

Hydrogeochemistry and lead contamination of groundwater in the north part of Esfahan province, Iran

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ABSTRACT

Geochemical and hydrogeochemical studies were conducted to assess the origin and geochemical mechanisms driving lead enrichment in groundwaters of semi-arid regions in Central Iran. In this study, 149 water samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS). Concentrations of Pb and As in about 68% and 27% of the samples, respectively, exceeded WHO guidelines. Analyzing the results of ICP-MS of parental rocks and aquifer sediments shows that unweathered volcanic rocks were the primary source for lead mobilizing to groundwaters.

Key words | groundwater, hydrogeochemical, ICP-MS, Iran, lead

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INTRODUCTION

Water shortage has become an increasingly serious problem in Iran, especially in arid and semi-arid zones. To provide safe water for drinking, domestic use, industry and agriculture, exploitation of groundwater has increased dramatically since 2000. Groundwater makes up 20% of the world's fresh water supply (Khanam & Singh 2014) and plays an important role in strengthening the economic growth of developing countries, like Iran (Kumar *et al.* 2017). It is necessary to identify the processes that are responsible for groundwater chemistry for sustainable development and effective groundwater management (Jeevanandam *et al.* 2007; Yang *et al.* 2016). Although some heavy metals (e.g., Cu, Mn, and Cr) are essential for humans, their presence in excess amounts may be toxic. However, some metals (e.g., As, Hg, Cd, and Pb) are highly toxic at very low concentration with no known benefit for human health (Saha *et al.* 2017). High arsenic and fluoride contaminated groundwater is common and

widespread with documented evidence from many parts of the world (Mukherjee-Goswami *et al.* 2008; Hoang *et al.* 2010; Reilly *et al.* 2010; Selim Reza *et al.* 2010; Kim *et al.* 2011; Pazand & Javanshir 2013), but few studies have been conducted on groundwater quality assessment and risk caused by Pb. The World Health Organization suggests a permissible value of 10 µg/L for lead in drinking water (WHO 2004). The maximum concentrations found in water are related to acidic water (Jordana & Batista 2004). The United States Environmental Protection Agency estimates that approximately 20% of human exposure to lead is attributed to lead in drinking water (Jordana & Batista 2004). Pb is a bio-accumulative and highly toxic element that can cause irreversible damage to body organs such as kidneys and the nervous and reproductive systems (Todd *et al.* 1996). A few studies have reported the occurrence of high lead concentrations (>10 µg/L) in the groundwater of Iran (Fazel *et al.* 2010; Tavassol &

Gopalakrishna 2014; Meghdad *et al.* 2015; Alzamlr & Sobhanardekani 2016). In contrast to groundwater availability, groundwater quality has received little attention in North Esfahan, and the available data indicate that groundwater resources are frequently exposed to Pb contamination. Thus, the aims of this study were to understand the geochemical compositions of groundwater to determine the extent of water–rock interaction, elucidate the relationships between Pb and other parameters for better understanding of the geochemical processes and factors controlling mobilization of Pb in aquifers of North Esfahan area, Central Iran.

MATERIALS AND METHODS

Geological and hydrogeological setting

The study area is located in the northern part of the central basin of the Iranian plateau covering the Dagh-e-Sorkh playa. The area surrounding the playa is mainly composed of Eocene volcanic and pyroclastic rocks (Figure 1). The North Esfahan region is arid with hot, dry summers and cool winters, with low, irregular rainfall between 100 and 120 mm per annum. The playa is a flat (relief below few meters) area, on which vegetation is sparse and its environment contains shrubs and sprigs (Pazand *et al.* 2016). In the Oligocene–Miocene epoch, marl, limestone, sandstone, shale, and gypsum units known as Qom Formation, become widespread in this area, and even more extensive in depressions. In the Late Miocene epoch, deposition of sandstone, marl, conglomerate, and evaporate rocks known as the Upper Red Formation developed in a molasses-type condition of a sedimentary environment as a result of slow positive movement of the basin (Babaahmadi *et al.* 2010). The study area is a hydrologically closed basin located in northeastern Ardestan, Iran (Figure 2). From the hydrogeological point of view, the most important water resources are found associated with alluvial aquifers in the alluvial plains and in non-carbonate aquifers in the mountain areas. Water circulation in volcanic rocks can lead to hydrological complexes of relative importance and is related to fractures, cooling joints, or unconformities between lava flows (Dinelli *et al.* 2012).

Sampling procedures and field analyses

A total of 148 groundwater samples from pits (from Dagh-e-Sorkh playa), springs, wells and aqueducts were collected during the period of June 2014 to July 2014 in the study area. The geographical location of the sampling sites is shown in Figure 2. The samples were collected and stored in 100 mL polyethylene bottles.

