



Spatial Distribution and Chemical Speciation of Some Potentially Toxic Elements in Qena Governorate Groundwater, Egypt

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Abstract

Potentially toxic elements (PTEs) distribution and speciation follow up become one of the most challenging issues in the last decades owing to their hazardous health impact. The element's species determines its toxicity, mobility, bioavailability and treatment possibility. This study focuses on the distribution and speciation of PTEs in Qena Governorate Groundwater by using GIS, MINTEQ and chemical techniques. Twenty-eight samples were collected and chemically analyzed according to standard methods. The concentrations of Fe, Mn, As, Cd, Cr, Ni and Pb were 25.95, 12.25, 8.07, 1.92, 52.35, 19.52 and 7.2 µg/L, respectively. Geochemically, the aquifer environment is reducing as appeared from negative value of Oxidation-reduction potentiality. Water-rock interaction is prevailing in this area with forward ion exchange reactions. Based on WHO specifications for drinking water, the studied samples have acceptable concentrations of Fe and Ni, but some samples have undesirable levels of Mn, As, Cd, Cr and Pb. The speciation model indicated that the studied elements occur as (HAsO₄)⁻², Cd⁺², Cr(OH)₃, PbCO₃, Ni⁺², Fe(OH)₂⁺ and Mn⁺². These species are mostly of low toxicity and aquifer chemical conditions favor the co-precipitation of elements with iron hydroxides. Even though, the water can be used safely for irrigation with respect to PTEs. The main problem facing the use of this water for irrigation is the salinity (EC > 2250 µS/cm), in 71% of the studied samples. Finally, understanding the PTEs speciation in water will help comprehending the mobility, bioavailability and health hazards.

Keywords: Speciation; PTEs; Modelling; Groundwater; West Qena.

1. Introduction

Chemical Varying concentrations of harmful elements were recorded in the Nile Valley and the Delta groundwater, and the danger of these elements to different organisms, especially human health, was indicated. Aamer et al., [1] investigated groundwater and cow milk at Qena, Sohag and Assiut Governorates and recorded unacceptable concentrations of Fe and Pb in the examined water and milk. According to Asmoay [2] the groundwater at El Minya Governorate is highly polluted with Cd and Pb to the degree of inducing carcinogenic and non-carcinogenic diseases between the residents of the study area. Mohallel and Gomaa [3] recorded 13.1-40.9 µg/L Pb in the Quaternary Aquifer in Qena Governorate. The contamination with PTEs can lead to shoot, root and production reduction in plants [4]. In human it can cause many health problems; kidney

failure, cancer, anemia, ...etc. [5].

It turned out that the element species in the environment is much more important than its total concentration, as it controls its mobility and toxicity [6]. The species of element in the environment control its mobility and toxicity; As⁺³, and Cr⁺⁶ are the toxic species of As and Cr. As⁺³ is 25–60 times more toxic than As⁺⁵ [7]. Cr⁺³ is insoluble, immobile and has low toxicity as well as considered a micronutrient in contrast to Cr⁺⁶ which is highly mobile and toxic [8, 9]. Therefore, the study of the form of an element has become of great importance in recent years to know the harmful effect of the presence of the element, as well as the extent to which it is possible to get rid of the element. It has been noted that chronic arsenic poisoning is found in areas where As⁺³ appears in groundwater. Also, the treatment of water polluted with As⁺³ is difficult because it tends to remain undissociated [10].

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Speciation of elements in groundwater can be done through the thermodynamic speciation codes as WATEQ4F [11], PHREEQC [12] and Visual MINTEQ [13]. MINTEQ is a geochemical model that has the ability to compute the equilibrium between the dissolved, adsorbed, solid, and gas phases in water [14]. Its advantage than the other codes is its easy use owing to the nice input-data file [13]. The modelling application for element speciation is widely used for prediction of elements forms in aqueous media [e.g. 15-18]. Previous studies on groundwater in the Nile valley focus on the hydrochemistry of water, its suitability for different purposes, its content of PTEs [e.g. 1-3]. This study focus mainly on PTEs speciation and spatial distribution in groundwater of Qena Governorate, in addition the suitability of water for drinking and irrigation.

2. Materials and Methods

2.1. Study area

The Qena governorate is characterized as the narrowest part of the Nile River Valley. It is located between latitudes of 25°42' to 26°18' N and longitudes of 32°00' to 33°00' E (Fig. 1). It forms a green land strip of only 1–2 km on either sides of the river, bordered by the west and east deserts on both sides. The total surface area of the Qena Governorate is estimated to be 10,798 km², which represents approximately 1.1% of Egypt's total surface area. Qena has an estimated population of approximately 3 million people according to the national Egyptian census; 21.4% of them live in urban areas and 78.6% in rural areas. Qena includes many heavy industries; sugar and aluminum and cement. The climate in the area is arid, with extremely hot and dry summers and little or no rain in the winter. Sporadic rain events do occur on occasion, although they are extremely rare.

2.2. Hydrogeological settings

Many authors studied the geology of Qena [e.g. 19-26]. Qena area (Fig. 2) covered by sediments and sedimentary rocks ranging in age from Lower Eocene to Recent.

Hydrologically, the main aquifer in the study region is the Quaternary aquifer. It consists of Pleistocene water-bearing formations overlain by Holocene sediments (recent) and underlain by Pliocene sediments. According to Abd El-Bassier [27] and Abd El Monem [28] the groundwater is

provided from Pleistocene gravely sand intercalated with clay lenses, sandwiched between Holocene clay-silt layer (aquitar) and Pliocene marine clay (aquiclude). The clay-silt layer of Holocene is absent in the reclaimed lands, hence unconfined conditions prevail underneath the desert fringes and semiconfined conditions in floodplain areas. The thickness of Pliocene clay, water bearing unit and clay silt layer was 56.5, 49.5 and 8.5 m, respectively [29]. The aquifer at desert fringes is covered by a recent Wadi Deposits formed from the reworking of pre-existing sediments and disintegration of the nearby Eocene carbonates [23]. Pleistocene aquifer is not uniform due to the impact of the fault system of the Nile, ranging from 5 and 120 m in thickness [30, 31]. Generally, the aquifer thickness increases towards the flood plain in the north-northwest direction.

