to make health problems [4]. Thus, the continued monitoring of groundwater becomes obligatory in order to lessen groundwater pollution and have control over the contamination-caused factors [5].

The Water Quality Index (WQI) is considerably used to estimate the fitness of surface water, as well as groundwater for drinking and agriculture [6]. The water quality index is defined as a ranking, reflecting the composite impact of various water quality parameters [7]. By specifying the suitable weightage to the parameters, WQI can be determined precisely [8].

The large-scale applications of nitrogenous fertilizer and application of animal manure are considered as the essential source of nitrate ($NO_3$) contamination to the groundwater in many rural areas [9], [10], which have harmful influences on human healthiness and the environment [11]. Inorganic nitrogen occurs in the forms of nitrate ($NO_3$), nitrite ($NO_2$), and ammonia ($NH_4$) in soil, and the most easily obtainable forms for plants are $NO_3$ and $NH_4$. Nevertheless, both $NO_2$ and $NH_4$ generally exist in groundwater at very little concentrations because they are readily converted to $NO_3$ [12]. Repeated exposure to nitrate, as one of the main contaminants in aquifers, leading to harmful health impacts like methemoglobinemia (blue-baby syndrome), and particularly in infant's categories [13]. Because of the severe impacts of nitrate on human health, a guideline of 50 and 15 mg $L^{-1}$ for adults and infants, respectively, in drinking water, was recommended by the World Health Organization (WHO) [14].

The main objective of the study is to 1) determine the suitability of groundwater for drinking and irrigation purposes via applying drinking water quality index (DWQI) and irrigation water quality index (IWQI), and 2) assessing human health risk due to nitrate exposure.

### 1.2 Description of the study area

The study area is located within a rural region, north Baiji city. There are four villages (i.e. Al-hinshi, Shwaish, Albojwari, and Al-Laqlaq village) with thousands of residents who depend on groundwater for irrigation as well as domestic uses. Besides, there are industrial activities represented by North Refineries Company, Detergents plant, Thermal Power Plant and Gaseous Power Plant, which adding substantial quantities of pollutants via effluent and gases and aerosols emitted from chimneys. The study area lies in between northern 351160 to 371087 and eastern 3862912 to 3887201 in UTM units Figure (1).

### 1.3 Geology of study area

The study area is located in Hemrin - Makhul Subzone or foothill zone which characterized by a thick cover of sediments. The formations exposed in the area belong to the Fatha Formation (Middle Miocene) characterized by dominant evaporates facies that consist of halite, gypsum, and anhydrite, as well as Injana Formation (Upper Miocene) which distinguished by silty claystone, siltstone, and sandstone with thin layers of gypsum nodules [15]. Quaternary deposits (Pleistocene and Holocene) distinguished by river terraces, flood plain deposits, valley fillings, and gypseous soils are covering Injana Formation.

From the viewpoint of hydrogeology, study area consists of two aquifers, one belongs to Quaternary deposits which are characterized by shallow wells and it is an unconfined type [16], whereas the other belongs to Injana Formation which is characterized by deep wells and it is a confined type according to [17].

## 1.4 Materials and Methods

33 samples of groundwater were sampled during May 2013 as in Table 1 and Figure 1. Collecting groundwater samples carried out using polyethylene containers to analyze pH, TDS, major ions, and trace elements. For physiochemical tests, the polyethylene bottles were rinsed with water samples three times and filled to the neck. For determining trace elements, the samples were filtered using a 45µm membrane filter to get rid of colloids and hen acidify them to a pH value less than two with high purity $HNO_3$ acid [18]. All of the collected samples were kept in a cool box in the field and then stored in a refrigerator (4 – 6 °C) before sending it to the laboratory.

### 1.4.1 Calculating Drinking Water Quality Index (DWQI)

The water quality index is a worthy and distinctive parameter for determining the water quality and its sustainability for drinking uses. It represents the combined effect of various water quality parameters and provides water quality data to governmental decision-makers and the general populace [19]. For calculating WQI four steps are pursued as follows:

1. Each of the used parameters has been assigned a weight ($w_i$) according to its relative significance in the total quality of water for drinking uses. The minimum weight assigned is one (the least effect on drinking water quality), and the maximum weight assigned is five (the highest effect on drinking water quality) (Table 2). Thereafter, the relative weight for each parameter ($RW_i$) is figured by dividing its unit weight by the totality of unit weight of all parameters as the next Eq. [20]:

$RW_i = wi/\sum_{i=1}^{n} \mathrm{w}$ ………. (1)

Where: n is the number of chosen parameters (n = 21 in this study).

2. Calculating the rating scale ($Q_i$) for each parameter by dividing its concentration by its allowable limit value and the outcome is multiplied by 100 according to the next Eq.:

$Q_i = (ci - li/Si - li) \times 100$ ………. (2)

Where: *Ci* is the concentration of each parameter, *li* is the ideal value for each parameter (0 for all parameters excepting pH (7)), *Si* is the standard value as recommended by [21], [22].

3. Calculating the water quality sub-index value ($SI_i$) for each parameter by multiplying its rating scale ($Q_i$) with its relative weight ($RW_i$) as follows:

$SI_i = Q_i \times RW_i$ ………… (3)

4. Calculating DWQI via summing of the sub-indices of all parameters as follow:

DWQI = $\sum_{i=1}^{n} SIi$ ……….. (4)

Then, the groundwater quality types are classified according to the computed DWQI values, where these types are arranged into five categories [23], as shown in Table 3.

### 1.4.2. Calculating Irrigation Water Quality Index (IWQI)

The quality and the quantity of the dissolved components in the irrigation water are used to determine the water quality [24]. The permeability and infiltration hazard takes place when elevated sodium ions minimize the rate at which irrigation water gets in the soil's lower layers, and therefore, the crop cannot withdraw sufficient water from the soil, which lessens agriculture production [25]. The SAR value of irrigation water defines the relative ratios of $Na^{+}$ to $Ca^{2+}$ plus $Mg^{2+}$ and is calculated as:

$$SAR = Na \Big/ \sqrt{\frac{(Ca+Mg)}{2}} \ \ldots\ldots\ldots (5)$$

Where the concentration of Na, Ca and Mg are expressed in meq $L^{-1}$.