The bottles were rinsed several times with deionized water followed by three times with the groundwater to be sampled to minimize the chance of any contamination prior to being filled with groundwater samples. The water samples from bore wells were collected after pumping out water for about 10 min to remove stagnant water from the wells. Immediately after sampling, pH, Eh, dissolved oxygen concentration, electrical conductivity (EC), and total dissolved solids (TDS) were measured in the field using a multi-parameter portable meter (HACH, Germany). At each site, the pH electrode was calibrated using two buffers (Merck, Germany) that bracketed the measured pH and that were thermally equilibrated with the water sample. The samples for the determination of metals were vacuum filtered through a 0.45 μm pore size membrane, acidified to a final concentration of about 1% nitric acid. Titration techniques with HCl were used to analyze total alkalinity ($\text{HCO}_3^- + \text{minor CO}_3^{2-}$). Chloride (Cl^-) was determined by the standard AgNO_3 titration method and sulfate (SO_4^{2-}) by spectrophotometric turbidimetry. Cations and other major and trace elements were measured by inductively coupled plasma mass spectrometry (ICP-MS) in the filtered and acidified water samples within 2 weeks of sampling. The analytical precision for the measurements of ions was determined by the ionic balances, calculated as $100 \times (\text{cations} - \text{anions}) / (\text{cations} + \text{anions})$, which is generally within $\pm 5\%$.

RESULTS AND DISCUSSION

Groundwater hydrochemistry

The statistical parameter (mean, range, standard deviation) of various physico-chemical parameters including pH, oxidation–reduction potential (ORP), EC, TDS, and major ion and trace elements that were analyzed are given in

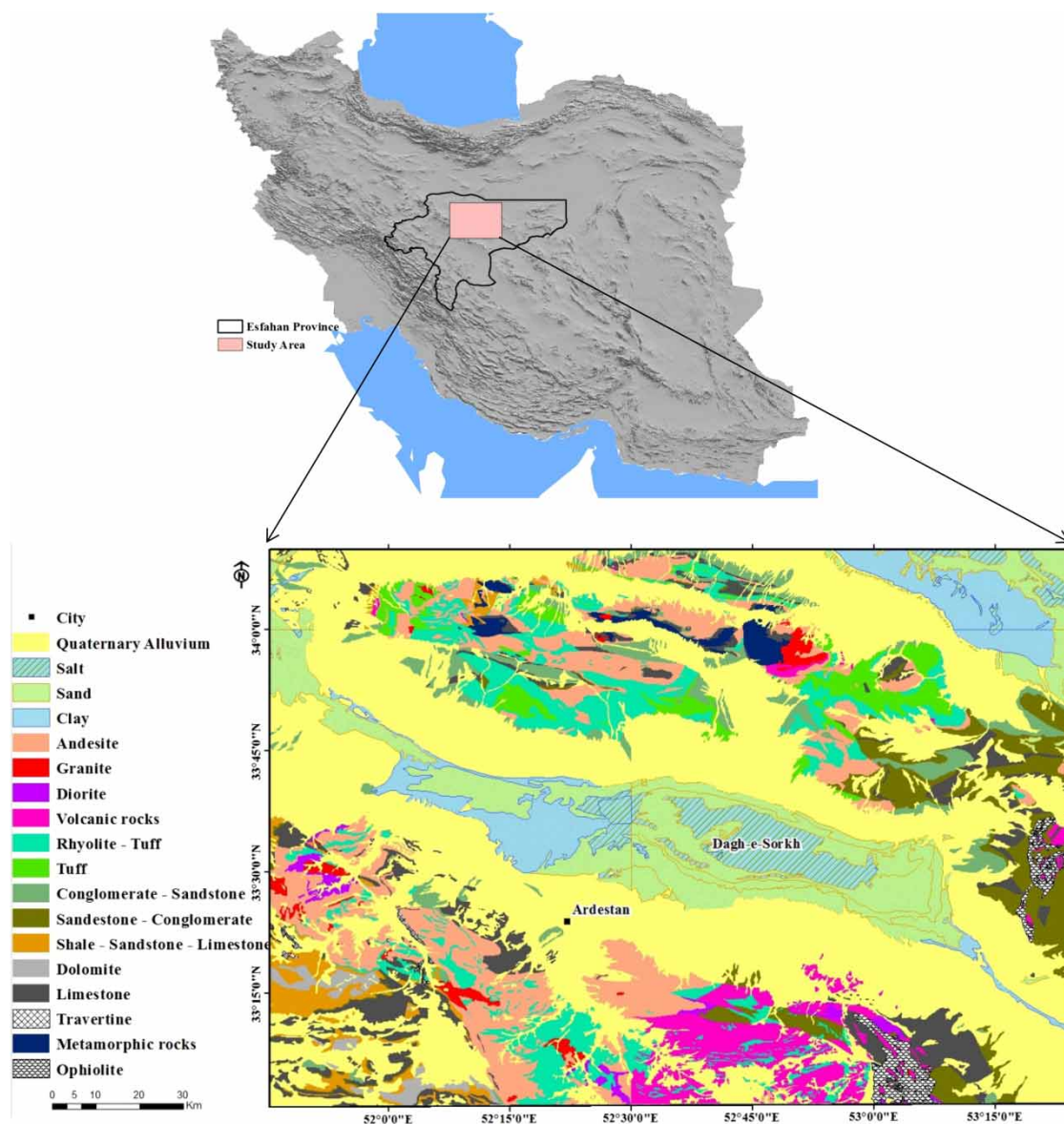


Figure 1 | Location and geological map of the study area (modified from Sharkovski *et al.* 1981; Amidi & Zahedi 1988).

Table 1. Figure 2 shows groundwater flow direction and sample location. The ORP of the groundwater in the study area ranges from -151.6 to 339.9 with an average value of 190.4 demonstrating the presence of mild oxidizing to moderate/strong reducing aquifers in the study areas.