2.3. Sampling and analyses

Water samples were collected from twenty-eight wells in Qena Governorate, Egypt (Fig. 1). Once the samples were collected, the temperature, pH, TDS and electrical conductivity (EC) were measured immediately in situ using calibrated HANNA HI 991300 instrument. The redox potential (Eh), also, was measured in situ using Hanna HI 98120 device. Samples were kept at 4°C in ice-box till transport into the lab. In the lab, samples were filtered using 42 µm Whatman filter paper and analyzed for chemical constituents according to APHA [33]. Volumetric analyses were applied to determine calcium (Ca) and magnesium (Mg) by EDTA, carbonate (CO₃) and bicarbonate (HCO₃) by H₂SO₄ and chloride (Cl) by AgNO₃. Colorimetric analyses were used to measure NO₃ and SO₄ by using HANNA HI 83399 spectrophotometer. Jenway PFP7 flame photometer was used to determine sodium (Na) and potassium (K). PTEs (As, Cd, Cr, Cu, Fe, Mn and Pb) were determined by Inductively Coupled Plasma (ICP Ultima 2).

Inverse distance weighting (IDW) was used to create spatial distribution maps of elements within the study area. This technique has been used to conduct environmental monitoring, understand and predict pollutant spread [34, 35]. Visual MINTEQ 3.1 software was used to predict the element phases.

Sodium absorption ratio (SAR) (Eq. 1) [36] was calculated to predict the suitability of water for irrigation (all values in meq L⁻¹):

$$\text{SAR} = \text{Na} / [(\text{Ca} + \text{Mg})/2]^{1/2} \dots\dots\dots (1).$$

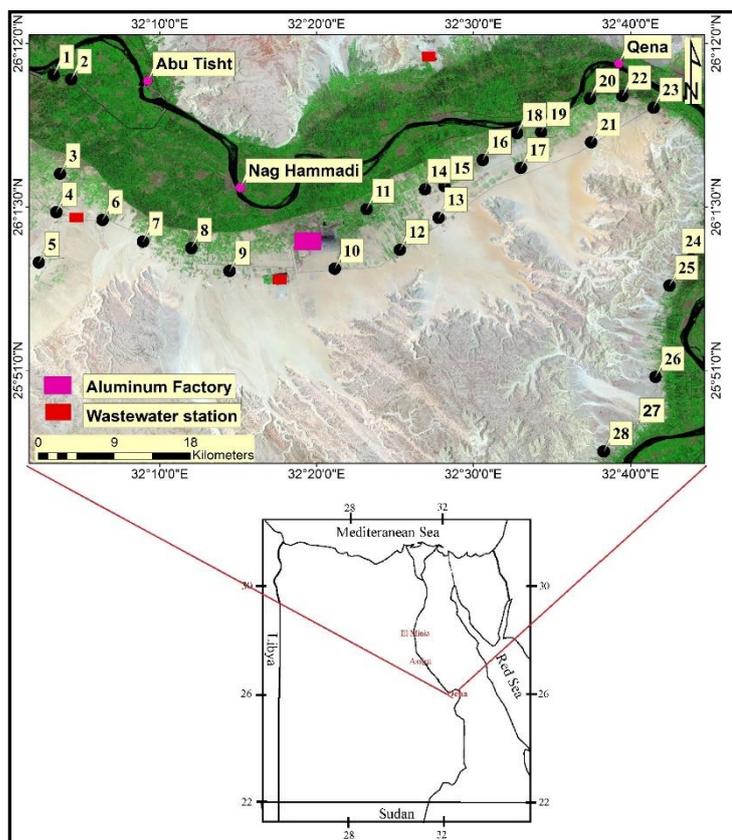


Fig. 1. Location map of the study area showing sampled wells.

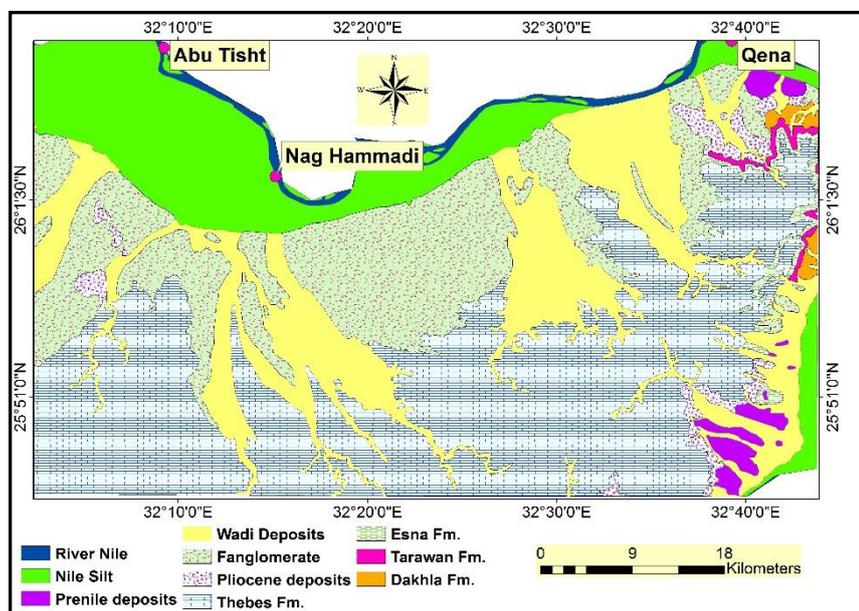


Fig. 2. Geological map of the study area (modified from [32]).