In this paper, Irrigation Water Quality Index (IWQI) is calculated depending on the method given by [25], [26], [27] and [28]. Five different hydrochemical groups (Table 4) were chosen, all five groups were included at the same time in the analysis and were integrated to form a single value, which is then evaluated to define the suitability of the groundwater for irrigation purposes. In the indicator methodology, each of the hazard groups (Table 4) is given a particular weight from 1 (least considerable group in quality of irrigation water) to 5 (most considerable group in quality of irrigation water). Based on their importance for assessing the quality of irrigation water, the maximum weight of 5 has been assigned to EC, whereas the minimum weight of 1 has been allocated to pH, $HNO_3$ and $NO_3$. The other hazard categories were designated a weight between 5 and 1 based on their significance in the overall irrigation water quality. The scale of quality rating is ranged from 3, high suitableness for irrigation, to 1, low suitableness for irrigation, for each component as in Table 4. The IWQI, to evaluate the integrated influence of irrigation water quality parameters, is calculated as:

$$Wi = w/N \sum_{i=1}^{N} Ri \ldots\ldots\ldots (6)$$

$$\text{IWQI} = \sum Wi \ldots\ldots\ldots\ldots (7)$$

where *i* is an incremental indicator, *W* is the contribution of every one of the five hazard classes that are important to estimate the irrigation water quality, *ω* represents the weight value of each hazard class, N is the overall number of water quality parameters in each hazard class, and R is the rating value of each parameter as listed in Table 4. Calculated IWQI values are usually categorized depending on the irrigation suitability for consumption (Table 7).

### 1.4.3. Assessing Exposure hazard to nitrates

The contaminated groundwater can negatively affect the health of human beings through diversities of exposures including direct ingestion, dermal contact, washing, etc. [9]. The absorption of potential toxins (e.g. nitrate) getting into the human body via drinking water can be expressed by Chronic Daily Intake (CDI) (mg kg$^{-1}$ d$^{-1}$). The formulation for figuring intake is via the following Eq. [11], [29].

$$\text{CDI} = Cw \times IR \times EF \times ED/BW \times AT \ldots\ldots\ldots\ldots (8)$$

Where CDI is the exposure represented by a mass of a substance per unit weight of body per unit time (mg kg$^{-1}$ d$^{-1}$); $C_w$ is the concentration of nitrate ion in water (mg L$^{-1}$); IR represents person ingestion rate of water (d$^{-1}$); EF represents the exposure frequency (d

$yr^{-1}$); ED indicates the exposure duration (yr); AT is the averaging time (AT=365×ED, d), and BW is the average body weight (kg).

The intake of a probable toxic substance by the human body via the dermal contact pathway can be assessed by calculating DAD. The Eq. for calculating DAD is as follow [11]:

$$\text{DAD} = DA \times SA \times EF \times ED \times EV/BW \times AT \ldots\ldots\ldots\ldots \text{(9)}$$

Where DAD indicates the dermal absorbed dose of nitrate (mg $kg^{-1}$ $d^{-1}$); $SA$ is the skin surface area available for contact ($cm^2$); $EV$ is the bathing recurrence (times/day). DA refers to the exposure dose of every individual event (mg $cm^{-2}$), and it can be evaluated utilizing Eq. 10 [30], where K refers to the coefficient of skin permeability (cm $h^{-1}$), $C_w$ is the concentration of the contaminant in water (mg $L^{-1}$), t is the contact time for single bathing (h $d^{-1}$), and it is roughly 0.4 h per day for adults, children, and infants, $CF$ is the unit conversion factor ($cm^{-3}$). The parameters used to compute the health risk for three age sets via ingestion and dermal contact pathway are listed in Table 8.

$$\text{DA} = \text{K} \times \text{C}_w \times \text{t} \times \text{CF} \ldots\ldots\ldots\ldots \text{(10)}$$

Non-carcinogenic impact of nitrate in groundwater via oral and dermal contact pathways can be expressed as hazard quotient (HQ) using Eq.s (11) and (12) [35].

$$\text{HQ}_{\text{oral}} = CDI/RfDoral \ldots\ldots\ldots\ldots \text{(11)}$$

$$\text{HQ}_{\text{dermal}} = DAD/RfDdermal \ldots\ldots\ldots\ldots \text{(12)}$$

The RfD is the reference dose of a particular contaminant which is stated in mg/kg per day, and it is of great importance in the calculating of the assessment of non-carcinogenic risk. Its value are listed in table 8. The value of HQ < 1 refers that the hurtful impacts of exposure cannot be predicted, but HQ > 1, points out that the non-carcinogenic risk exceeds the accepted level [35]. Total hazard quotient (THQ) can be calculated by the sum of $HQ_{oral}$ and $HQ_{dermal}$ and is expressed as [33]:

$$THQ = HQ_{oral} + HQ_{dermal} \ldots\ldots\ldots (13)$$

## Results and Discussion

The results of different physicochemical parameters of groundwater are listed in Table 9, and the trace elements are presented in Table 10. The calculated DWQIs for the groundwater wells w2, w5, w12, and w13 indicate good quality of water (Figure 2), and this might be caused by the low content of trace elements as well as major ions relative to the WHO admissible level. The other wells which represent 88% of total groundwater wells under Investigation are of poor water, and this due to elevating content of some of the chemical parameters caused by industrial and agricultural activities.

Irrigation water was categorized based on IWQI given in Figure 3. IWQI values are ranged from 30 to 39 in north Baiji city during the study period. Accordingly, 15 % and 85 % of the total groundwater wells are highly and moderately suitable for irrigation purposes respectively.

Assessing human risk by means of two pathways (oral and dermal) for three age groups (i.e. infants, children, and adults) was carried out. The highest value for $HQ_{oral}$ was 1.11, for infants; 1.19, for children; and 0.34 for adults (Figure 4), indicating there are non-carcinogenic health hazards of nitrates that influence on infants and children via drinking groundwater, whereas there are no health risk effects on adults. However, only two wells (i.e. w21 and w28) had an $HQ_{oral}$ value greater than 1 for infants and children, whereas all other wells had $HQ_{oral}$ values less than 1.

For $HQ_{dermal}$, all values were much less than 1 for infants, children, and adults (Figure 5), suggesting no adverse health risks due to bathing by nitrate-containing groundwater.

The values of THQ showed a very minor change when compared with $HQ_{oral}$ values (Figure 6).

## 1.5 Conclusions

In the current research, the suitability of groundwater for drinking and irrigation utilization was evaluated using two water quality indices, as well as assessing the health risk of nitrate ions on rural residents. Using of DWQI model for drinking purposes indicated that 12% of wells were good quality which considers fit for human consumption, whereas 88% of wells were of poor water quality. The values of IWQI model showed that the water quality is ranged from high to medium suitability for irrigation purposes.