EC of groundwater widely varies from 212.6 to $445,000$ $\mu\text{S}/\text{cm}$. Highest EC values were observed at deep aquifers. High EC values of some samples indicate the presence of saline groundwater (Halim *et al.* 2009). The pH value in the study area ranges from 5.2 to 9.1 with a mean

value of 7.6 indicating an acidic to alkaline environment. TDS values range from 104.4 to $327,000$ mg/L with an average value of $8,410.4$ mg/L . The large variation in TDS is mainly attributed to geochemical processes prevailing in this area and influenced by the chemical and biochemical interaction between groundwater and the geologic materials as the water flows through the aquifer layers. The concentration of major cations, e.g., Ca^{2+} (0.8 – $46,760$ mg/L), Mg^{2+} (2.7 – $13,550$ mg/L), Na^+ (12.1 – $117,230$ mg/L), and K^+ (0.2 – $2,018$ mg/L) exhibit high variation in water samples.

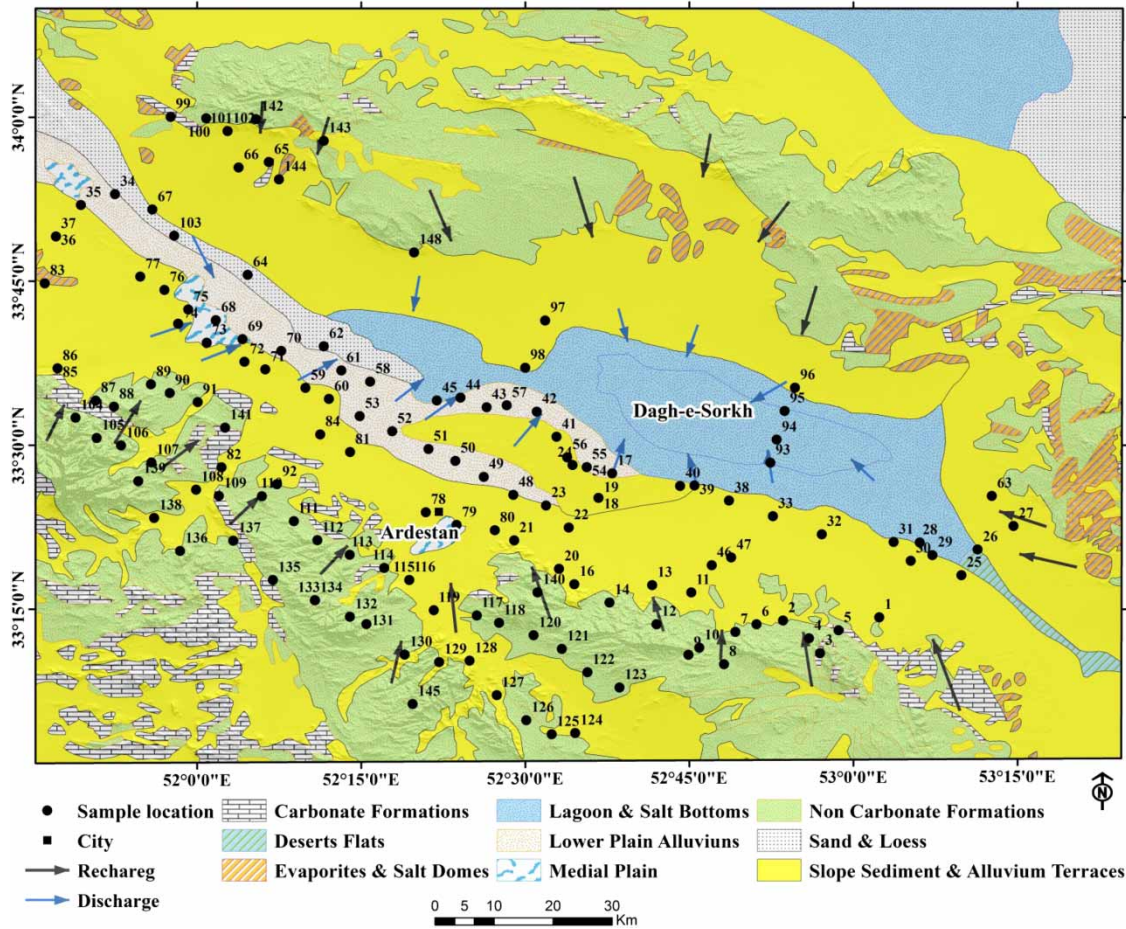


Figure 2 | Hydrological map of study area.

The major anions HCO_3^- (4–456.2 mg/L), CO_3^{2-} (1.4–151.5 mg/L), SO_4^{2-} (1–4,500 mg/L), and Cl^- (9–210,671.7 mg/L) also have great variability in area. The abundance of the major ions in groundwater is in the following order: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{CO}_3^{2-}$. The groundwater samples were plotted onto Piper's diagrams and five groundwater groups were identified on the basis of major ion concentrations (Figure 3). The groundwater types are a function of the lithology, solution kinetics, and flow patterns of the aquifer, which was developed in order to understand and identify the water composition in different classes (Raju *et al.* 2009; Esameili-Vardanjani *et al.* 2015). Results show that groundwater types are: Na-Cl, Na- SO_4 , Na- HCO_3 , Ca- HCO_3 , and Ca- SO_4 that represent 52, 25, 11, 10, and 2% of the total number of water samples, respectively (Figure 3). Thus, five groundwater types were

identified, indicating the variable nature of the groundwater chemistry which suggests there may be a considerable number of different processes influencing the chemistry of groundwater in the study area (Salifu *et al.* 2012).

