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Assessing the Quality of the Groundwater and the Nitrate Exposure, North Salah Al-Din Governorate, Iraq

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Abstract: Groundwater quality is a topic that concerns millions of people because it is essential for agriculture and drinking. As a result, this paper aims to assess the groundwater quality of the northern region of Salah al-Din Governorate (Bayji as a case study) and the health risks posed by nitrate ions to infants, children, and adults living in villages. Samples were taken from 30 wells in the industrial district of the Baiji area in April 2022. Two water quality indices were applied to determine whether groundwater can be used for drinking and irrigation or not. The drinking water quality index (DWQI) found that 96.67% of the water samples were poor, and 3.33% were abysmal. Based on the values of the irrigation water quality index (IWQI), the tested water quality ranged from medium to high. In addition, the study required assessing the health risks posed by nitrate ions in the groundwater to residents. According to the oral hazard quotient (HQ_{oral}) calculation results, 93.33 and 96.67 % of the water samples were below one, indicating no health risks for children or infants. However, 6.67 and 3.33% of the total samples were above one, indicating health risks. All HQ_{oral} values were less than one when it came to the health effects of nitrates on adults, indicating that there were no risks. Because the Hazard Quotient (HQ_{dermal}) through the dermal pathway was less than one, showering posed no health risks for adults, children, or infants.

تقييم جودة المياه الجوفية ومخاطر التعرض للنترات، شمال محافظة صلاح الدين، العراق

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الخلاصة

تعد جودة المياه الجوفية موضوع مهم لملايين الناس لأنها ضرورية للزراعة والشرب. ونتيجة لذلك، فإن أهداف هذه الورقة هي تقييم جودة المياه الجوفية للمنطقة الشمالية من محافظة صلاح الدين (بيجي كحالة دراسية) والمخاطر الصحية التي تشكلها أيونات النترات على الرضع والأطفال والبالغين الذين يعيشون في القرى. تم أخذ عينات من 30 بئراً من المنطقة الصناعية في مدينة بيجي في أبريل 2022. لتحديد ما إذا كان يمكن استخدام المياه الجوفية للشرب والري، تم استخدام مؤشرين لنوعية المياه. وجد مؤشر جودة مياه الشرب (DWQI) أن 96.67٪ من عينات المياه كانت رديئة، و3.33٪ كانت سيئة للغاية. بناءً على قيم مؤشر جودة مياه الري(IWQI) ، تراوحت جودة المياه من متوسط إلى مرتفع. بالإضافة إلى ذلك، تطلبت الدراسة تقييم المخاطر الصحية التي تسببها أيونات النترات في المياه الجوفية للسكان. وفقًا لنتائج حساب معدل الخطر الفموي(HQ_{oral}) ، كانت 93.33 و96.67 % من عينات المياه أقل من واحد، مما يشير إلى عدم وجود مخاطر صحية للأطفال أو الرضع، على التوالي. ومع ذلك، فإن 6.67 و3.33٪ من إجمالي العينات كانت أعلى من واحد، مما يشير إلى وجود مخاطر صحية. كانت جميع قيم HQ_{oral} أقل من واحد عندما يتعلق الأمر بالتأثيرات الصحية للنترات على البالغين، مما يشير إلى عدم وجود مخاطر. نظرًا لأن حاصل الخطر (HQ_{dermal})عبر المسار الجلدي كان أقل من واحد، فإن الاستحمام لا يشكل أي مخاطر صحية للبالغين أو الأطفال أو الرضع.

الكلمات الدالة: مؤشر جودة المياه الجوفية، التعرض للنترات، تقييم المخاطر الصحية، مؤشر جودة المياه، مؤشر جودة مياه الري.

1.INTRODUCTION

Groundwater is an essential source of drinking water for thousands of rural residents in addition to watering crops [1, 2]. Groundwater contamination issues are caused by various factors, including climate change, population growth, and industrialization [3]. Both natural and human-caused factors have an impact on the quality of groundwater [4,5]. Examples of sources of contamination that can contaminate water and pose health risks include insecticides, fertilizer, and household sewage [6,7]. As a result, subsurface water monitoring regularly becomes essential for determining the predominant pollutants and water contamination [8]. The water quality is a useful indicator of the water type and the ecosystem's health [9]. The Water Quality Index (WQI) is frequently used to determine whether or not surface and subsurface water is suitable for irrigation and drinking [10]. The WQI is a rating that shows how different factors that affect groundwater quality work together [11]. The water quality index can be accurately defined by determining the appropriate weight for variables [12]. Using nitrogen fertilizers and animal manure is one of the main factors that contribute to the contamination of groundwater in rural areas with nitrate (NO_3^-) [13, 14], which has negative effects on human and environmental health [15]. While ammonia, nitrate, and nitrite are all inorganic nitrogen found in soil, NO_3^- and NH_4^+ are the most readily available to plants. However, due to their rapid transformation into NO_3^-, NO_2^-, and NH_4^+, they have deficient concentrations in groundwater [16]. As a contaminant in aquifers, NO_3^- exposure is harmful to health and can result in methemoglobinemia, especially in infants [17]. WHO recommended that nitrate concentrations in drinking water must not exceed 15 and 50 mg/liter for adults and infants, respectively [18], due to their detrimental effects on human health [19]. Al-Allaf and Al-Shwany 2022 [20] found that well water is not safe to drink in terms of high concentrations of nitrate ions, which pose a threat to human and animal health, whether they are cancerous or non-cancerous. By using WQIs for irrigation and drinking, the study aims to evaluate the quality of groundwater for 30 wells in the industrial district of the Baiji area, northern Salah al-Din Governorate, for irrigation and drinking, as well as the health risks posed to nitrate exposure.