3. Results and Discussion

3.1. Groundwater hydrochemistry

The descriptive statistics of the analyzed parameters of the collected samples are illustrated in Table (1). The water was slightly alkaline with pH = 7.52±0.3, with identical temperature (T = 27.8±1.9 °C) for the sampling time. The pH range lies within the permissible limit (6.5-8.5) for drinking and irrigation. With respect to TDS, which ranged from 222.6 to 4669.4 mg/L, 82% of the studied samples were unacceptable for drinking. The salinity of water can be attributed to water rock interaction and intrusion of saline water from the underling aquifers along fault planes under over-pumping [37, 38]. The studied samples characterized by the prevailing of Na (482.3±365.5 mg/L) and SO₄ (733.5±735.2 mg/L) ions. The prevailing of this elements indicated the

dissolution of evaporite minerals (anhydrite, gypsum, halite). The molar Na/Cl>1 indicating that Na has another source than evaporites; weathering of silicates and forward ion exchange. The water-rock interactions are the contributor to the elevated concentrations of ions in the studied groundwater as shown from Gibbs [39] and End-member diagrams [40], especially silicate weathering and evaporates dissolution (Fig. 3). NO₃ ranged from 0 to 930 mg/l, the very high concentration may be resulted from the direct injection sewage wastewater into the aquifer by the residents in some places. The contamination of groundwater with NO₃ is mostly related to human activities; N-fertilizer application and sewage irrigation, and become a global problem threatening human health [41, 42].

Table 1. Descriptive statistics of the studied parameters results in comparison with MAL.

	unit	Mean	Median	SD	Min	Max	Q1	Q3	MAL-D	MAL-I
WD	m	79.1	73.0	44.2	10.0	200.0	58.0	95.5	-	-
DWT	m	27.5	29.0	14.6	3.0	57.0	15.3	36.3	-	-
pH	-	7.52	7.50	0.30	7.05	8.38	7.34	7.67	6.5 – 8.5	6.5 – 8.5
T	°C	27.8	28.4	1.9	23.5	31.2	26.3	29.4	-	-
TDS	mg/L	1981.9	1588.5	1271.2	222.6	4669.4	1080.6	2543.2	1000	-
EC	µS/cm	3967.7	3177.0	2548.5	435.2	9338.9	2161.3	5061.8	1500	2250
Eh	mV	-30.0	-25.0	20.3	-95.0	-2.0	-37.8	-17.8	-	-
TH	mg/L	463.3	378.8	334.6	96.1	1235.8	186.4	609.1	300	-
Ca		104.6	90.2	74.8	21.8	260.7	43.1	129.7	75	-
Mg		87.2	70.9	63.6	18.0	247.3	34.3	113.9		-
Na		482.3	365.3	365.5	28.3	1587.5	239.1	613.3	250	-
K		6.1	4.0	5.0	1.5	24.0	3.0	7.3		-
HCO ₃		303.7	299.4	105.9	151.3	676.0	235.8	343.5		-
SO ₄		733.5	480.0	735.2	11.0	2920.0	263.8	1048.0	250	-
Cl		339.1	263.2	254.5	7.5	840.1	175.8	453.3	250	-
CO ₃		7.3	0.0	12.7	0.0	46.5	0.0	11.6		-
NO ₃		108.1	37.0	212.4	0.0	930.0	13.5	77.0	50	-
Fe	µg/L	25.95	0.00	65.03	0.00	338.00	0.00	29.05	300	5000
Mn		120.25	4.90	314.85	0.00	1320.90	1.30	43.48	400	200
As		8.07	8.00	7.65	0.00	20.00	0.00	11.25	10	100
Cd		1.92	1.80	0.98	0.30	4.00	1.18	2.20	3	10
Cr		52.35	29.10	65.79	0.00	311.80	16.58	63.65	50	100
Ni		19.52	19.80	4.68	10.30	28.60	15.98	22.38	70	200
Pb		7.20	8.15	4.88	0.00	18.00	3.95	9.45	10	5000
Error	-	2.2	3.2	2.5	-4.5	4.6	1.6	4.1	±5	±5
SAR	-	8.7	8.3	4.8	1.0	19.4	5.5	10.6	-	10
r(Na/Cl)	-	2.98	2.36	2.31	0.72	12.23	1.55	3.97	-	-

SD: Standard deviation

WD: Well depth

DWT: Depth to water table

Q1: 1st quartile (25% of samples)

Q3: 3rd quartile (75% of samples)

MAL-D: maximum allowable limit for drinking (after WHO 2017) [43]

MAC-I: Irrigation water allowable concentration according to USDA [44].