Three important natural mechanisms controlling the major ion chemistry of the groundwater, atmospheric precipitation, rock weathering, and evaporation were plotted by Gibbs (1970). A Gibbs plot of the data indicates that the majority of the samples fall into the evaporation and rock–water interaction zone. This observation suggests that rock weathering is the leading chemical process in the study area. Also, evaporation greatly increases concentrations of ions formed by chemical weathering, leading to higher salinity (Figure 4).

In arid regions, the build-up of dissolved species through evaporation is a major factor contributing to groundwater salinity (He *et al.* 2012). Cl^- , Na^+ , and TDS can be used to

Table 1 | Statistical summary of the chemical characteristic of groundwater from study area

Parameter	pH	ORP mV	EC µS/cm	TDS mg/L	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻	HCO ₃ ⁻	Ca ²⁺	K ⁺	Na ⁺	Mg ²⁺	Fe	Mn	As µg/L
Mean	7.6	190.4	11,052.1	8,410.3	6,158.5	561.9	54.5	147.9	838.5	35.8	2,922.2	274.9	149.0	2.0	17.1
Max	9.1	339.9	445,000.0	527,000.0	210,671.7	4,500.0	151.5	456.2	46,760.0	2,018.0	11,7230.0	13,550.0	990.0	28.8	296.6
Min	5.2	-151.6	212.6	104.4	9.0	1.0	1.4	4.0	0.8	0.2	12.1	2.7	<0.01	<0.01	<0.5
SD	0.7	97.5	48,981.1	41,654.9	30,341.5	640.8	28.5	98.8	4,667.6	211.2	12,700.8	1,532.1	311.7	5.5	38.1
Parameter	Ba µg/L	Bi	Co	Cr	Cu	Li	Mo	Ni	Pb	Sb	Si	Sn	V	W	Zn
Mean	48.4	3.9	1.7	18.6	62.9	58.6	7.8	27.2	38.9	23.1	12.6	5.6	13.4	26.0	143.8
Max	1,179.6	14.3	15.0	40.0	361.6	541.1	81.9	156.9	423.0	58.2	29.5	11.1	62.7	416.7	6,230.0
Min	<1	0.2	<1	<1	<1	0.0	0.2	2.6	<1	<0.1	0.0	0.7	<1	5.6	<1
SD	132.6	3.6	1.7	15.7	57.4	83.8	9.7	26.1	51.0	11.1	7.2	2.1	13.8	42.3	737.7

represent the intensity of evaporation (Pazand & Sarvestani 2013). In the study area, Cl⁻ and Na⁺ concentrations increased with increasing TDS directly in all of the groundwater samples (Figure 5).

Except HCO₃⁻ and CO₃²⁻ for all major ions examined, concentrations tend to increase with increasing TDS, suggesting the leaching of readily soluble salts from the soil zone, where these salts are precipitated under the influence of high rates of evaporation. This positive correlation between K⁺ and TDS suggests the impact of agricultural activities and weathering of sylvite (KCl) partly controls the K⁺ chemistry; other possible sources of K⁺ in groundwater such as K-feldspars and K-bearing minerals are rare in the studied area.

The Na⁺-Cl⁻ relationship has been used to identify the mechanisms for acquiring salinity and saline intrusions in semi-arid regions (Yang *et al.* 2016). If sodium comes from only halite dissolution, the Na⁺/Cl⁻ ratio is approximately 1 (Meybeck 1987). Figure 6(a) shows the value of Cl⁻ as a function of Na⁺ in groundwater samples indicating that excess Na⁺ was due to silicate weathering and the influence of salt dissolution. The scatter plots of SO₄²⁻ + HCO₃⁻ versus Ca²⁺ + Mg²⁺ (Figure 6(b)) show that the chemistry of three bore well samples was strongly influenced by silicate weathering. A positive correlation between Ca²⁺ and SO₄²⁻ was found, indicating solubility of gypsum and anhydrite in the study area (Figure 6(c)).

Occurrence and distribution of lead and other metals

Concentration of metals in groundwater including Pb and As is presented in Table 1. Pb is a general toxicant and a cumulative poison which is present in water to some extent as a result of dissolution from natural sources, although the excessive lead may be primarily from household plumbing (Mahmood *et al.* 1998). The content of Pb and As in groundwaters is above the WHO guideline for drinking water (<10 µg/L) as well as the Iranian drinking water standard (<10 µg/L). Concentrations of dissolved Pb in the aquifers of the study area ranges from below detection limit (<1 µg/L) to as high as 423 µg/L. Concentration of As in groundwater was observed to be between <0.5 and 296.6 µg/L in the study area. In this area, about 68% and 27% of the samples were found to have Pb and As