2. DESCRIPTION OF THE STUDY AREA

The study area can be found in the northern part of the Iraqi governorate of Salah al-Din. Fig. 1 depicts how its inhabitants use groundwater for drinking and irrigation. The detergent plant, the thermal and gaseous power plants, and the Baiji Refineries Company are all examples of anthropogenic activities that release a significant amount of pollutants into the environment. The study area's boundaries are located between 35°11'60" to 37°20'00" north and 38°68'00" to 38°85'00" east. The study area is in the Hemrin- Makhul Subzone, also known as the foothill zone, which has a thick sediments cover. The Fatha Formation and the Injana Formation are the exposed rock formations in the area of interest. The dominant evaporates of gypsum, halite, and anhydrite distinguish the Fatha Formation (Middle Miocene). Sandstone, siltstone, and silty claystone with gypsum nodules as thin layers make up the Upper Miocene Injana Formation. Floodplain deposits, river terraces, and the gypsiferous soil that covers the Injana Formation distinguish Quaternary deposits (Pleistocene and Holocene) [21]. From a hydrogeological point of view, the area is divided into two aquifers: one belongs to the Quaternary deposits, which have shallow wells and are of the unconfined type [22], and the other is the Injana Formation, which has deep wells and is of the confined type, as stated in [23, 24].

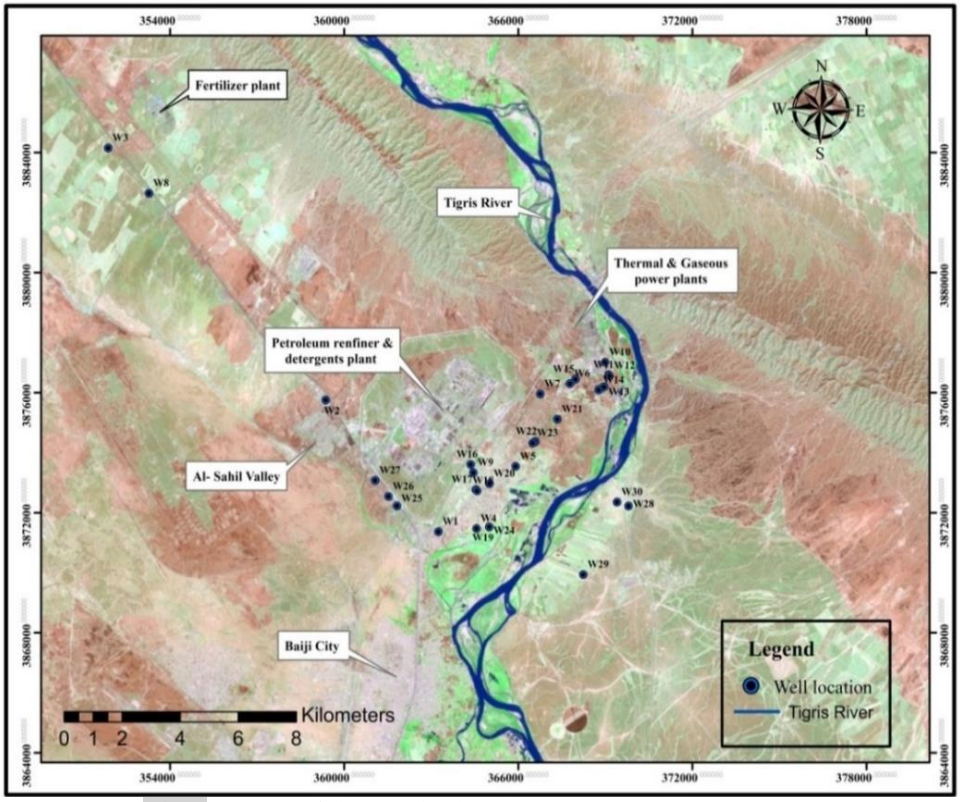

Fig.1 A Map of the Studied Location with Sampling Sites.

3.METHODOLOGY

Thirty wells in the industrial district of the Baiji area were sampled. Polyethylene containers were used to collect water samples from wells in April 2022 for chemical and physical tests [25,26]. The water samples were filtered through a 45-micron laboratory filter, then acidified with concentrated nitric acid until the pH reached 2 [25,27, 28]. Each sample was kept at 4-6 °C before being sent to the laboratory.

3.1.Calculating the Drinking Water Quality Index (DWQI)

The water quality index is crucial in determining the sustainability and quality of irrigation and drinking water. It provides important data on water quality to the public and government decision-makers [29]. The process for calculating the WQI is as follows:

1. Determine each variable weight (w_i) depending on its relative importance in the overall water quality. It ranges from 1, which considers a minimum weight (i.e., has the lowest impact on water quality), to 5 which assumes a maximum weight (i.e., has the highest impact on water quality) as illustrated in Table 1. Then, the relative weight of each variable (RW_i) is computed by Eq. 1 [30]:

$$\mathrm{RW_i} = \frac{\mathrm{w_i}}{\sum_{i=1}^{n} w_i} \qquad (1)$$

where n refers to the number of variables selected (21 in this study).

2. Divide each variable's measured value by its permissible limit value to determine its rating scale (Q_i), then multiply the result by 100 using the following Eq. 2:

$$\mathrm{Q_i} = \left(\frac{\mathrm{C_i - I_i}}{\mathrm{S_i - I_i}}\right) \mathrm{x}\ 100 \qquad (2)$$

where the measured value of each variable is referred to as C_i, the ideal value for each variable is referred to as Ii (zero for all variables except pH = 7), and S_i is the standard value that was suggested by Gibrilla et al. 2011 and WHO 2017 [31, 32].

3. Multiply each variable's rating scale (Q_i) by its relative weight (RWi) to get the water quality sub-index (SI_i) value, Eq. 3:

$$\mathrm{SI_i} = \mathrm{Q_i x\ RW_i} \qquad (3)$$

4. Sum the sub-indices of all parameters, as follows, to get the DWQI, Eq.4.

$$\mathrm{DWQI} = \sum_{i=1}^{n} \mathrm{SI}_i \qquad (4)$$

The groundwater quality types are classified into five classes according to the calculated DWQI values [33], as listed in Table 2.