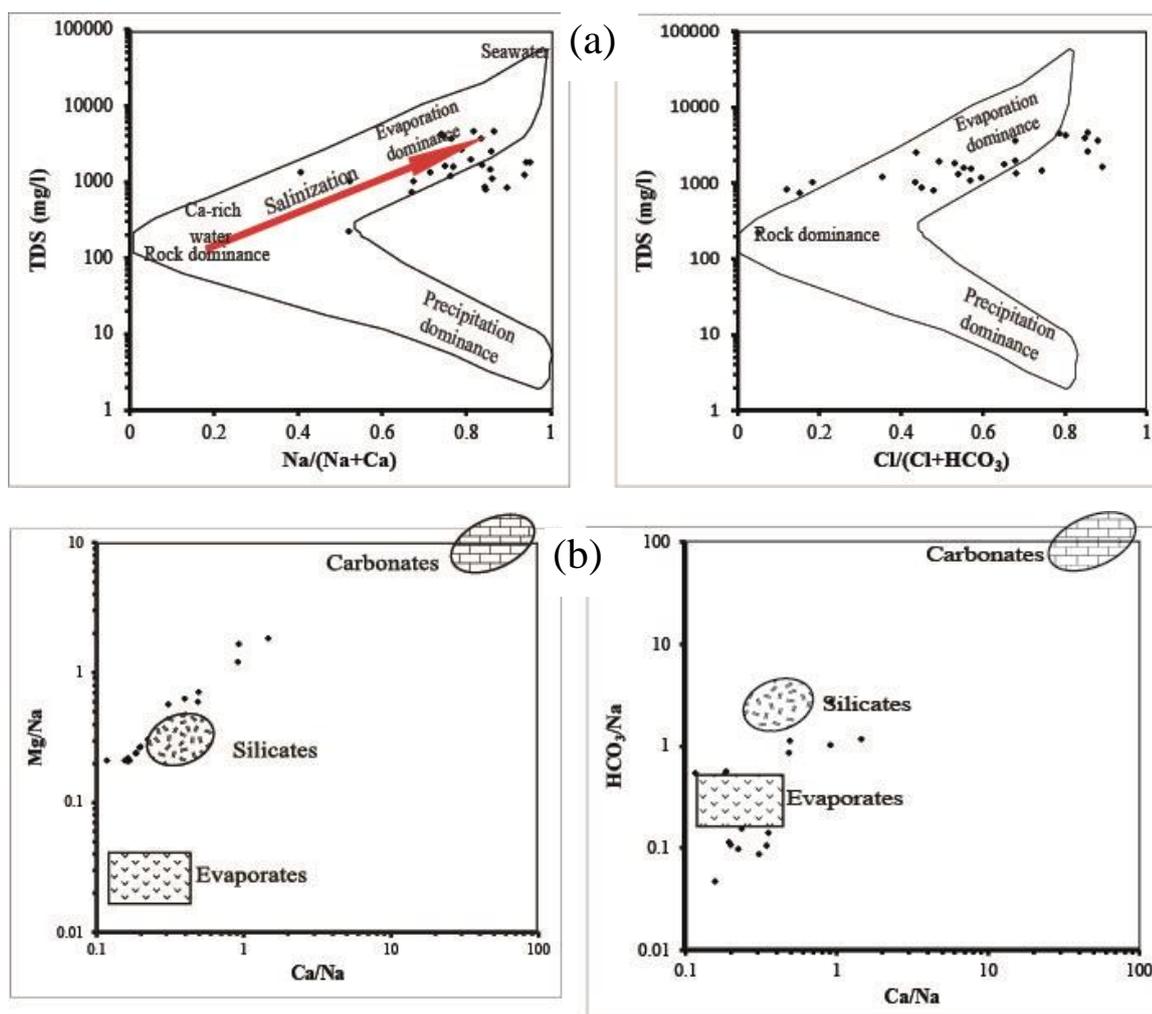


Fig. 3. (a) Gibbs and (b) End-member diagrams showing main water-rock interaction.

The concentration of As, Cd, Cr, Ni, Pb, Fe and Mn (Table 1) was 8.07, 1.92, 52.35, 19.52, 7.2, 25.95 and 120.25 $\mu\text{g/L}$, respectively. Worldwide background of these elements in natural water was 2, 0.03, 1, 1.5, 3, 100 and 15 $\mu\text{g/L}$, respectively [45]. Accordingly, the studied elements were enriched in the studied groundwater except Fe. Abd El Raheem [46] found that the water bearing sediments in the Nile Valley contain 15017 – 24746, 200 – 290, 1.68 – 2.39, 0.28 – 110.4 and 10.73 – 26.75 $\mu\text{g/g}$ of Fe, Mn, Cd, Cr and Pb, respectively. The Nile Valley sediments are enriched in As, Cd, Cr and Ni [47] most of As is present in the mobile fraction and can easily filtrate into groundwater [6]. Omer [48] found that the distribution pattern of Fe and Mn in the groundwater of the Nile Valley is mainly controlled by the composition of water bearing sediments. The anthropogenic contribution to the occurrence of As, Cd, Cr and Pb is appeared from the significance positive correlation of them with NO₃ (Fig. 4). The

occurrence of As in groundwater become a worldwide problem, where the people (>137 million capita) in 70 countries consume groundwater polluted with As [49, 50]. It was observed, worldwide, that the Late Pleistocene to Holocene aquifers has high As groundwater [51, 52]. Many samples have desirable concentrations of As, Cr and Pb (50%, 29% and 18% of the studied samples, respectively) for drinking. The exposure to the polluted water with these elements can cause many health problems such as kidney, lung and liver damage [53].

The spatial variations in TDS, As, Cd, Cr, Ni, Pb, Fe and Mn were mapped (Fig. 5). The results revealed the irregular spatial distribution of these parameters. The TDS increases southeastwards, reflecting the impact of the leachate effects from the marine deposits which occur in this area. As and Cr increased in the central part of the study area near the industrial area. Cd, Ni, Fe and Mn increase eastwards. The increase of Fe, Mn and Ni in this

direction may be related to the occurrence of sediments rich in ferromagnesian minerals. Pb has its special distribution, where it increases westward.

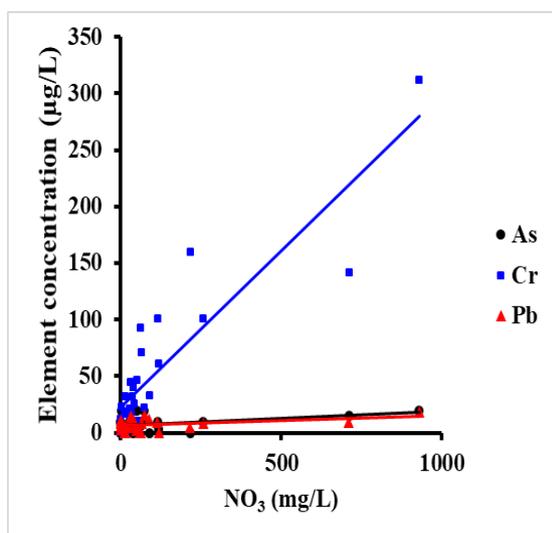


Fig. 4. Relationship between NO₃ and As, Cr and Pb.

3.2. Potentially toxic elements speciation

The distribution of chemical species plays the essential role in the process of element adsorption as metal ions in the free ionic and inorganic states will be bioavailable and hence toxic [54]. The Visual Minteq model has extracted the forms of the studied PTEs in groundwater (Table 2). The dominant form of As was HAsO₄⁻² owing to the high pH value (>6.9) of the studied groundwater. The prevailing of this As⁺⁵ forms has good implication for the As elimination from water [55].