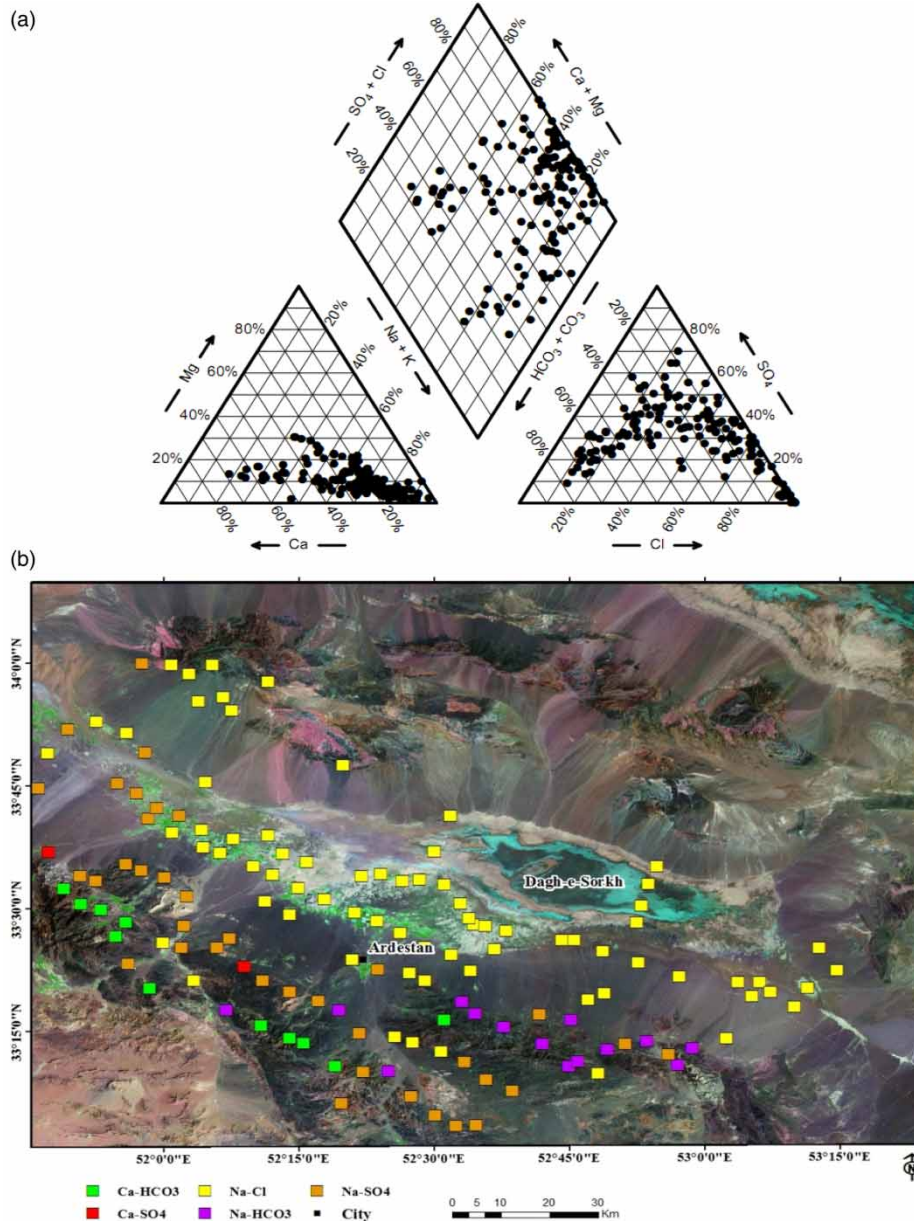


Figure 3 | (a) Piper diagram and (b) distribution of water types in the groundwater of the study area.

concentrations greater than the standard value for drinking water, respectively. The plot of Pb versus As (Figure 7) shows that a distinctive trend was missing as no visible correlation was observed between them.

The correlation coefficients of the studied parameters are shown in Table 2. It is helpful in determining the relationships among the variables and influencing factors, which help in the identification of the sources of different

elements (Kumar *et al.* 2017). There is not a very strong correlation among all the metals, which indicates multiple sources could be responsible for the metals present in the groundwater of this area. A significant positive correlation was observed between As with Ni ($r = 0.75$), Zn ($r = 0.62$), Cu ($r = 0.58$), and Ba ($r = 0.48$).

Arsenic showed maximum positive correlation with V ($r = 0.39$), which indicated that they were naturally derived