Table 1 Demonstrates the Relative Weight (RWi) and Weight (w_i) of Each Variable Related to the Recommendations Made by Gibrilla et al. 2011 and WHO 2017 [31, 32].

Variables	Guideline values	Unit	(w_i)	RW_i	S_i	Q_i
pH	8.5	--	4	0.056	1.6	29.3
TDS	1000	mg/l	4	0.056	13.1	236.6
Na^+	200	mg/l	2	0.028	4.0	144.1
Mg^+	30	mg/l	2	0.028	10.8	390.4
Ca^{++}	75	mg/l	2	0.028	10.9	393.5
K^+	12	mg/l	2	0.028	1.3	46.9
NO_3^-	50	mg/l	5	0.069	1.6	22.8
$SO_4^=$	250	mg/l	3	0.042	21.5	516.1
Cl^-	250	mg/l	3	0.042	4.5	108.9
U	30	µg/l	3	0.042	1.2	28.9
As	10	µg/l	5	0.069	1.5	21
B	2.4	mg/l	3	0.042	2.0	48.9
Fe	300	µg/l	2	0.028	0.4	13.9
Cr	50	µg/l	5	0.069	1.8	26
Cu	2000	µg/l	2	0.028	0.02	0.8
Mn	400	µg/l	4	0.056	4.0	71.7
Ni	70	µg/l	3	0.042	0.5	11.5
Cd	3	µg/l	5	0.069	17.7	254.5
Pb	10	µg/l	5	0.069	38.5	554.1
Se	40	µg/l	5	0.069	1.0	14.3
Zn	3000	µg/l	3	0.042	0.1	2.8
			$\sum = 72$	$\sum = 1$		

Table 2 Human Consumption-Based Guidelines for DWQI Values.

DWQI range value	Water quality	Clarification
< 50	Excellent	Good for health of human
50.1–100	Good	Suitable for human Consumption
100.1–200	Poor	Water not in good status
200.1–300	Very Poor	Need treating before use
> 300.1	Unsuitable	Need too much attention

3.2. Calculating Irrigation Water Quality

The quantity and quality of the dissolved substance in the irrigation water determine the quality of the water [34]. The access of irrigation water to the soil layers is reduced due to the high sodium ion as crops cannot absorb sufficient water from the soil under sodic condition, soil particles disperse, and clays swell as well as the toxicity of sodium to the crops, which reduce agricultural production [35]. The value of the Sodium Adsorption Ratio (SAR) for irrigator water is calculated as [36]:

$$\mathrm{SAR}\left(\frac{\mathrm{meq}}{\mathrm{l}}\right)^{0.5} = \frac{(\mathrm{Na})}{\sqrt{\frac{(\mathrm{Ca}+\mathrm{Mg})}{2}}} \qquad \textbf{(5)}$$

where Na, Ca, and Mg ions concentrations are measured in meq/l.

IWQI was investigated using the approach described in [35, 37, 38, 39] in the present work. Table 3 lists five different hydrochemical models. In order to determine whether or not groundwater could be used for irrigation, all five models were simultaneously tested and combined to produce a single value. According to Table 3, the indicator methodology assigns specific weight to each hazard category, ranging from one (for groups with the least impact on water quality) to five (for groups with the greatest impact on water quality). HNO_3^-, NO_3^-, and pH each received a weight of one based on their significance, while EC received a weight of five. Depending on their significance in the overall IWQI, the other hazard categories received weights ranging from one to five (Salinity hazard, infiltration and permeability, particular ion toxicity, Trace element toxicity, and Miscellaneous effects to sensitive cops). In this context, the salinity hazard sub-index is (SI_1), and it is calculated using Eq.(6):

$$SI_1 = w_1 \times r_1 \qquad \textbf{(6)}$$

where w is the weight value, and r is the rating value Table 3. The second hazard group (SI2) is the infiltration and permeability hazard, which is calculated using the EC and SAR values, as shown in Eq.(7):

$$SI_2 = w_2 \, X \, r_2 \qquad m \qquad \textbf{(7)}$$

where w is the weight value, and r is the rating value Table 4. As a result, the specific ion toxicity (SI3) is the third hazard group (SI3), which includes two parameters (SAR, Chloride), as shown in the weighted average Eq.(8):

$$SI_3 = \frac{w_3}{n}\sum_{j=1}^{2} r_j \qquad \textbf{(8)}$$

where j is the number of contributed parameters, w is the weight value of this group, and r is the rating value of each parameter Table 3. The fourth hazard group (SI4) is trace element toxicity, which is calculated by contributing various elements as listed in Table 5 and using the weighted average Eq.(9):

$$SI_4 = \frac{w_4}{n}\sum_{k=1}^{n} r_k \qquad \textbf{(9)}$$

where k is the number of contributed indexes, n is the total number of trace elements available for analysis, w is the weight value of this group, and r is the rating value of each parameter Table 5.

The final and fifth hazard groups (SI5) are miscellaneous effects on sensitive crops. The weighted average Eq.(10) is used to calculate this hazard using three parameters (nitrate and bicarbonate ions, and pH):

$$SI_5 = \frac{w_3}{3}\sum_{m=1}^{3} r_m \qquad \textbf{(10)}$$

Where m is the number of the contributed index, w is the weight value of this group, and r is the rating value of each parameter Table 3. Finally, Eq. (11), as shown below, is used to sum all the previous sub-indices to calculate the last value of IWQI, which is compared with the values in Table 6 which shows the suitability of the studied water resource for irrigation purposes.

$$\mathrm{IWQI} = \sum_{i=1}^{5} SI_i \qquad \textbf{(11)}$$

Where i is the number of contributed sub-indices, and SI is the hazard group sub-index.

Table 3 IWQI Parameter Rating [35, 37, 38, 39].