Generally, about 53.54% of the total Cd exists as mobilized Cd²⁺ ions, and the rest of Cd are in the form of CdCO₃, CdHCO₃⁺, CdCl⁺, and CdSO₄. Cd concentrations in groundwater are controlled by co-precipitation and sorption rather than chemical equilibrium [56]. Unlike all other elements, with co-precipitation and sorption reactions Cd remains dissolved as a complex anion (e.g. CdCl⁺ and (CdSO₄)₂⁻²), and dissolved organic matter, this behavior makes it one of the most mobile elements in the environment [57]. With the increasing of pH, Cd become less mobile and precipitate as carbonate mineral otavite (CdCO₃) and sorbet by clay minerals and Fe-oxyhydroxides/oxides [58].

Chromium has two important species Cr⁺³ and Cr⁺⁶; Cr⁺³ is essential species for biological functions, while Cr is a highly toxic species. The recorded species in the studied ground water were mainly Cr(OH)₃ (89.65%), Cr(OH)₂⁺¹ (8.73%) and CrOH⁺² (1.53%) all of Cr⁺³. The occurrence of Cr⁺⁶ in the quaternary aquifer of the Nile Valley is limited (about 10.6% of total Cr) and linked to anthropogenic activities [35].

Lead (Pb) is the second priority toxic element known till now [59]. About 70.5% of the recorded Pb is present in the less soluble aqueous forms; PbCO₃ (65.46%) and PbSO₄ (4.84%). Unfortunately, about 30% appear in free ionic forms which can be mobilized easily and bioavailable.

The toxic effects of Ni on organisms, depend on its total concentration, species, physical form and exposure route [60]. It was found that the toxic effect of Ni is raised from Ni⁺² species at pH<7.6 [17]. The main recorded species of Ni in the studied groundwater were Ni⁺², NiHCO₃⁺, NiSO₄ and NiCO₃, with Ni⁺² as the dominant species, 56.93% of the total concentration (Table 2). The recorded species (except Ni⁺²) haven't any health impacts at various pH gradients [17]. It was observed that the concentration of Ni is decreased with pH increasing (Fig. 6h), and this support strong impact of pH on Ni speciation and concentration.

The most abundant PTEs in the environment are Fe and Mn; with different oxidation states based on the redox conditions. Therefore, the redox conditions are the main controller of Fe and Mn aquatic cycle and their transformation from soluble reduced forms to the insoluble oxides [61]. The most dominant forms of Fe are Fe⁺² (at pH<7 and Eh<110 mV) and Fe⁺³ (Fe(OH)₃) (at pH>7 and Eh>110 mV). The occurrence of Fe(OH)₃ has special interest, because indicated that the chemical reactions are start to control by Fe⁺³ instead of Fe⁺². Also, Fe(OH)₃ precipitates and co-precipitates with other elements, and hence considered as excavator of other elements. Generally, the iron hydroxide occurrence leads to an increase in the number of surface sites available to absorb charged species and to reduce their concentration in water. It will also help to form colloidal particles that include humic and fulvic materials [62].