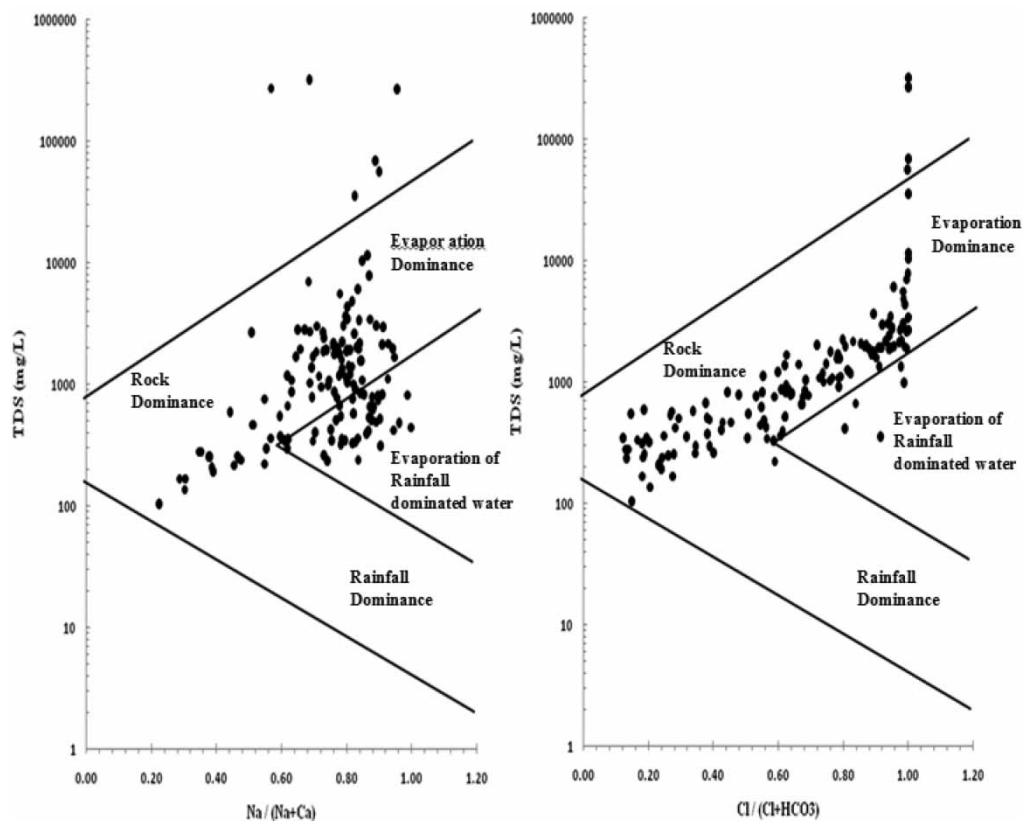


Figure 4 | Gibbs diagram showing the mechanisms controlling the chemistry of groundwater.

from local rock types. There was a negative correlation ($r = -0.15$) between Pb and SO_4^{2-} . In addition, no positive correlation was shown between As and SO_4^{2-} , which indicates that Pb and As have not been directly mobilized from sulfide minerals.

Possible sources of Pb in groundwater

In many areas of the world, Pb and As in the environment can be related to human activities and industrial sources (Chitsazan *et al.* 2009; Ayuso & Foley 2016). However, the main source for contamination drinking water aquifers worldwide is naturally occurring. Since no industrial activity and no Pb-As bearing pesticide/fertilizer usage exist in the study area, the probable source of Pb and As in groundwater is geogenic and may be restricted to rocks and sediments that originated from parental rocks. Acidic volcanic material such as rhyolite and tuff is very reactive and volatile elements can subsequently be transferred into

the water system during water-rock interactions. Thus Pb and As occurrence may be associated with the presence of silicate rocks and their weathering products (Rango *et al.* 2010). The results of ICP-MS analysis (Table 3) show that samples which came from parental rocks have high Pb and As contents. High Pb and As concentrations were recorded in volcanic rocks in the study area. The occurrence of clays and iron-manganese oxides along the groundwater pathway would tend to lower the Pb and Zn concentrations.

CONCLUSIONS

The hydrogeochemical characteristics and lead contamination of groundwater were evaluated in the north of Esfahan, Central Iran. Groundwater is mostly Na-Cl and Na- SO_4 type in the aquifers with Cl^- and Na^+ as the dominant anion and cation, although other types of water were