From the perspective of non-carcinogenic health risk assessment, the $HQ_{oral}$ values were under the safety level (i.e., $HQ < 1$), suggesting that groundwater nitrate in all wells would have no significant adverse health effects on these age groups, except w21 and w28 which had $HQ_{oral}$ values above 1 for children and infants only. $HQ_{dermal}$ values were much less than 1 for the three age groups, indicating there are no adverse health risks via the dermal contact pathway. The non-carcinogenic health risk calculated for the age groups through $HQ_{oral}$ were in the order of children > infants > adults. While for $HQ_{dermal}$, the age groups were in the order of infants > children > adults.

## Declarations

### Availability of data and materials

All data generated or analyzed during this study are local personal data from the author's work and effort.

### Competing interests

The authors declare they have no competing interests.


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Table 1 Coordinate of Groundwater Samples at Study Area

| Well no. | Location | Eastern | Northern | Well no. | Location | Eastern | Northern |
|---|---|---|---|---|---|---|---|
| **W1** | Shwaish village | 368255 | 3874477 | **W18** | Shwaish village | 367136 | **3875200** |
| **W2** | Al-bojwari village | 364502 | 3870045 | **W19** | Al-bojwari village | 366070 | **3873853** |
| **W3** | Al-hinshi village | 366864 | 3877000 | **W20** | Al-bojwari village | 365098 | **3871237** |
| **W4** | Shwaish village | 368028 | 3875350 | **W21** | Al-bojwari village | 364256 | **3871347** |
| **W5** | Al-hinshi village | 368127 | 3876689 | **W22** | Al-bojwari village | 363891 | **3873087** |
| **W6** | Al-bojwari village | 367478 | 3873474 | **W23** | Al-bojwari village | 362650 | **3871417** |
| **W7** | Al-bojwari village | 365861 | 3872147 | **W24** | Hana Khalil farm | 361547 | **3872471** |
| **W8** | Al-bojwari village | 363131 | 3870461 | **W25** | Campus of detergents factory | 360278 | **3874042** |
| **W9** | Al-bojwari village | 365028 | 3872987 | **W26** | Al-Nesrain fuel station | 359493 | **3875638** |
| **W10** | Al-bojwari village | 365198 | 3873907 | **W27** | Firas Almuhsin crusher factory | 359507 | **3874551** |
| **W11** | Al-bojwari village | 367326 | 3874203 | **W28** | Mohammed Alqadori farm | 352114 | **3884144** |
| **W12** | Shwaish village | 365966 | 3875450 | **W29** | Jazerat Alarab fuel station | 356547 | **3878497** |
| **W13** | Al-bojwari village | 364211 | 3872439 | **W30** | Al-Baraka block factory | 357736 | **3877112** |
| **W14** | Al-bojwari village | 366268 | 3873069 | **W31** | Al-Saafi block factory | 359055 | **3876042** |
| **W15** | Shwaish village | 368830 | 3875779 | **W32** | Al-Laqlaq village | 368085 | **3869665** |
| **W16** | Al-hinshi village | 368759 | 3877010 | **W33** | Al-Laqlaq village | 369405 | **3872354** |
| **W17** | **Shwaish village** | **367084** | **3875740** | | | | |

Table 2 the weight ($w_i$) and relative weight ($RW_i$) of each parameter with the standard values reported by [21] and [22].

| Parameter | Guideline values | Weight ($w_i$) | Relative weight ($RW_i$) |
|---|---|---|---|
| **pH** | 8.5 | 4 | 0.056 |
| **TDS** | 500 mg $L^{-1}$ | 4 | 0.056 |
| **Ca** | 75 mg $L^{-1}$ | 2 | 0.028 |
| **Mg** | 30 mg $L^{-1}$ | 2 | 0.028 |
| **Na** | 200 mg $L^{-1}$ | 2 | 0.028 |
| **K** | 12 mg $L^{-1}$ | 2 | 0.028 |
| **Cl** | 250 mg $L^{-1}$ | 3 | 0.042 |
| **$SO_4$** | 250 mg $L^{-1}$ | 3 | 0.042 |
| **$NO_3$** | 50 mg $L^{-1}$ | 5 | 0.069 |
| **As** | 10 µg $L^{-1}$ | 5 | 0.069 |
| **B** | 2.4 mg $L^{-1}$ | 3 | 0.042 |
| **Cd** | 3 µg $L^{-1}$ | 5 | 0.069 |
| **Cr** | 50 µg $L^{-1}$ | 5 | 0.069 |
| **Cu** | 2000 µg $L^{-1}$ | 2 | 0.028 |
| **Fe** | 300 µg $L^{-1}$ | 2 | 0.028 |
| **Mn** | 400 µg $L^{-1}$ | 4 | 0.056 |
| **Ni** | 70 µg $L^{-1}$ | 3 | 0.042 |
| **Pb** | 10 µg $L^{-1}$ | 5 | 0.069 |
| **Se** | 40 µg $L^{-1}$ | 5 | 0.069 |
| **U** | 30 µg $L^{-1}$ | 3 | 0.042 |
| **Zn** | 3000 µg $L^{-1}$ | 3 | 0.042 |
| | | $\sum = 72$ | $\sum = 1$ |

Table 3 criterion DWQI values of water for human consumption

| DWQI range value | Water quality | clarification |
|---|---|---|
| **< 50** | Excellent Water | Good for human health |
| **50.1–100** | Good Water | Fit for human consumption |
| **100.1–200** | Poor Water | Water not in good condition |
| **200.1–300** | Very Poor Water | Need attention before use |
| **> 300.1** | Unsuitable | Need too much attention |

Table 4 Rating for IWQI parameters

| Hazard | Weight | Parameter | Range | Rating | Suitability |
|---|---|---|---|---|---|
| **Salinity hazard** | 5 | Electrical conductivity (µS/cm) | EC < 700 | 3 | High |
| | | | 700 ≤ EC ≤ 3000 | 2 | Medium |
| | | | EC > 3000 | 1 | Low |
| **Infiltration and permeability hazard** | 4 | See Table 5 for details | | | |
| **particular ion toxicity** | 3 | Sodium adsorption ratio | SAR < 3.0 | 3 | High |
| | | | 3.0 ≤ SAR ≤ 9.0 | 2 | Medium |
| | | | SAR > 9.0 | 1 | Low |
| | | Boron (mg $L^{-1}$) | B < 0.7 | 3 | High |

| | | | | | |
|---|---|---|---|---|---|
| | | | $0.7 \leq B \leq 3.0$ | 2 | Medium |
| | | | $3.0 > B$ | 1 | Low |
| | | Chloride (mg $L^{-1}$) | $Cl < 140$ | 3 | High |
| | | | $140 \leq Cl \leq 350$ | 2 | Medium |
| | | | $350 > Cl$ | 1 | Low |
| **Trace element toxicity** | 2 | See Table 6 for details | | | |
| **Miscellaneous effects to sensitive cops** | 1 | Bicarbonate (mg $L^{-1}$) | $HCO_3 < 90$ | 3 | High |
| | | | $90 \leq HCO_3 \leq 500$ | 2 | Medium |
| | | | $500 > HCO_3$ | 1 | Low |
| | | pH | $7.0 \leq pH \leq 8.0$ | 3 | High |
| | | | $6.5 \leq pH < 7.0$ and $8.0 < pH \leq 8.5$ | 2 | Medium |
| | | | $pH < 6.5$ or $pH > 8.5$ | 1 | Low |