Hazard	Weight	Parameter	Range	Rating	Suitability
Salinity hazard	5	EC (μS/cm)	$EC < 700$	3	High
			$700 \le EC \le 3000$	2	Medium
			$EC > 3000$	1	Low
Infiltration and permeability hazard	4	See Table 4 for details			
particular ion toxicity	3	SAR	$SAR < 3.0$	3	High
			$3.0 \le SAR \le 9.0$	2	Medium
			$SAR > 9.0$	1	Low
		B (mg/l)	$B < 0.7$	3	High
			$0.7 \le B \le 3.0$	2	Medium
			$3.0 > B$	1	Low
		Cl (mg/l)	$Cl < 140$	3	High
			$140 \le Cl \le 350$	2	Medium
			$350 > Cl$	1	Low
Trace element toxicity	2	See Table 5 for details			
Miscellaneous effects to sensitive cops	1	HCO_3 (mg/l)	$HCO_3 < 90$	3	High
			$90 \le HCO_3 \le 500$	2	Medium
			$500 > HCO_3$	1	Low
		pH	$7.0 \le pH \le 8.0$	3	High
			$6.5 \le pH < 7.0$ and $8.0 < pH \le 8.5$	2	Medium
			$pH < 6.5$ or $pH > 8.5$	1	Low

Table 4 Permeability and Infiltration Risk Classification [35, 37, 38, 39].

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

Table 5 Trace Element Toxicity Classification.

Parameter	Range	Rating	Suitability
Arsenic (mg/l)	$As < 0.1$	3	High
	$0.1 \le As \le 2.0$	2	Medium
	$2.0 > As$	1	Low
Aluminum (mg/l)	$Al < 5.0$	3	High
	$5.0 \le Al \le 20.0$	2	Medium
	$Al > 20.0$	1	Low
Chromium (mg/l)	$Cr < 0.1$	3	High
	$0.1 \le Cr \le 1.0$	2	Medium
	$1.0 > Cr$	1	Low
Cadmium (mg/l)	$Cd < 0.01$	3	High
	$0.01 \le Cd \le 0.05$	2	Medium
	$0.05 > Cd$	1	Low
Copper (mg/l)	$Cu < 0.2$	3	High
	$0.2 \le Cu \le 5.0$	2	Medium
	$5.0 > Cu$	1	Low
Cobalt (mg/l)	$Co < 0.05$	3	High
	$0.05 \le Co \le 5.0$	2	Medium
	$5.0 > Co$	1	Low
Iron (mg/l)	$Fe < 5.0$	3	High
	$5.0 \le Fe \le 20.0$	2	Medium
	$20.0 > Fe$	1	Low
Lithium (mg/l)	$Li < 2.5$	3	High
	$2.5 \le Li \le 5.0$	2	Medium
	$5.0 > Li$	1	Low
Lead (mg/l)	$Pb < 5.0$	3	High
	$5.0 \le Pb \le 10.0$	2	Medium
	$Pb > 10.0$	1	Low
Molybdenum (mg/l)	$Mo < 0.01$	3	High
	$0.01 \le Mo \le 0.05$	2	Medium
	$0.05 > Mo$	1	Low
Manganese (mg/l)	$Mn < 0.2$	3	High
	$0.2 \le Mn \le 10.0$	2	Medium
	$10.0 > Mn$	1	Low
Nickel (mg/l)	$Ni < 0.2$	3	High
	$0.2 \le Ni \le 2.0$	2	Medium
	$2.0 > Ni$	1	Low
Selenium (mg/l)	$Se < 0.01$	3	High
	$0.01 \le Se \le 0.02$	2	Medium
	$0.02 > Se$	1	Low
Vanadium (mg/l)	$V < 0.1$	3	High
	$0.1 \le V \le 1.0$	2	Medium
	$1.0 > V$	1	Low
Zinc (mg/l)	$Zn < 2$	3	High
	$2 \le Zn \le 10.0$	2	Medium
	$10.0 > Zn$	1	Low

Table 6 Classifying Water Quality Index for Irrigation (IWQI) [39].

IWQI	**Water suitability for irrigation**
> 37	High
22-37	Medium
< 22	Low

3.3 Assessing Exposure Hazards to Nitrates

Various exposures; including oral and dermal contact, bathing, swimming, and washing; may negatively impact human health from groundwater contamination [13]. Eq. (12) provides a formula for the chronic daily intake (CDI) (mg/kg/day) of nitrate that is absorbed by the human body through water consumption [15, 40].

$$\mathrm{CDI} = \frac{\mathrm{C_w \ x\ EF\ x\ IR\ x\ ED}}{\mathrm{AT\ x\ \ BW}} \qquad \textbf{(12)}$$

where the exposure measured by a material's concentration per unit of body weight and time (mg/kg/day) is referred to as the CDI. The rate at which a person consumes water (l/day) is represented by IR. The nitrate ion concentration in water (in mg/l) is shown by C_w. The exposure's duration (year) is indicated by ED. The frequency of the exposure (days/year) is represented by EF. BW is the average body weight in kg, and AT is the average time (AT = 365 ED, day). The Dermal Absorbed Dose (DAD) can be calculated using Eq. 13 to assess a toxic substance's intake by the human body [15]:

$$\mathrm{DAD} = \frac{\mathrm{DA\ x\ \ SA\ x\ \ EF\ x\ \ ED\ x\ \ EV}}{\mathrm{AT\ x\ BW}} \qquad \textbf{(13)}$$

where the nitrate dermal absorbed dose (mg/kg/day) is referred to as DAD. The term "SA" refers to the area of skin that can be touched (cm^2). The frequency of bath recurrence (time/day) is EV. The exposure dose for each state (mg/cm^2) is referred to as DA. Eq.14 can be used to calculate DA, where K is the skin permeability coefficient expressed as cm/hour; C_p is the measured value of pollutants in water expressed as mg/liter; t is the bathing time expressed as hours per day, approximately 0.4 hours per day, for infants, children, and adults; and CF stands for conversion factor (l/cm^3) [41]. Table 7 lists the used variables to calculate the health risks for infants, children, and adults based on dermal and oral contact pathways.