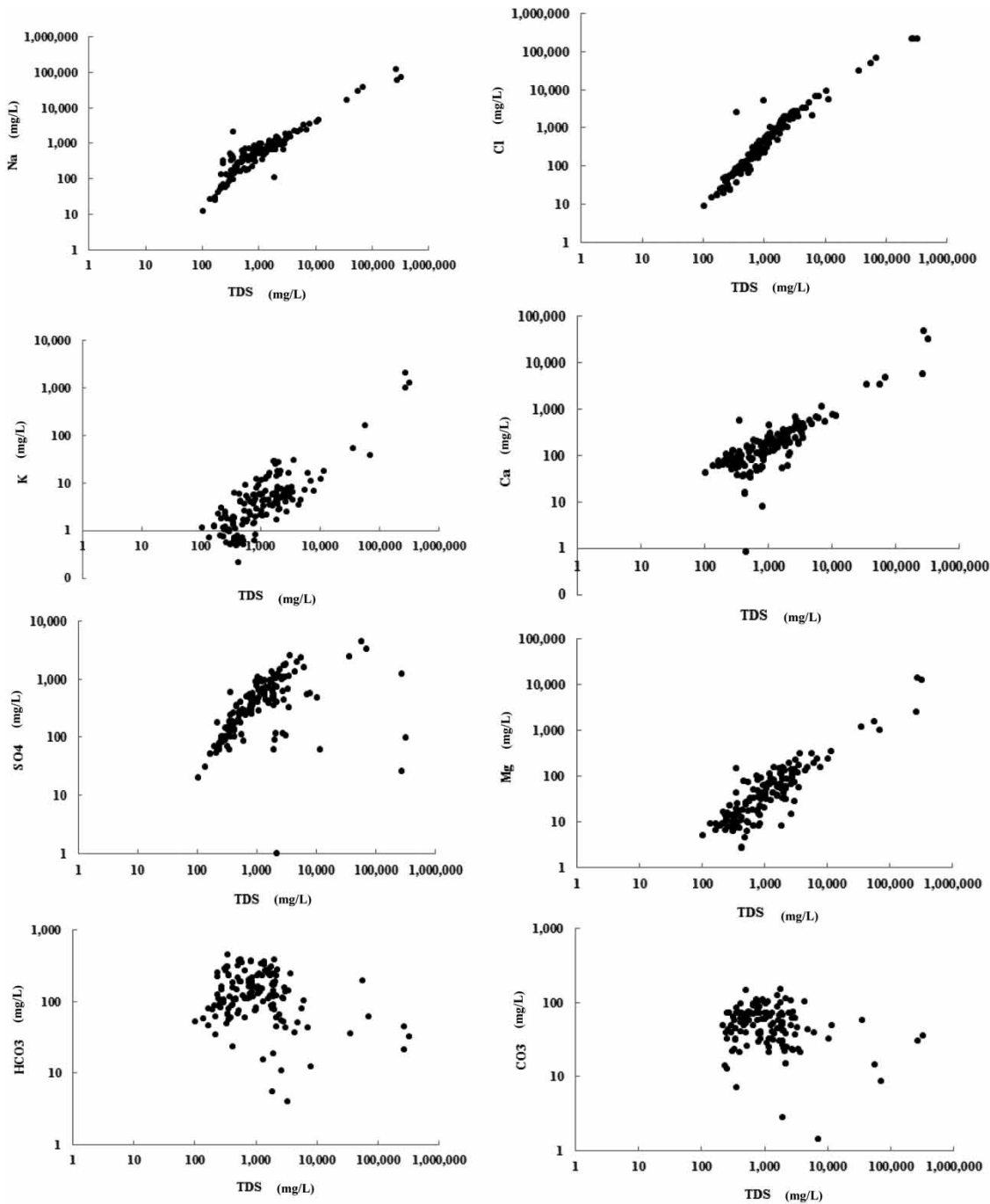


Figure 5 | Relationships between ion concentrations for Na^+ , K^+ , Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , CO_3^{2-} , and HCO_3^- with TDS.

observed. Compositional relations were employed to investigate the origins of solutes and confirm the predominant hydrogeochemical processes responsible for the various ions in the groundwater.

The results revealed that silicate rock weathering, evaporation, salt dissolution, and ion exchange are the dominant factors affecting the major ion compositions in the study area. The adopted WHO standard shows

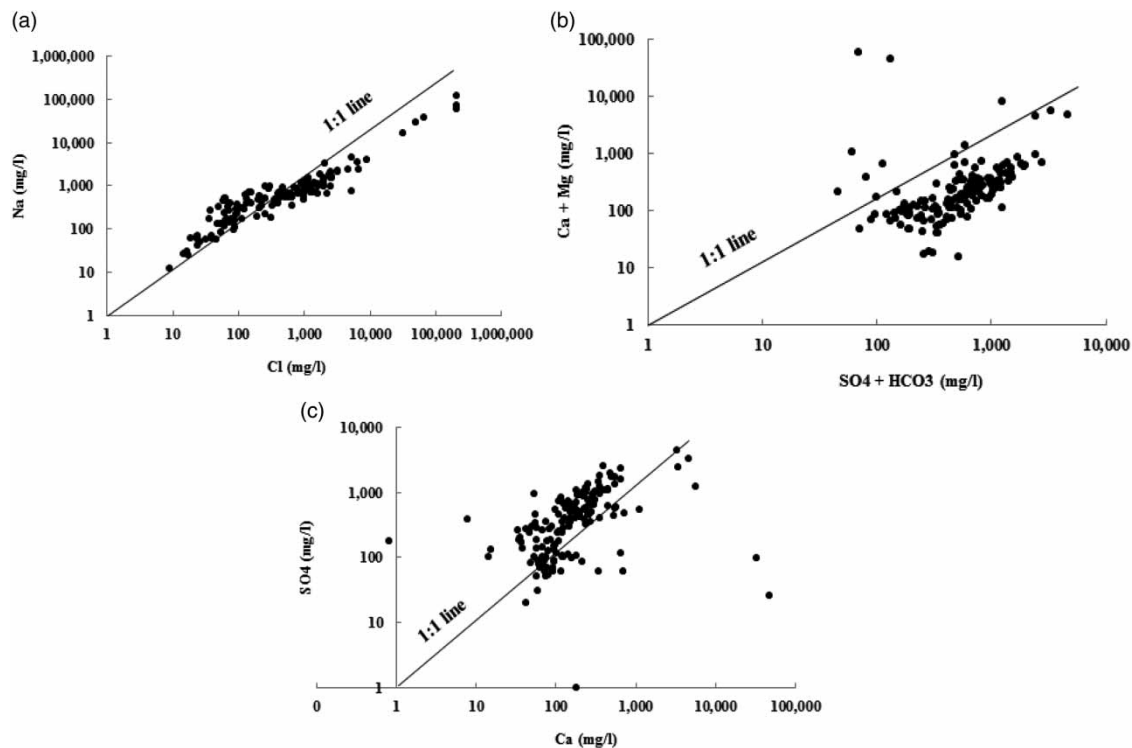


Figure 6 | Ion scatter diagrams for groundwater in the study area: (a) Na⁺ versus Cl⁻ scatter; (b) SO₄²⁻ + HCO₃⁻ versus Ca²⁺ + Mg²⁺; Ca²⁺ versus SO₄²⁻.