Table 5 Classification for infiltration and permeability hazard

| | **SAR** | | | | | **Rating** | **Suitability** |
|---|---|---|---|---|---|---|---|
| | < 3.0 | 3-6 | 6-12 | 12-20 | > 20 | | |
| **EC** | >700 | >1200 | >1900 | >2900 | >5000 | 3 | High |
| | 700-200 | 1200-300 | 1900-500 | 2900-1300 | 5000-2900 | 2 | Medium |
| | <200 | <300 | <500 | <1300 | <2900 | 1 | Low |

Table 6 Classification for trace element toxicity

| Parameter (mg $L^{-1}$) | Range | Rating | Suitability |
|---|---|---|---|
| **Aluminum** | $Al < 5.0$ | 3 | High |
| | $5.0 \leq Al \leq 20.0$ | 2 | Medium |
| | $Al > 20.0$ | 1 | Low |
| **Arsenic** | $As < 0.1$ | 3 | High |
| | $0.1 \leq As \leq 2.0$ | 2 | Medium |
| | $2.0 > As$ | 1 | Low |
| **Cadmium** | $Cd < 0.01$ | 3 | High |
| | $0.01 \leq Cd \leq 0.05$ | 2 | Medium |
| | $0.05 > Cd$ | 1 | Low |
| **Chromium** | $Cr < 0.1$ | 3 | High |
| | $0.1 \leq Cr \leq 1.0$ | 2 | Medium |
| | $1.0 > Cr$ | 1 | Low |
| **Cobalt** | $Co < 0.05$ | 3 | High |
| | $0.05 \leq Co \leq 5.0$ | 2 | Medium |
| | $5.0 > Co$ | 1 | Low |
| **Copper** | $Cu < 0.2$ | 3 | High |
| | $0.2 \leq Cu \leq 5.0$ | 2 | Medium |
| | $5.0 > Cu$ | 1 | Low |
| **Iron** | $Fe < 5.0$ | 3 | High |
| | $5.0 \leq Fe \leq 20.0$ | 2 | Medium |
| | $20.0 > Fe$ | 1 | Low |
| **Lead** | $Pb < 5.0$ | 3 | High |
| | $5.0 \leq Pb \leq 10.0$ | 2 | Medium |
| | $Pb > 10.0$ | 1 | Low |
| **Lithium** | $Li < 2.5$ | 3 | High |
| | $2.5 \leq Li \leq 5.0$ | 2 | Medium |
| | $5.0 > Li$ | 1 | Low |
| **Manganese** | $Mn < 0.2$ | 3 | High |
| | $0.2 \leq Mn \leq 10.0$ | 2 | Medium |

| | | | |
|---|---|---|---|
| | 10.0 > Mn | 1 | Low |
| **Molybdenum** | Mo < 0.01 | 3 | High |
| | 0.01 ≤ Mo ≤ 0.05 | 2 | Medium |
| | 0.05 > Mo | 1 | Low |
| **Nickel** | Ni < 0.2 | 3 | High |
| | 0.2 ≤ Ni ≤ 2.0 | 2 | Medium |
| | 2.0 > Ni | 1 | Low |
| **Selenium** | Se < 0.01 | 3 | High |
| | 0.01 ≤ Se ≤ 0.02 | 2 | Medium |
| | 0.02 > Se | 1 | Low |
| **Vanadium** | V < 0.1 | 3 | High |
| | 0.1 ≤ V ≤ 1.0 | 2 | Medium |
| | 1.0 > V | 1 | Low |
| **Zinc (mg $L^{-1}$)** | Zn < 2 | 3 | High |
| | 2 ≤ Zn ≤ 10.0 | 2 | Medium |
| | 10.0 > Zn | 1 | Low |

Table 7 Classification Irrigation water quality index (IWQI) [28]

| IWQI | Suitability of water for irrigation |
|---|---|
| **< 22** | Low |
| **22-37** | Medium |
| **> 37** | High |

Table 8 the parameters utilized in the health risk assessment model

| Parameters | Values | | | Reference |
|---|---|---|---|---|
| | infant | Child | Adult | |
| **BW (kg)** | 6.94 | 15 | 70 | [31], [32] |

| | | | | |
|---|---|---|---|---|
| **ED (yr)** | 0.5 | 12 | 30 | [9], [31] |
| **EF (d /yr)** | | 365 | | [31] |
| **AT (d)** | | ED × 365 | | |
| **SA ($cm^2$)** | 3416 | 6600 | 18000 | [31], [32] |
| **IR ($d^{-1}$)** | 0.25 | 1.5 | 3.0 | [30],[34] |
| **EV (times $d^{-1}$)** | | 1 | | [29] |
| **K (cm $h^{-1}$)** | | 0.001 | | [29] |
| **t (h)** | | 0.35 | | [29] |
| **CF l $cm^{-3}$** | | 0.001 | | [34] |
| **$RfD_{oral}$ (mg $kg^{-1}$ $d^{-1}$)** | | 1.6 | | [34] |
| **$RfD_{dermal}$ (mg $kg^{-1}$ $d^{-1}$)** | | 0.8 | | [34] |