$$\mathrm{DA} = \mathrm{K\ x\ C_p\ x\ t\ x\ CF} \qquad \textbf{(14)}$$

The hazard quotient (HQ) [42] can be used to demonstrate the non-carcinogenic effect of nitrates in groundwater through oral and dermal contact using Eqs. 15 and 16.

$$\mathrm{HQ_{oral}} = \frac{\mathrm{CDI}}{\mathrm{RfD_{oral}}} \qquad \textbf{(15)}$$

$$\mathrm{HQ_{dermal}} = \frac{\mathrm{DAD}}{\mathrm{RfD_{dermal}}} \qquad \textbf{(16)}$$

The reference dose for a specific pollutant, expressed in mg/kg/day, is referred to as RfD. It plays a crucial role in determining the assessment of non-carcinogenic risks. Table 7 shows what it should be. A value of HQ less than or equal to 1 indicates no carcinogenic risk, while a value of HQ greater than or equal to 1 indicates a carcinogenic risk [38]. An aggregate of HQ_{oral} can be used to calculate the Total Hazard Quotient (THQ), and the HQ_{dermal} is denoted by Eq. (17) [43]:

$$\mathrm{THQ} = \mathrm{HQ_{oral}} + \mathrm{HQ_{dermal}} \qquad \textbf{(17)}$$

4. RESULT AND DISCUSSION

The results of the groundwater (GW) physical and chemical variables are displayed in Table 8, and Table 9 lists the trace elements. According to the calculated DWQI, 96.67 % of all wells have poor water quality (186.2 > DWQI > 100.6) Fig. 2. As a result of the EC, TDS, and salinity fluctuation might be the interaction between rock and water and/or due to the agricultural activities [47]. The other wells, which account for 3.33 % of the total groundwater under investigation, have abysmal water (DWQI= 206.3) due to agricultural and industrial activities raising chemical standards. Fig. 3 shows the classification of irrigation water using the IWQI. In the study area, IWQI scores range from 30 to 39. As a result, 15% and 85% of groundwater wells can be used for irrigation to a medium or high degree, respectively. The oral and dermal contact pathway of children, infants, and adults was used to assess human health risk, as shown in Fig. 4. The highest HQ_{oral} value for children, infants, and adults was 1.18, 1.11, and 0.34, respectively, indicating a non-carcinogenic health risk from nitrates in groundwater for all wells, with two wells (21 and 28) having an HQ_{oral} value > 1 for infants and children. Adults, on the other hand, faced no health risks. HQ_{dermal} is shown in Fig. 5. For adults, children, and infants; all values were significantly < 1, indicating that bathing in nitrate-rich groundwater poses no health risks. When compared to HQ_{oral}, the THQ values showed slight variation (see Fig. 6).

Table 7 Variables Used in the Model of Health Risk Assessment.

Variables	Value			Ref.
	infant	Child	Adult	
BW (kg)	6.94	15	70	[44, 45]
ED (year)	0.5	12	30	[15, 13]
EF (day/year)		365		[45]
AT (day)		ED × 365		[44]
SA (cm^2)	3416	6600	18000	[44,15]
IR (l/day)	0.25	1.5	3.0	[41, 46]
EV (times/day)		1		[40]
K (cm/h)		0.001		[40]
t (h)		0.35		[40]
CF l/cm^3		0.001		[46]
RfD$_{ing.}$ (mg/kg/day)		1.6		[46]
RfD$_{der.}$ (mg/kg/day)		0.8		[46]

Table 8 GW's Chemical and Physical Variables.

Well No.	pH	Ca^{2+} mg/l	Mg^{2+} mg/l	Na$^+$ mg/l	K$^+$ mg/l	Cl$^-$ mg/l	SO$_4^{2-}$ mg/l	HCO$_3^-$ mg/l	NO$_3^-$ mg/l	TDS mg/l	EC µS/cm	SAR (meq/l)$^{0.5}$
1	7.4	303	105	170	7	330	1030	23	12.5	1991	3254	2.1
2	7.2	290	66	370	6.1	175	1256	15	13	2000	3670	5.1
3	7.3	150	45	120	2.5	104	570	42	9.67	1055	1700	2.2
4	7.2	277	90	360	4.5	287	1299	13	13.8	2450	3250	4.8
5	7.4	388	140	200	5.1	78	1588	11.9	10.1	2565	3564	2.2
6	7.1	380	85	120	1.9	65	1400	7.5	11	2080	3500	1.4
7	7.3	250	103	360	3.4	440	1055	24	9.5	2288	3652	4.8
8	7.3	386	109	184	2.76	196	1287	17.5	9.42	2211	3796	2.1
9	7.8	287	121	390	5.4	200	1445	23	10.7	2569	4120	4.9
10	7.1	300	210	303	7	500	1389	23.6	12.3	2770	4166	3.3
11	7.6	250	103	335	9.7	376	1120	23.2	11.3	2390	3660	4.5
12	7.3	266	79.5	204	13	167	1078	17	14.7	1876	3456	2.8
13	7.1	207	88	350	5.1	137	1430	36	7.6	2350	3980	5.1
14	7.6	420	140	375	3	203	2010	26.8	10.6	3245	5100	4.0
15	7.7	201	60	163	7.3	96.5	863	9.1	9.5	1413	2444	2.6
16	7.2	140	70	112	8.5	96.4	654	48.3	11	1288	2100	1.9
17	7.3	310	142	195.3	7.4	113	1499	16.9	13.6	2333	3706	2.3
18	7.4	286	167	345	4.1	487	1222	29.4	9.5	2655	4405	4.0
19	7.9	311	145	225	5.9	290	1190	16.9	11.8	2222	3456	2.6
20	7.4	299	90	209	9	365	910	12.3	10.9	2001	3252	2.7
21	7.3	250	100.4	363.5	5.1	324	1190	7.9	16.9	2300	3410	4.9
22	8.1	369	98.2	301	2.5	492	1053	27	10.9	2390	3500	3.6
23	7.3	299	128.3	229	4.3	359	1103	37.1	9.7	2210	3100	2.8
24	7.7	365	200	510	4.1	237	2300	20.6	10.8	3688	5622	5.3
25	8	205	107	354	3.1	248.3	1265	18	9.6	2650	3000	5.0
26	7.4	345	155	360	3.9	201	1933	16	11.1	3150	4680	4.0
27	7.4	392	199	449	4.8	550	1559	18.9	10.9	3222	5100	4.6
28	7.2	278	126.4	200	9.1	245	1110	21.8	18.9	2100	3009	2.5
29	7.5	219	101	388	6.9	161	1455	35.8	8.9	2400	4010	5.4
30	7.7	431	140	400	6.1	644	1445	21.3	11.2	3120	5310	4.3