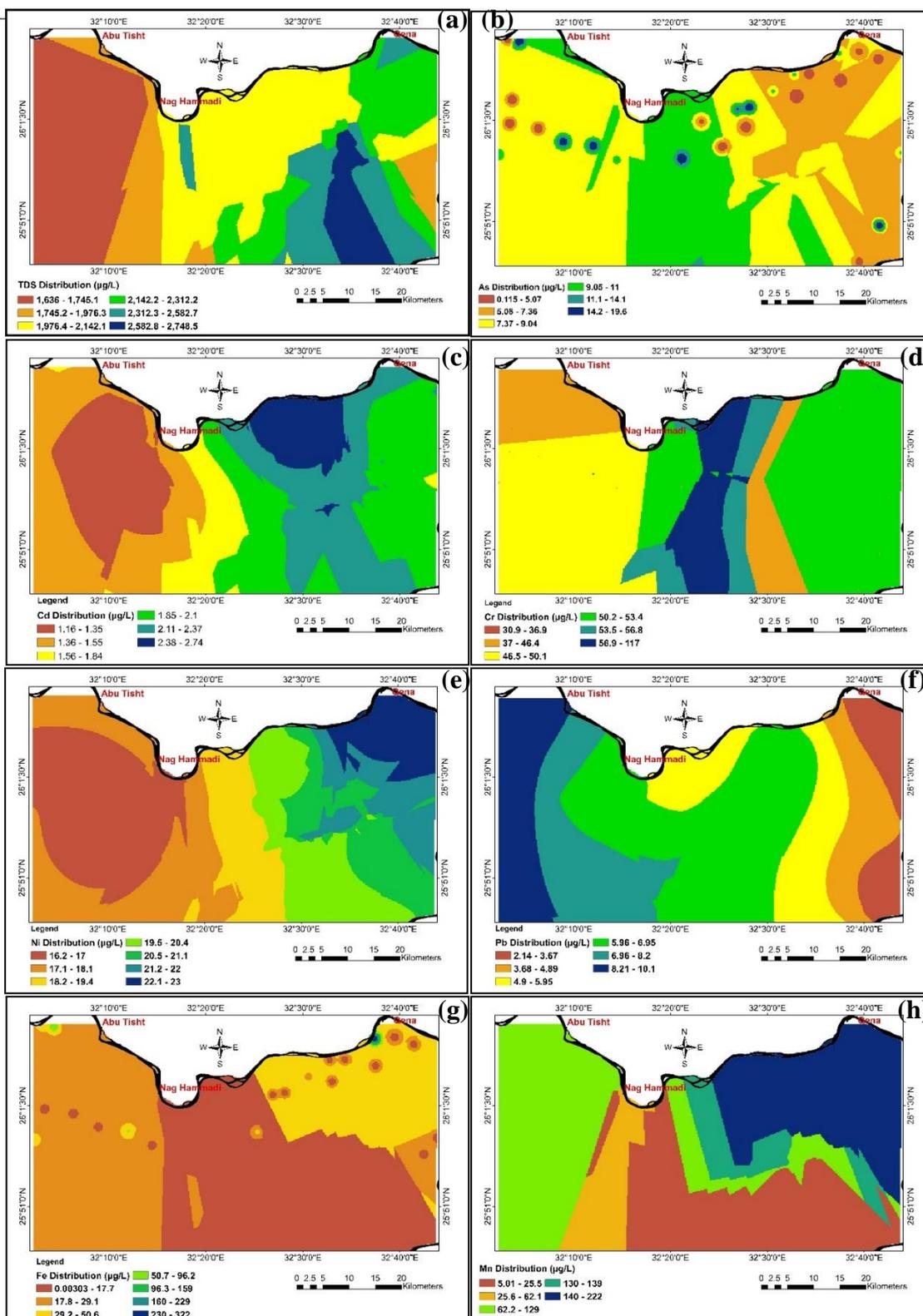


Fig. 5. Thematic maps showing the spatial distribution of (a) TDS, (b) As, (c) Cd, (d) Cr, (e) Ni, (f) Pb, (g) Fe and (h) M

Table 2. Recorded species of the studied elements in groundwater.

Element	Species	Min	Max	Average	Element	Species	Min	Max	Average	
As	(AsO ₄) ⁻³	0.01	0.08	0.03	Ni	Ni ⁺²	33.43	73.16	56.93	
	(HAsO ₄) ⁻²	64.60	97.96	83.30		(NiOH) ⁺	0.05	1.38	0.30	
	(H ₂ AsO ₄) ⁻	1.95	35.40	16.68		Ni(OH) ₂ (aq)	0.01	0.48	0.15	
Cd	Cd ⁺²	30.80	79.42	53.54		(NiCl) ⁺	0.02	0.27	0.12	
	(CdOH) ⁺	0.02	1.13	0.21		Ni(OH) ₂ (aq)	0.02	0.02	0.02	
	Cd(OH) ₂ (aq)	0.02	0.03	0.02		NiSO ₄ (aq)	0.42	32.73	13.02	
	(CdCl) ⁺	0.89	42.98	17.78		Ni(SO ₄) ₂ ⁻²	0.01	0.03	0.02	
	CdCl ₂ (aq)	0.02	3.02	0.93		NiNO ₃ ⁺	0.02	1.01	0.12	
	CdSO ₄ (aq)	0.64	29.13	12.72		NiCO ₃ (aq)	1.68	48.56	11.95	
	(Cd(SO ₄) ₂) ⁻²	0.04	8.88	1.84		NiHCO ₃ ⁺	7.87	31.44	17.57	
	(CdNO ₃) ⁺	0.01	0.73	0.10		Fe	FeOH ⁺²	0.01	0.09	0.04
	(CdHCO ₃) ⁺	1.26	10.58	4.53			Fe(OH) ₂ ⁺	39.09	99.20	89.92
	CdCO ₃ (aq)	0.68	40.16	8.59	Fe(OH) ₃ (aq)		0.56	7.63	2.37	
	(Cd(CO ₃) ₂) ⁻²	0.01	2.81	0.32	Fe(OH) ₄ ⁻		0.16	55.01	7.67	
	Cr	(Cr(OH) ₂) ⁺¹	0.60	18.91	8.73	Mn	Mn ⁺²	32.85	83.36	65.60
(CrOH) ⁺²		0.02	5.30	1.53	MnCO ₃ (aq)		2.60	61.77	17.19	
Cr(OH) ₃ (aq)		74.58	99.25	89.65	MnOH ⁺		0.01	0.25	0.06	
(Cr(OH) ₄) ⁻		0.01	0.15	0.04	MnCl ₂ (aq)		0.01	0.03	0.02	
CrOHSO ₄ (aq)		0.02	1.55	0.29	MnCl ⁺		0.01	0.81	0.31	
Pb	Pb ⁺²	0.58	17.92	7.23	MnSO ₄ (aq)		0.35	33.47	13.55	
	PbOH ⁺	1.39	5.83	3.54	MnNO ₃ ⁺		0.01	0.70	0.09	
	Pb(OH) ₂ (aq)	0.01	0.69	0.10	Mn(NO ₃) ₂ (aq)		0.02	0.02	0.02	
	PbCl ⁺	0.02	5.26	1.66	MnHCO ₃ ⁺		1.31	6.67	3.24	
	PbCl ₂ (aq)	0.01	0.16	0.08						
	PbSO ₄ (aq)	0.02	17.11	4.84						
	(Pb(SO ₄) ₂) ⁻²	0.01	11.89	0.80						
	(PbNO ₃) ⁺	0.01	1.26	0.14						
	Pb(NO ₃) ₂ (aq)	0.01	0.02	0.01						
	(Pb(CO ₃) ₂) ⁻²	0.28	20.82	3.37						
	PbCO ₃ (aq)	38.10	83.77	65.46						
	(PbHCO ₃) ⁺	1.08	28.33	13.33						

The environmentally and biologically important oxidation states of Mn are +2, +4, and +7 [63], of Mn⁺² and Mn⁺⁷ are chemically stable and soluble forms while Mn⁺⁴ is insoluble. The most naturally occurring form is Mn⁺², and in the presence of dissolved oxygen, bacteria and chlorine, it is oxidized and precipitated as MnO₂ [64]. The Mn species often occurs with Fe⁺³ as indicated by the significant correlation between Fe and Mn (Fig. 6i).

A Pourbaix diagram (Eh-pH) for an element [65] explains some of the most important features of its chemistry. It represents the formulation of the equilibria of all possible thermodynamic reactions in electrochemical systems in aqueous solution [66, 67]. According to the Pourbaix (Eh-pH) diagrams (Fig. 6a-g) under the standard conditions, the forms of As, Cd, Cr, Ni, Pb and Mn in the study area were (HAsO₄)⁻², Cd⁺², Cr(OH)₃, Ni⁺², PbCO₃ and Mn⁺², respectively which were in agreement with the results calculated by Minteq software. While Figure (6f) shows that Fe occurs in two forms Fe⁺² and Fe(OH)₃

indicating the direction of forming of hydroxides in water and the presence of the two forms owing to the well depth and reducing conditions.