Table 9 Physicochemical parameters of groundwater

| **Well no.** | **pH** | **TDS ppm** | **EC µS/cm** | **Ca ppm** | **Mg ppm** | **Na ppm** | **K ppm** | **Cl ppm** | **SO4 ppm** | **$HCO_3$ ppm** | **$NO_3$ ppm** | **SAR** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **w1** | 7.1 | 1980 | 3150 | 299 | 108 | 164 | 6 | 332 | 1020 | 21.80 | 12 | 2.06 |
| **w2** | 7.4 | 1990 | 3400 | 169 | 56 | 378 | 6 | 85 | 1267 | 13.70 | 11 | 6.43 |
| **w3** | 7.1 | 1050 | 1700 | 156 | 43 | 116 | 3 | 93 | 576 | 39.00 | 11 | 2.12 |
| **w4** | 7.3 | 2400 | 3300 | 270 | 93 | 369 | 4 | 270 | 1358 | 11.00 | 14 | 4.94 |
| **w5** | 7.2 | 2425 | 3500 | 378 | 147 | 197 | 5 | 75 | 1571 | 11.00 | 10 | 2.18 |
| **w6** | 7.3 | 2075 | 3560 | 394 | 88 | 118 | 2 | 63 | 1355 | 7.80 | 11 | 1.40 |
| **w7** | 7.1 | 2250 | 3550 | 241 | 106 | 358 | 3 | 438 | 1035 | 23.00 | 9 | 4.83 |
| **w8** | 7.1 | 2150 | 3850 | 376 | 100 | 181 | 3 | 192 | 1269 | 16.70 | 9 | 2.15 |
| **w9** | 8 | 2500 | 4100 | 266 | 112 | 374 | 5 | 199 | 1501 | 22.60 | 10 | 4.85 |
| **w10** | 7.2 | 2770 | 4160 | 311 | 199 | 299 | 6 | 511 | 1400 | 25.00 | 12 | 3.26 |
| **w11** | 7.5 | 2190 | 3700 | 245 | 105 | 331 | 9 | 350 | 1100 | 22.00 | 11 | 4.46 |
| **w12** | 7.3 | 1875 | 3350 | 279 | 89 | 206 | 11 | 160 | 1080 | 16.00 | 16 | 2.74 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **w13** | 7.7 | 2150 | 3900 | 208 | 79 | 356 | 4 | 145 | 1300 | 34.00 | 7 | 5.33 |
| **w14** | 7.3 | 3200 | 5000 | 411 | 138 | 381 | 3 | 206 | 2016 | 28.00 | 11 | 4.15 |
| **w15** | 7.9 | 1410 | 2400 | 199 | 57 | 157 | 8 | 99 | 867 | 9.30 | 9 | 2.52 |
| **w16** | 7.2 | 1188 | 2000 | 145 | 67 | 115 | 10 | 99 | 687 | 47.00 | 11 | 1.98 |
| **w17** | 7.2 | 2330 | 3700 | 315 | 146 | 198 | 8 | 115 | 1519 | 17.80 | 15 | 2.32 |
| **w18** | 7.5 | 2600 | 4400 | 287 | 177 | 355 | 5 | 500 | 1220 | 30.70 | 10 | 4.06 |
| **w19** | 7.6 | 2230 | 3500 | 300 | 161 | 231 | 6 | 295 | 1196 | 17.80 | 12 | 2.68 |
| **w20** | 7.8 | 1885 | 3250 | 301 | 95 | 198 | 9 | 356 | 901 | 11.00 | 11 | 2.55 |
| **w21** | 7.6 | 2220 | 3400 | 244 | 109 | 368 | 4 | 341 | 1124 | 8.10 | 17 | 4.92 |
| **w22** | 7.9 | 2340 | 3500 | 367 | 97 | 298 | 3 | 481 | 1050 | 26.60 | 10 | 3.57 |
| **w23** | 7.4 | 2200 | 3100 | 301 | 125 | 234 | 5 | 368 | 1114 | 36.40 | 10 | 2.86 |
| **w24** | 7.7 | 3680 | 5620 | 355 | 209 | 500 | 5 | 231 | 2313 | 21.00 | 12 | 5.20 |
| **w25** | 7.9 | 1975 | 3000 | 196 | 99 | 290 | 3 | 246 | 1112 | 17.60 | 9 | 4.21 |
| **w26** | 7.6 | 3100 | 4680 | 356 | 155 | 362 | 4 | 198 | 1941 | 16.60 | 11 | 4.03 |
| **w27** | 7.6 | 3220 | 5000 | 390 | 201 | 457 | 5 | 556 | 1562 | 19.50 | 10 | 4.68 |
| **w28** | 7.2 | 2050 | 3000 | 289 | 128 | 203 | 9 | 255 | 1131 | 22.10 | 19 | 2.50 |
| **w29** | 7.4 | 2390 | 4000 | 220 | 104 | 391 | 8 | 165 | 1450 | 39.00 | 8 | 5.44 |
| **w30** | 7.8 | 3110 | 5300 | 433 | 144 | 400 | 6 | 634 | 1450 | 22.00 | 11 | 4.25 |
| **w31** | 7.7 | 2455 | 3980 | 297 | 120 | 320 | 3 | 122 | 1565 | 13.80 | 10 | 3.96 |
| **w32** | 7.3 | 1245 | 1950 | 177 | 62 | 129 | 5 | 107 | 741 | 15.77 | 12 | 2.14 |
| **w33** | 7.1 | 2200 | 3100 | 324 | 135 | 179 | 3 | 173 | 1346 | 23.75 | 15 | 2.11 |