Table 9 Concentrations of Trace Elements in Groundwater.

Well No.	As	Mn	Cu	Zn	Pb	Fe	Cr	Cd	Ni	U	B	Se	Al	Co	Li	Mo	V
1	2.7	8.1	40.1	102.1	144	31.2	16.9	6.8	3	7.2	0.6	8.97	87	1.68	35.1	3.9	2.1
2	1.5	600.1	11.1	69.3	31.7	33.2	12.1	2.6	5.3	12.5	1.4	4.35	45	1.41	48.9	3.6	3.3
3	2.8	889.5	17.5	77.3	43.1	54.3	10.4	23.3	11.1	10.4	1.1	5.08	354	5.01	5.4	3.3	3
4	2.4	151	8.3	111.3	18.97	32.1	6.2	12.1	5.3	12.6	1.23	6.45	42	3.36	14.7	12	2.7
5	1.5	10.9	10.1	60.3	15.9	28.9	12.3	1.45	7.1	13.1	2.9	5.67	51	1.68	29.1	8.7	2.7
6	1.7	34.9	10.3	85.9	166.12	31.2	14.9	7.3	11.8	5.9	2.98	7.01	36	1.08	43.2	12.6	2.4
7	2.6	107.5	14.3	92.1	28.56	64.2	22.1	15.23	12.7	10.1	1.65	6.29	69	6.21	24.3	7.5	4.8
8	2.8	40.1	13.5	73.3	36.89	49.9	12.1	3.12	9.2	7.2	0.56	4.56	99	4.89	22.5	8.4	3.0
9	2.1	64.98	17.8	90.3	57.3	34	14.9	3.98	9.4	8.76	1.2	5.43	63	7.17	26.4	8.7	5.1
10	1.3	17.9	33.6	58.9	27.4	31	12.8	14.87	5.1	5.23	1.3	4.38	291	5.76	32.1	9.3	4.5
11	2.7	8.6	10.1	82.7	35.2	32	10.1	4.87	6.4	7.3	0.63	8.4	123	4.62	30.9	12.3	3.6
12	1.4	9.16	10.6	62.7	39.6	33	12.6	6.56	6.4	8.3	0.68	3.5	66	4.86	29.4	8.1	2.7
13	1.6	18.78	16.5	110.4	82.5	35	14.1	4.12	7.3	9.87	0.61	2.97	186	4.32	22.8	6.6	6.0
14	3.2	2599.	6.5	122.2	21.1	40	5.7	2.1	13.2	13.2	0.27	8.123	105	7.41	39.6	17.4	2.7
15	2.8	804.3	12.4	80.3	46.97	34.7	14.6	3.21	5.7	13.1	0.3	5.3	63	5.58	20.4	14.7	2.7
16	1.7	77.1	23.3	81.1	64.1	29.8	14.8	25.2	9.3	9.2	2.5	5.23	57	3.99	11.7	9.6	3.0
17	1.6	144.9	20.1	72.5	23.3	38.6	15.3	2.87	8.7	8.34	1.2	5.8	81	1.83	29.1	4.8	3.0
18	2.7	7.67	9.9	89.6	40.1	32.1	12.9	6.21	7.4	9.9	0.62	5.7	39	1.74	47.4	6.0	5.7
19	1.8	13.78	32.4	95.6	120.4	29.6	17.6	6.12	4.9	8.65	0.61	7.34	75	6.33	27.9	11.4	5.7
20	2.3	24.9	12.8	139.6	58.4	128.	10.4	29.3	13.3	1.23	0.11	7.12	57	6.18	33.6	12.6	5.7
21	1.8	88.1	9.3	65.3	35.3	31.1	10.2	1.5	5.8	6.98	1.3	4.78	63	4.74	34.2	9.3	6.0
22	1.5	1099	12.1	86.3	96.5	39.3	11.9	2.78	6.2	8.87	1.54	6.54	138	2.97	53.4	15.3	3.0
23	2.6	204.8	10.9	60.4	100.4	92.3	14.7	13.23	12.9	5.34	0.62	12.01	81	1.74	25.2	12.0	2.1
24	1.7	16.91	17.7	90.4	55.3	32.1	13.2	5.07	8.4	9.1	0.49	5.12	48	5.52	27.9	11.4	2.4
25	1.8	11.87	9.1	71.4	28.5	30.2	16.7	1.9	5.5	5.32	1.19	5.76	45	5.16	48.9	3.6	0.9
26	2.9	51.8	18	72.3	58.3	61.2	13.9	4.56	9.3	8.65	1.67	4.67	99	4.86	31.8	10.5	3.0
27	1.2	7.98	23.5	60.4	43.2	45.3	12.7	1.54	6.3	5.34	0.51	1.59	48	1.98	44.1	8.7	2.4
28	2.6	65.8	13.9	93.4	47.9	35.8	10.3	7.5	8.9	8.67	1.87	3.7	81	6.27	23.7	9.3	4.8
29	2.1	11.4	12.2	59.3	67.98	32.4	9.5	6.97	8.6	9.5	1.56	4.23	93	5.79	38.1	7.5	3.9
30	1.7	1414	11.9	100.1	27.3	31	14.3	2.73	6.48	9.84	1.98	5.112	69	6.39	27.3	8.4	2.7