3.3. Suitability for irrigation

These wells were constructed mainly for irrigation and desert fringes reclamation. One of the most important factors affecting the suitability of water for irrigation is salinity and the sodium hazard. To find out how dangerous sodium is, SAR (Sodium Absorption Ratio) was calculated. Salinity results (EC, Table 1) ranged from 435.2 to 9338.9 μS/cm, indicated that most of the water is unacceptable for

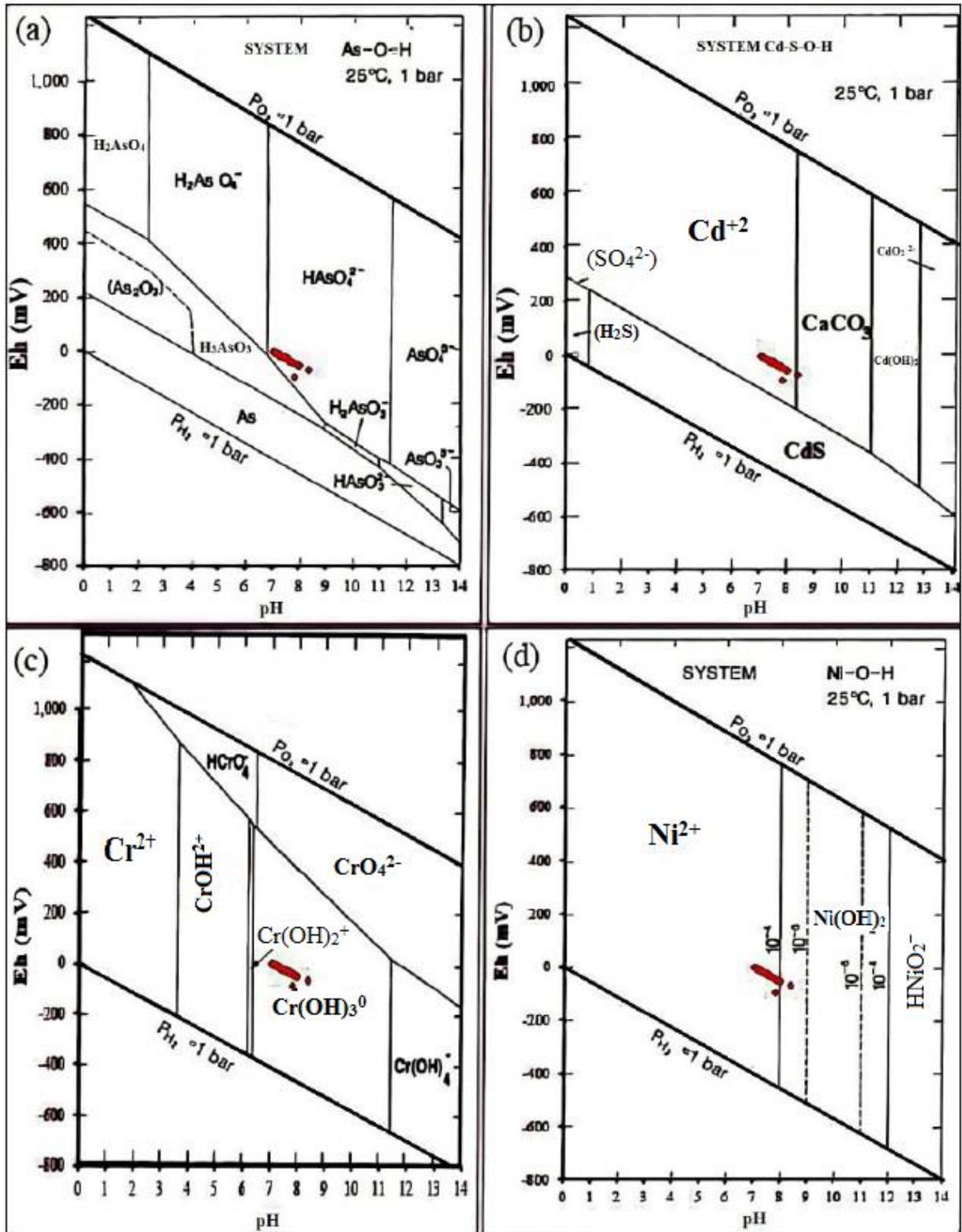


Fig. 6. Eh-pH diagrams for (a) As, (b) Cd, (c) Cr and (d) Ni, (e) Pb, (f) Fe, (g) Mn, and relationship (h) between pH and Ni, (i) Fe and Mn.