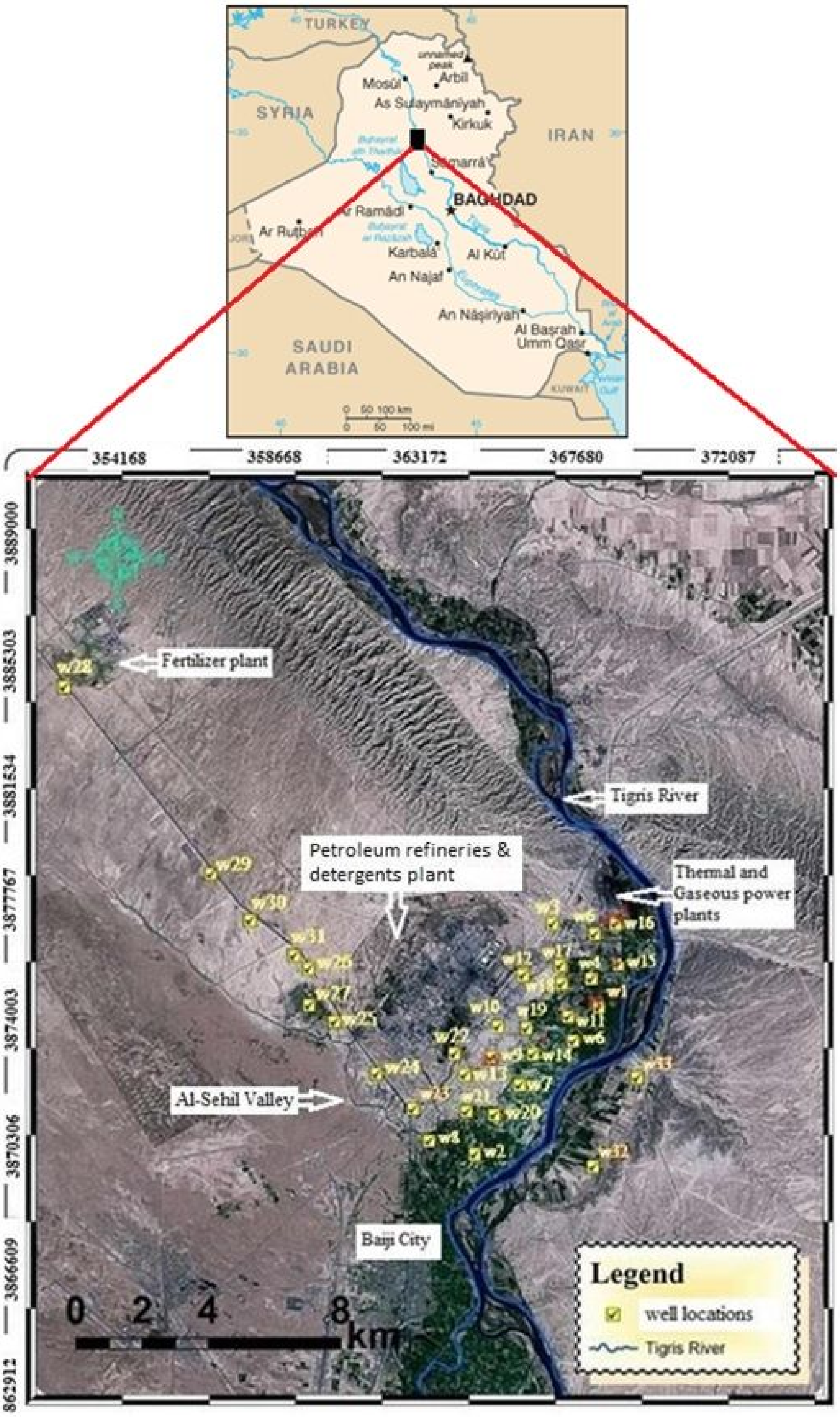
Table 10 trace element concentrations in groundwater