* The concentrations are all expressed in µg/L, other than B in mg/L

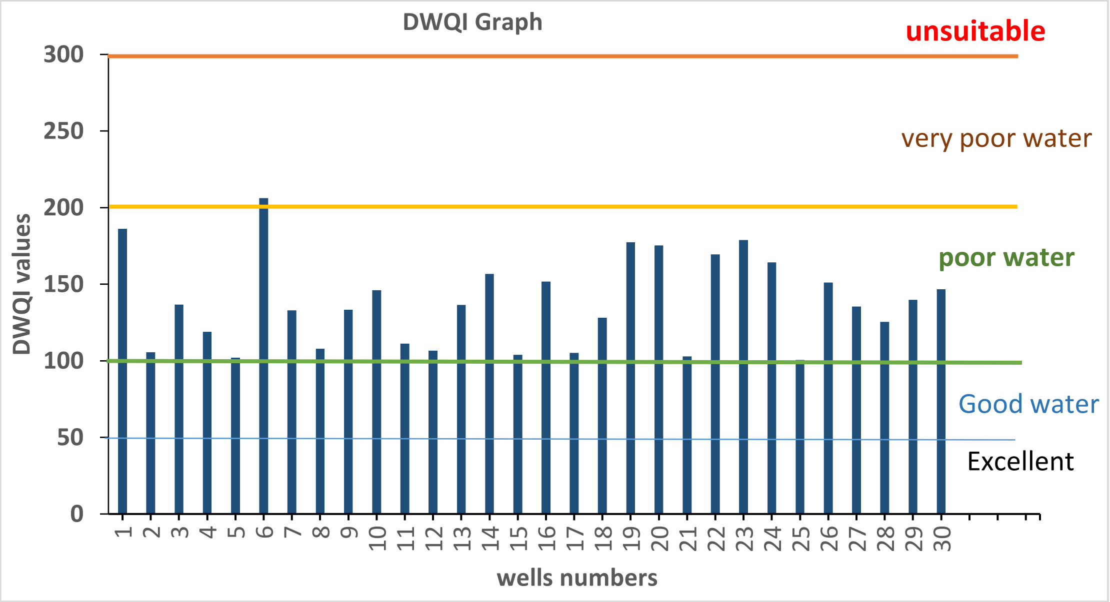

Fig. 2 The DWQI Scores for the Wells in the Study Area.

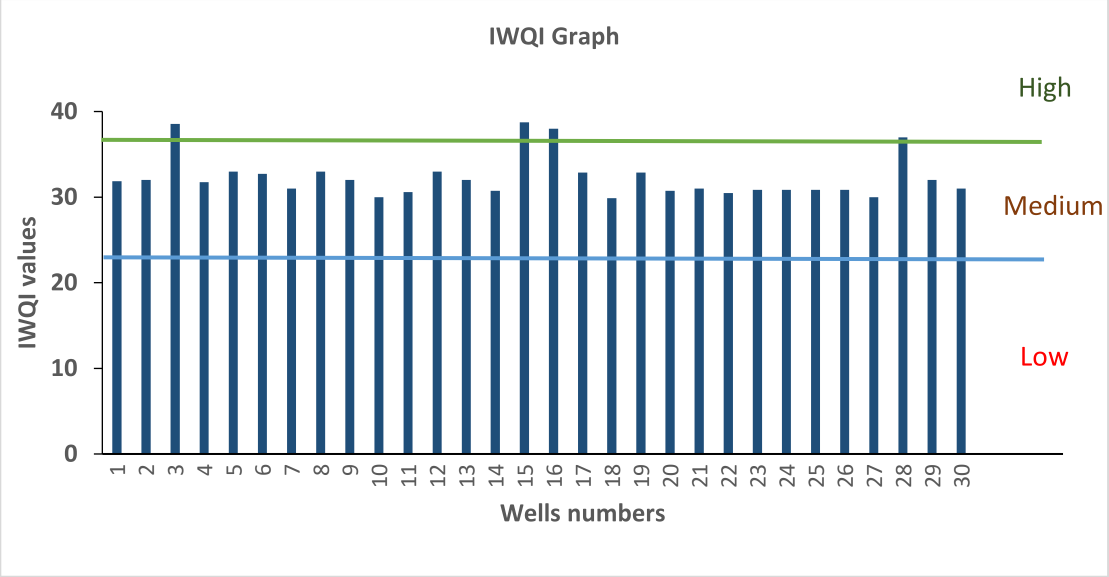

Fig. 3 The IWQI Values for the Study Area's Wells.