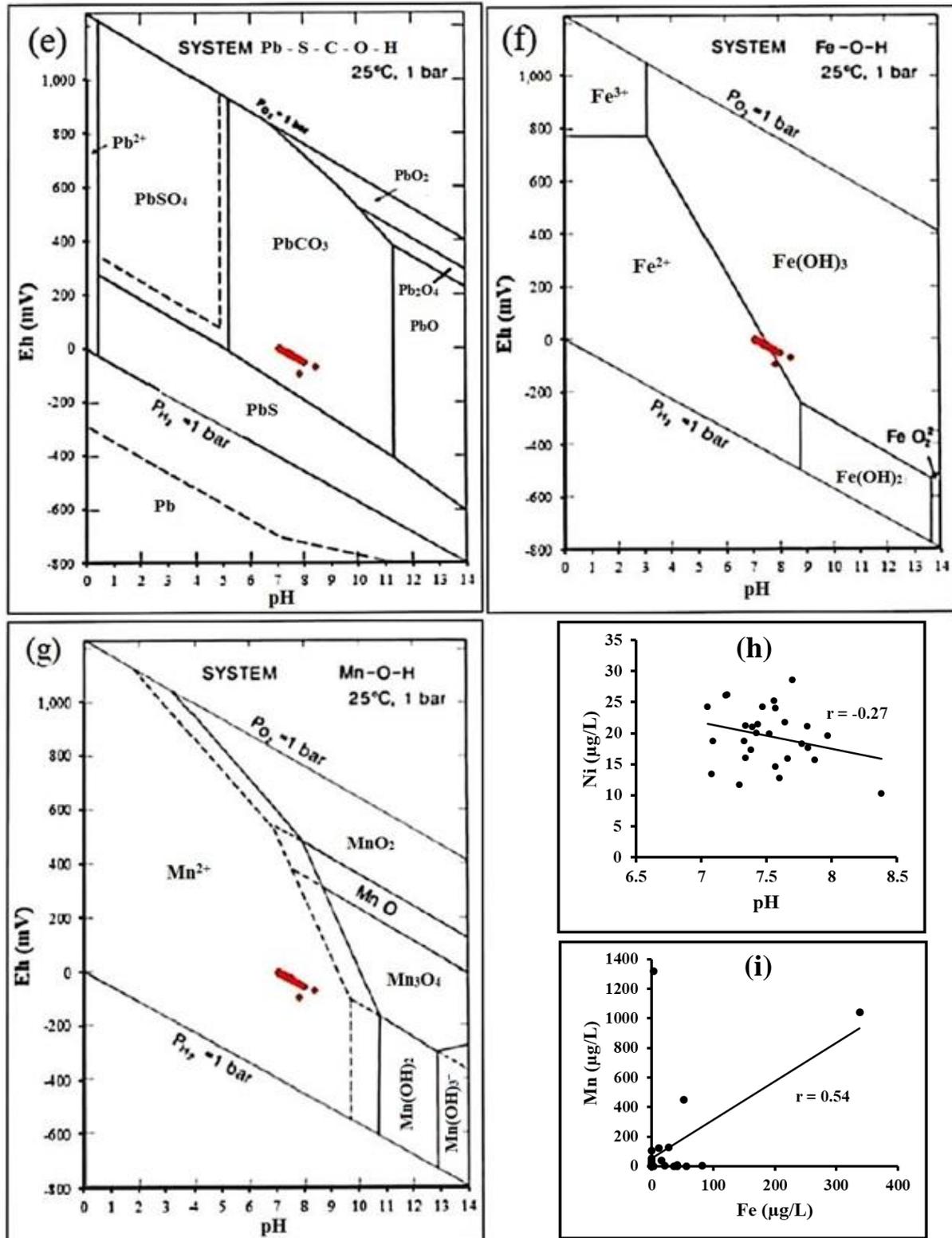


Fig. 6. (continued)

irrigation (Table 3). The calculated SAR ranged from 1 to 19.4 (Table 1), indicated that about 75% of samples are of low SAR hazard (Table 3) and can be used safely for irrigation. The results were plotted on USSL (EC-SAR) diagram to indicate the validity of the water for irrigation. The diagram (Fig. 7) shows that 8 samples are unsuitable for irrigation (lies in C4-S4 class). The samples lie in classes C2-S1 (1 sample), C3-S1 (3 samples) and C3-S2 (4 samples) can be used safely for irrigation, the rest of samples can be used for irrigating good drained soil and salt-tolerable plants.

Even though, the appearance of As, Cd, Cr, Ni, Pb, Fe and Mn in the studied groundwater, their concentrations were far away from the maximum allowable concentration for irrigation (Table 1). So, the studied water can be used safely for irrigation with the continuous monitoring of PTEs concentrations.

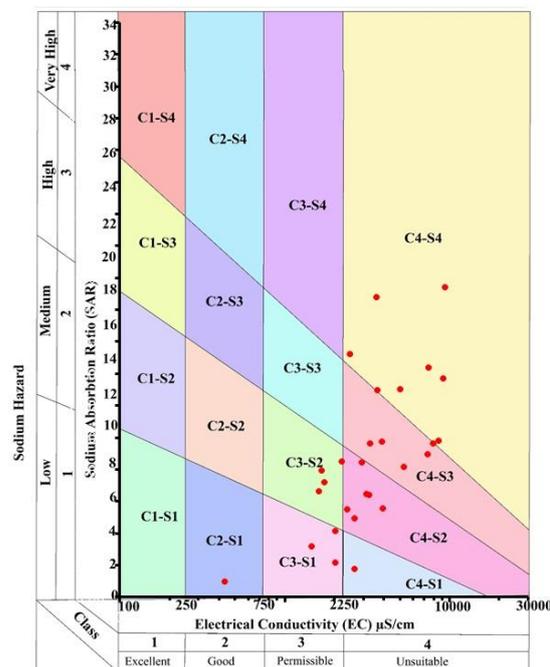
Table 3: Classification of groundwater samples for Irrigation use based on EC and SAR [36].

	Parameter Values	Class	Accepted samples
EC	<250	Excellent (C1)	---
	250 - 750	Good (C2)	1
	750 - 2250	Permissible (C3)	8, 9, 11, 13, 20, 22, 23,
	>2250	Unsuitable (C4)	2-7, 10, 12, 14-19, 21, 24-28
SAR	0 - 10	Low sodium water (S1)	1, 3-5, 8-15, 17-23, 26, 27
	10 - 18	Medium sodium water (S2)	6, 7, 16, 25, 28
	18 - 26	High sodium water (S3)	2, 24
	>26	Very high salinity (S4)	---

4. Conclusions

The Quaternary reservoir in western Qena Governorate suffers from a high percentage of salts and most of the samples are not suitable for human use. Most of the samples are dangerous for crop irrigation and need well-drained soil and salt-resistant plants. It is preferable to use drip irrigation instead of flood irrigation to avoid the effects of salts. The samples contain different concentrations of PTEs, which were found not to represent any danger to the use of that water for irrigation. These elements exist in different species; especially free ions (Cd, Mn and Ni), oxides (As), hydroxides (Cr and Fe), and

carbonates (Pb). The species of the element controls its mobility and toxicity. Fortunately, the studied elements exist in non-mobile forms and have limited toxicity. This work highlighted the importance of studying the species of elements, rather than their



total concentration, to determine the extent of their environmental danger.

Fig. 7. USSL diagram for irrigation water quality.

5. Conflicts of interest

There are no conflicts to declare

6. Formatting of funding sources

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