| **Well no.** | **As** | **Mn** | **Cu** | **Zn** | **Pb** | **Fe** | **Cr** | **Cd** | **Ni** | **U** | **B** | **Se** | **Al** | **Co** | **Li** | **Mo** | **V** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **w1** | 3 | 600.34 | 11.7 | 77.1 | 31.8 | 33 | 12.3 | 2.61 | 4.8 | 12.51 | 1.443 | 4.5 | 87 | 1.68 | 35.1 | 3.9 | 2.1 |
| **w2** | 1.5 | 11.46 | 9.6 | 62.7 | 15.9 | 30 | 12.6 | 1.29 | 5.1 | 13.05 | 2.184 | 6.3 | 45 | 1.41 | 48.9 | 3.6 | 3.3 |
| **w3** | 1.8 | 25.23 | 13.2 | 138.6 | 57.9 | 126 | 9.6 | 28.98 | 12.9 | 1.11 | 0.093 | 6.9 | 354 | 5.01 | 5.4 | 3.3 | 3 |
| **w4** | 3 | 2618.6 | 5.1 | 120.6 | 20.7 | 39 | 4.5 | 1.32 | 12.9 | 12.93 | 0.264 | 8.4 | 42 | 3.36 | 14.7 | 12 | 2.7 |
| **w5** | 1.5 | 11.64 | 8.4 | 70.2 | 24.3 | 30 | 15.6 | 1.83 | 5.1 | 4.92 | 1.2 | 5.7 | 51 | 1.68 | 29.1 | 8.7 | 2.7 |
| **w6** | 2.7 | 149.79 | 8.1 | 112.2 | 19.5 | 30 | 6.6 | 11.2 | 5.7 | 12.36 | 1.194 | 6.3 | 36 | 1.08 | 43.2 | 12.6 | 2.4 |
| **w7** | 2.1 | 8.1 | 9.6 | 88.5 | 39.9 | 33 | 12.6 | 6.21 | 6.9 | 10.05 | 0.618 | 5.7 | 69 | 6.21 | 24.3 | 7.5 | 4.8 |
| **w8** | 2.4 | 7.74 | 9.6 | 81.6 | 35.1 | 33 | 9.6 | 4.17 | 6 | 6.9 | 0.612 | 8.4 | 99 | 4.89 | 22.5 | 8.4 | 3.0 |
| **w9** | 1.5 | 7.77 | 39.6 | 101.4 | 143.7 | 30 | 16.5 | 6.42 | 3.3 | 7.41 | 0.564 | 7.8 | 63 | 7.17 | 26.4 | 8.7 | 5.1 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **w10** | 1.8 | 64.98 | 18.9 | 89.1 | 56.4 | 33 | 14.7 | 4.71 | 9.3 | 8.52 | 1.965 | 5.4 | 291 | 5.76 | 32.1 | 9.3 | 4.5 |
| **w11** | 2.7 | 921.4 | 17.4 | 76.8 | 42.6 | 57 | 9.9 | 22.73 | 10.8 | 10.26 | 0.999 | 5.1 | 123 | 4.62 | 30.9 | 12.3 | 3.6 |
| **w12** | 1.5 | 39.99 | 12.9 | 72.6 | 37.8 | 51 | 11.7 | 2.49 | 8.7 | 6.51 | 0.501 | 4.5 | 66 | 4.86 | 29.4 | 8.1 | 2.7 |
| **w13** | 1.8 | 11.25 | 14.4 | 76.8 | 35.7 | 36 | 15.3 | 2.22 | 9.3 | 9.81 | 0.651 | 6.3 | 186 | 4.32 | 22.8 | 6.6 | 6.0 |
| **w14** | 2.4 | 105.39 | 13.8 | 91.8 | 29.4 | 63 | 21.6 | 14.65 | 12.6 | 9.72 | 1.587 | 6.3 | 105 | 7.41 | 39.6 | 17.4 | 2.7 |
| **w15** | 2.7 | 805.5 | 11.7 | 79.2 | 47.1 | 33 | 14.1 | 2.97 | 5.4 | 12.51 | 0.291 | 5.7 | 63 | 5.58 | 20.4 | 14.7 | 2.7 |
| **w16** | 1.5 | 35.19 | 9.9 | 85.2 | 165.6 | 30 | 15.3 | 6.9 | 12.3 | 5.79 | 2.748 | 6.9 | 57 | 3.99 | 11.7 | 9.6 | 3.0 |
| **w17** | 1.5 | 1337.8 | 12.3 | 99.3 | 26.4 | 30 | 13.5 | 2.37 | 6.3 | 9.84 | 1.476 | 5.1 | 81 | 1.83 | 29.1 | 4.8 | 3.0 |
| **w18** | 1.5 | 1100.1 | 11.7 | 83.4 | 94.8 | 39 | 12.3 | 2.7 | 5.7 | 9 | 1.344 | 6.3 | 39 | 1.74 | 47.4 | 6.0 | 5.7 |
| **w19** | 1.5 | 13.89 | 31.2 | 94.8 | 118.2 | 30 | 17.1 | 5.82 | 4.8 | 8.67 | 0.588 | 7.5 | 75 | 6.33 | 27.9 | 11.4 | 5.7 |
| **w20** | 1.5 | 76.26 | 23.1 | 79.2 | 63.9 | 30 | 15.6 | 24.98 | 9 | 8.73 | 2.1 | 5.7 | 57 | 6.18 | 33.6 | 12.6 | 5.7 |
| **w21** | 2.7 | 51.72 | 18.3 | 70.5 | 53.7 | 60 | 12.3 | 4.41 | 9 | 7.41 | 1.71 | 4.8 | 63 | 4.74 | 34.2 | 9.3 | 6.0 |
| **w22** | 2.4 | 205.32 | 11.1 | 59.1 | 99.9 | 93 | 14.4 | 13.71 | 12.6 | 4.35 | 0.663 | 11.1 | 138 | 2.97 | 53.4 | 15.3 | 3.0 |
| **w23** | 1.8 | 10.38 | 11.7 | 58.8 | 68.1 | 33 | 9.6 | 6.69 | 8.4 | 9.42 | 1.428 | 4.5 | 81 | 1.74 | 25.2 | 12.0 | 2.1 |
| **w24** | 1.5 | 145.65 | 19.8 | 70.2 | 22.2 | 39 | 15 | 2.28 | 8.4 | 9.66 | 1.131 | 5.7 | 48 | 5.52 | 27.9 | 11.4 | 2.4 |
| **w25** | 1.5 | 18.51 | 34.8 | 58.5 | 26.4 | 33 | 12.6 | 15.81 | 5.1 | 5.01 | 1.41 | 4.8 | 45 | 5.16 | 48.9 | 3.6 | 0.9 |
| **w26** | 2.1 | 64.11 | 14.4 | 92.1 | 47.7 | 36 | 9.9 | 7.35 | 8.7 | 8.67 | 1.53 | 3.6 | 99 | 4.86 | 31.8 | 10.5 | 3.0 |
| **w27** | 1.5 | 7.38 | 9.6 | 61.5 | 59.7 | 51 | 7.8 | 2.79 | 6 | 4.47 | 1.767 | 2.1 | 48 | 1.98 | 44.1 | 8.7 | 2.4 |
| **w28** | 1.5 | 8.76 | 7.8 | 77.4 | 37.2 | 30 | 6.6 | 5.19 | 5.4 | 10.71 | 1.263 | 3.6 | 81 | 6.27 | 23.7 | 9.3 | 4.8 |
| **w29** | 1.5 | 9.42 | 23.7 | 59.1 | 41.1 | 45 | 13.8 | 1.23 | 6 | 5.34 | 0.534 | 1.8 | 93 | 5.79 | 38.1 | 7.5 | 3.9 |
| **w30** | 1.5 | 9.33 | 9.9 | 61.5 | 39.6 | 33 | 12.3 | 6.33 | 6.3 | 7.98 | 0.633 | 3.3 | 69 | 6.39 | 27.3 | 8.4 | 2.7 |
| **w31** | 1.5 | 87.99 | 8.7 | 64.2 | 35.1 | 30 | 9.3 | 1.41 | 5.7 | 6.78 | 1.173 | 4.2 | 36 | 1.44 | 41.4 | 9.6 | 4.2 |
| **w32** | 1.5 | 19.26 | 15.9 | 109.8 | 81.6 | 36 | 13.8 | 4.38 | 7.2 | 9.36 | 0.621 | 2.7 | 45 | 5.16 | 24.9 | 7.5 | 5.4 |
| **w33** | 1.5 | 17.4 | 18.3 | 89.1 | 53.4 | 33 | 12.6 | 5.07 | 9 | 8.58 | 0.483 | 5.1 | 39 | 4.74 | 31.2 | 6.6 | 2.7 |