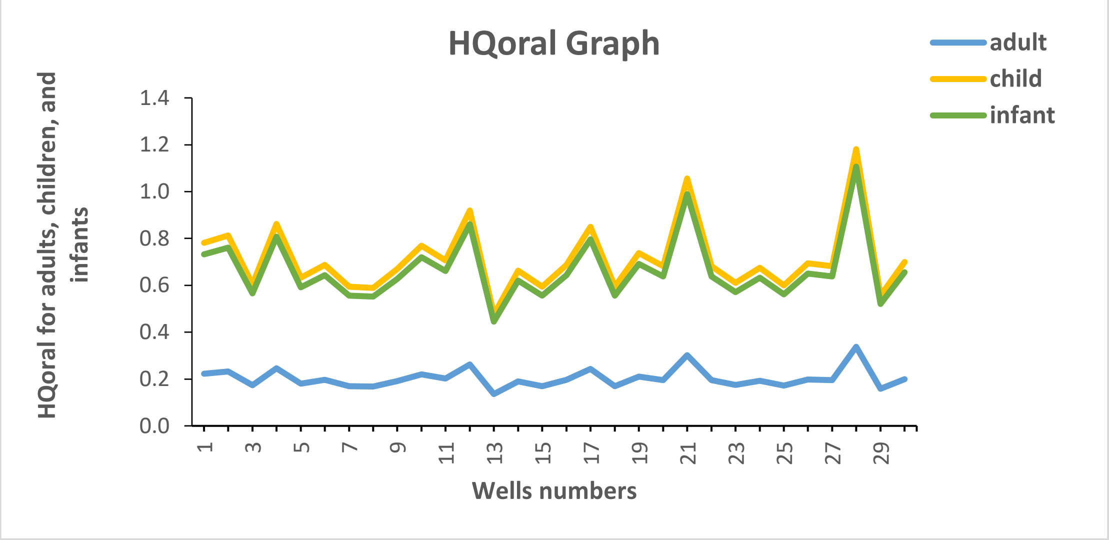

Fig. 4 An Illustration of the Hq_{oral} Graph.

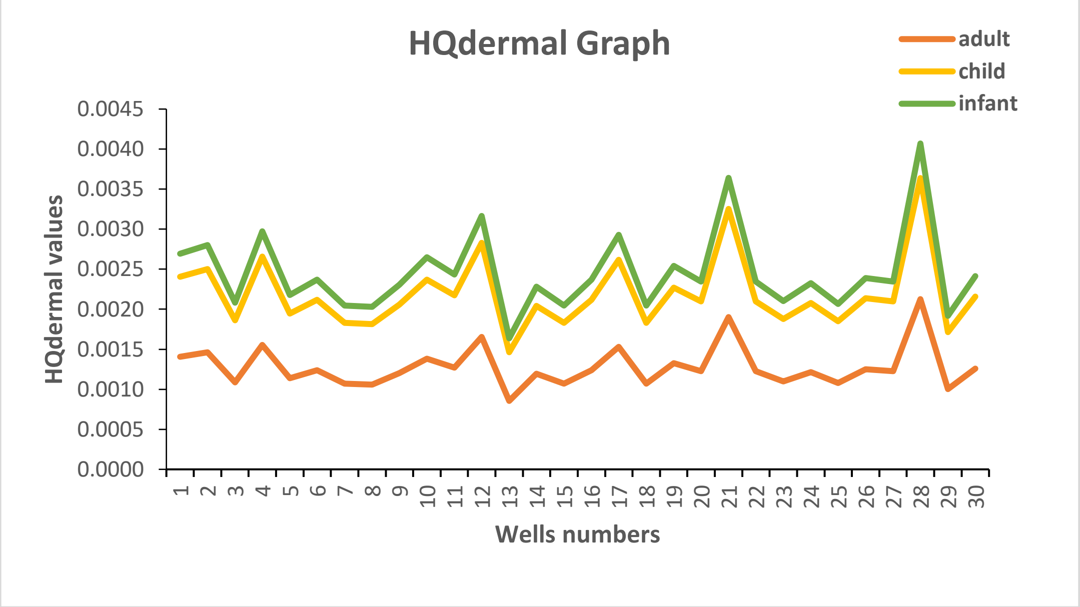

Fig. 5 An Illustration of the Hq_{dermal} Graph.

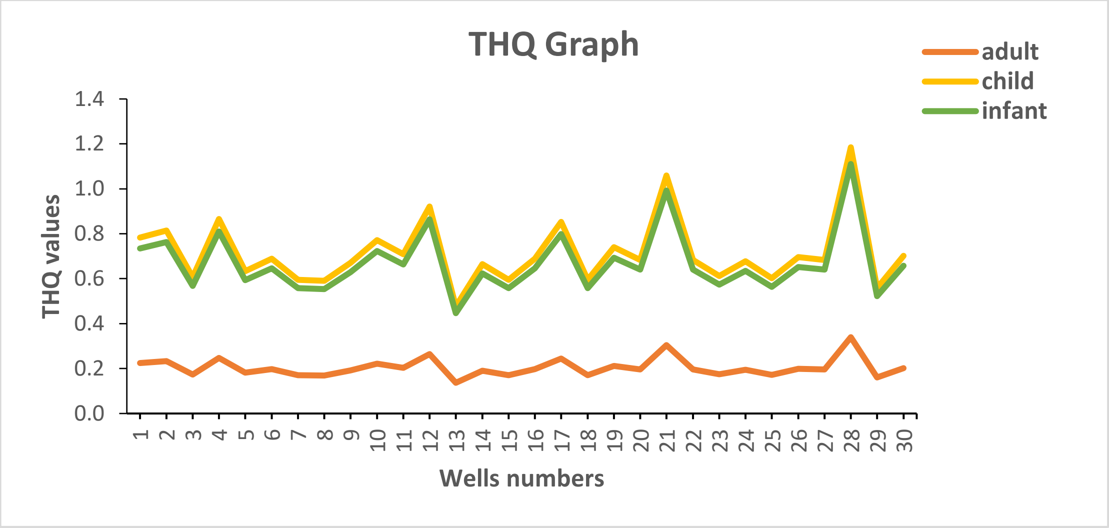

Fig.6 A Typical Graph for THQ.

5. CONCLUSIONS

WQIs were used to assess the quality of the groundwater used for drinking and irrigation, as well as the risk of nitrate exposure to the rural population in the study area. The DWQI indicated that all wells had poor water quality when used for drinking. The IWQI values demonstrated that the water's suitability for irrigation ranges from high to medium. The HQ_{oral} came from a health risk assessment that is non-cancerous. The HQ_{oral} values were less than 1, indicating that the district population would be insignificantly affected by nitrate ions in any of the studied wells, except wells 21 and 28, which had HQ_{oral} values more significant than one for children and infants only. The HQ_{dermal} values of less than one for each of the three age groups indicated that the dermal contact pathway posed no health risks.

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