* All concentrations are expressed in µg $L^{-1}$, except B are in mg $L^{-1}$

# Figures




## Figure 1

Location map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

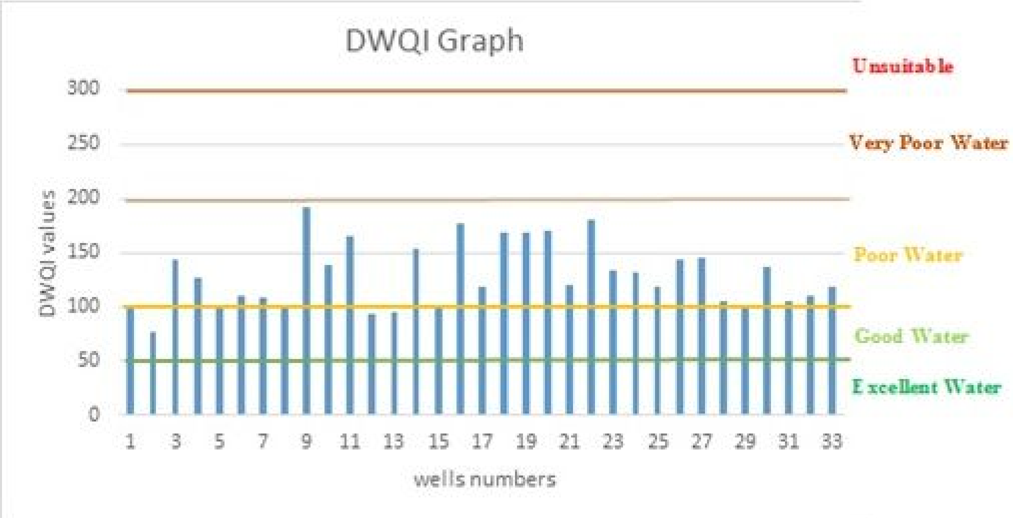



**Figure 2**

Graphical illustration of DWQI values

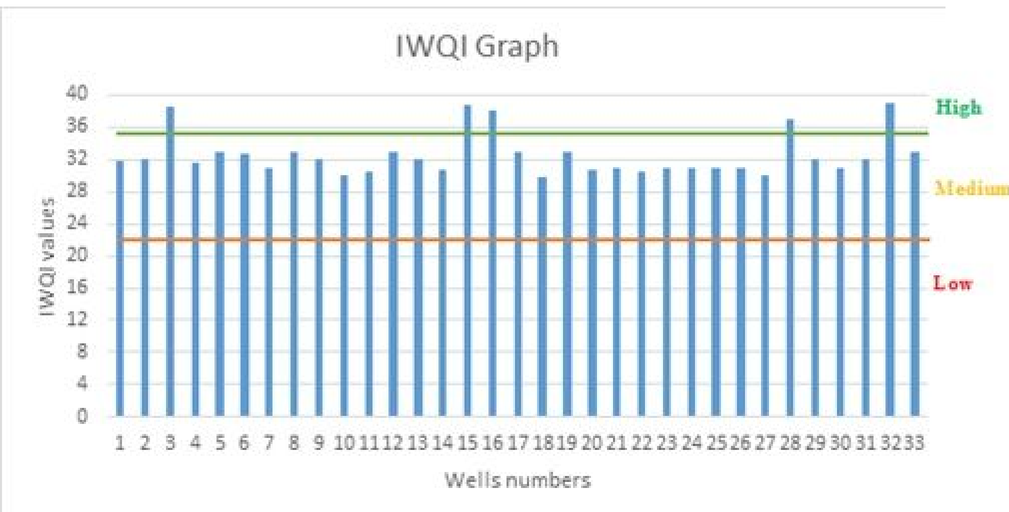



**Figure 3**

Graphical illustration of IWQI values

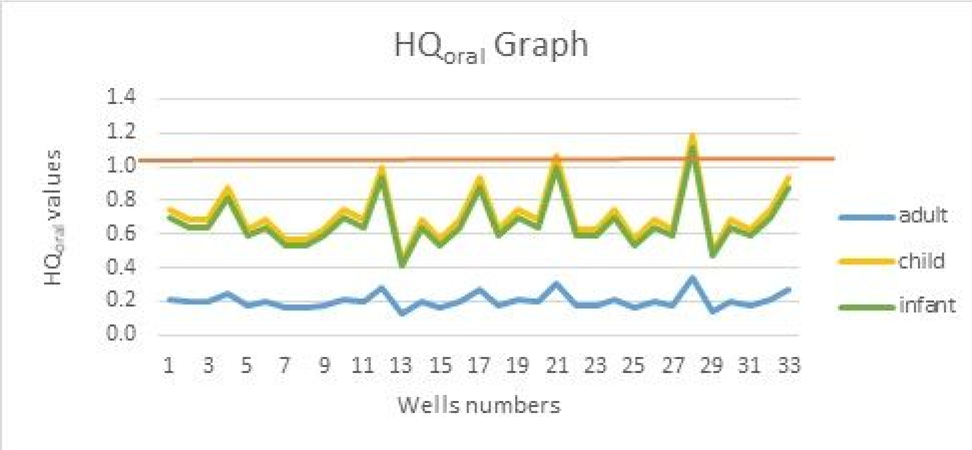



**Figure 4**

representative graph for HQoral

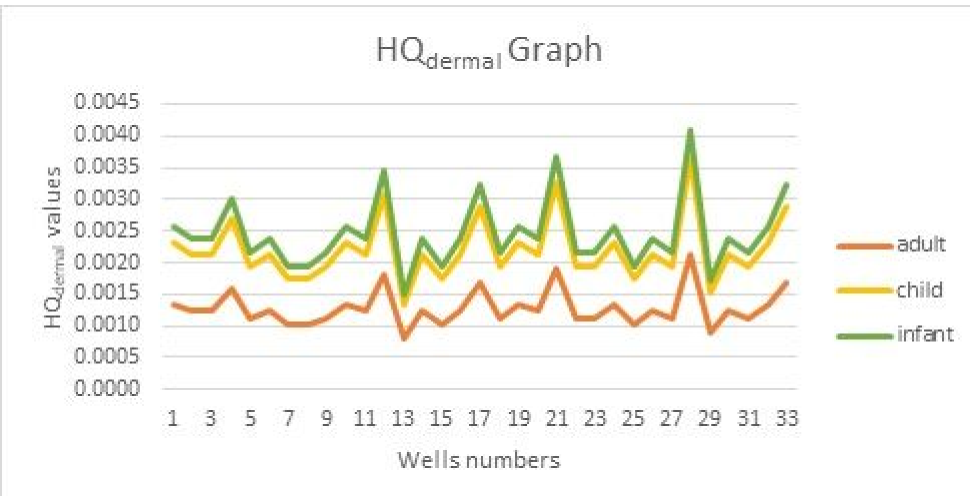



**Figure 5**

representative graph for HQdermal

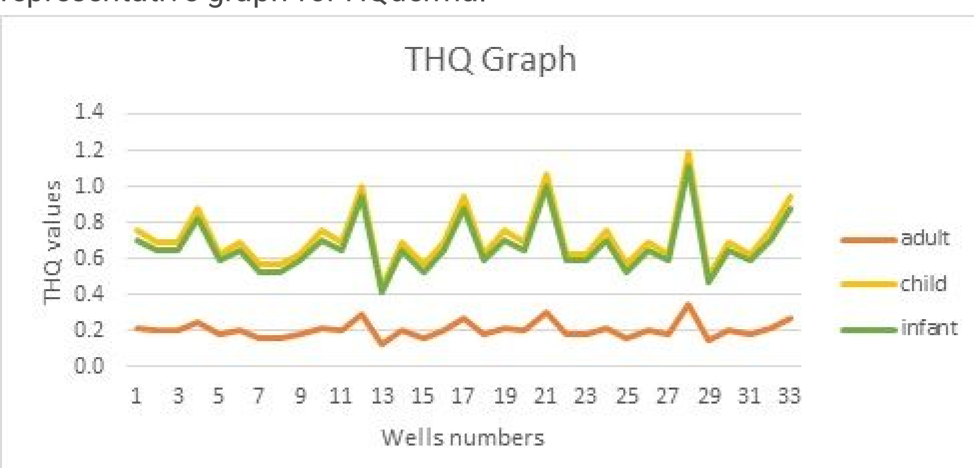



**Figure 6**

representative graph for THQ