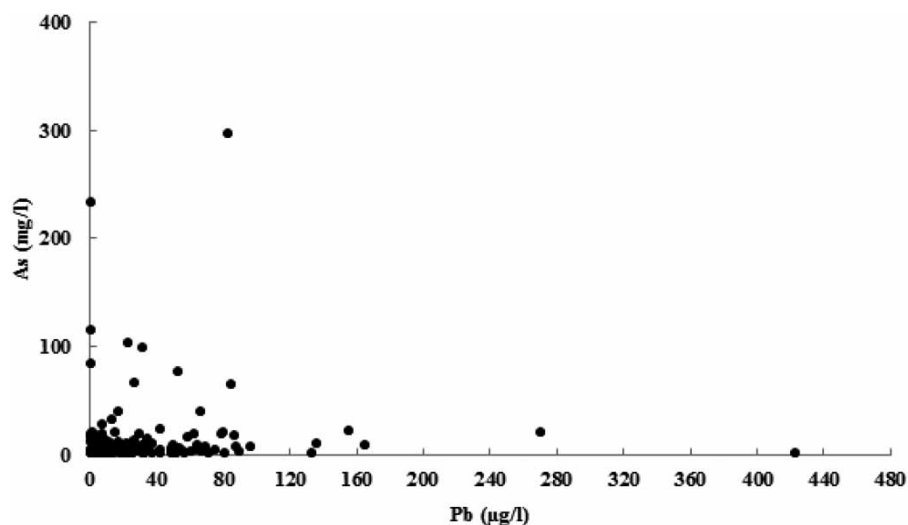


Figure 7 | Scatter plots showing behavior of Pb and As.

that Pb and As were found to be above the maximum permissible limit of drinking water quality in the study area. The concentrations of Pb and As exceeded the guidelines

values at most locations, indicating a natural contribution to the groundwater quality. The results of ICP-MS analysis of parental rocks and aquifer sediments shows that

Table 2 | Correlation coefficient of groundwater characteristics in study area

	pH	ORP	EC	TDS	Cl	SO ₄	HCO ₃	Ca	K	Na	Mg	Fe	Mn	As	Ba	Bi	Co	Cr	Cu	Li	Mo	Ni	Pb	Sb	Si	Sn	V	W	Zn	
pH	1.00																													
ORP	0.14	1.00																												
EC	-0.22	-0.46	1.00																											
TDS	-0.20	-0.47	0.98	1.00																										
Cl	0.05	0.28	0.28	0.26	1.00																									
SO ₄	0.09	0.12	0.27	0.25	0.65	1.00																								
HCO ₃	0.11	-0.22	0.20	0.19	-0.20	0.14	1.00																							
Ca	-0.02	0.23	0.25	0.23	0.81	0.62	-0.12	1.00																						
K	0.07	0.17	0.30	0.28	0.75	0.64	0.04	0.73	1.00																					
Na	0.00	0.25	0.33	0.30	0.92	0.64	-0.02	0.78	0.71	1.00																				
Mg	0.03	0.25	0.21	0.19	0.79	0.73	-0.01	0.86	0.82	0.74	1.00																			
Fe	-0.05	0.19	0.07	0.07	0.34	0.07	-0.24	0.24	0.15	0.29	0.15	1.00																		
Mn	-0.03	0.19	-0.14	-0.15	0.24	0.01	-0.51	0.28	0.14	0.09	0.17	0.23	1.00																	
As	0.08	-0.21	0.09	0.08	-0.23	0.01	0.31	-0.25	-0.16	-0.19	-0.23	-0.16	-0.20	1.00																
Ba	0.03	0.10	0.03	0.04	0.19	-0.16	-0.11	0.33	0.07	0.26	0.13	0.11	0.21	0.05	1.00															
Bi	0.13	-0.04	0.31	0.28	0.40	0.40	0.28	0.54	0.45	0.40	0.48	0.15	0.01	0.14	0.14	1.00														
Co	-0.12	0.19	-0.08	-0.05	0.23	0.12	-0.38	0.28	0.27	0.17	0.20	0.16	0.41	-0.10	0.20	-0.01	1.00													
Cr	-0.06	-0.09	0.06	0.07	0.08	0.03	0.23	0.09	-0.01	0.16	0.04	0.02	0.09	0.17	0.15	0.04	-0.04	1.00												
Cu	0.09	-0.04	0.14	0.11	-0.11	-0.07	0.45	0.01	-0.09	0.14	-0.12	-0.17	-0.25	0.06	0.40	0.09	-0.23	0.31	1.00											
Li	0.00	0.07	0.27	0.25	0.63	0.49	0.21	0.48	0.55	0.61	0.54	0.30	0.01	0.08	0.00	0.49	-0.01	0.27	-0.07	1.00										
Mo	0.18	0.10	-0.08	-0.08	0.02	0.21	0.07	-0.03	-0.05	0.14	-0.11	-0.24	-0.18	0.19	0.12	-0.07	-0.08	0.02	0.30	-0.21	1.00									
Ni	-0.03	0.07	-0.09	-0.09	-0.16	-0.25	0.15	0.04	-0.20	0.04	-0.17	-0.09	0.00	0.07	0.55	-0.16	0.11	0.24	0.63	-0.24	0.31	1.00								
Pb	0.11	0.11	-0.02	-0.01	-0.01	-0.15	0.12	0.01	-0.11	0.17	-0.09	-0.04	-0.07	0.15	0.48	-0.13	-0.07	0.23	0.58	-0.15	0.40	0.75	1.00							
Sb	-0.03	-0.10	-0.30	-0.30	-0.49	-0.26	-0.14	-0.48	-0.36	-0.55	-0.41	-0.22	0.07	0.24	-0.27	-0.29	0.18	-0.19	-0.42	-0.40	0.13	0.00	-0.14	1.00						
Si	0.12	-0.18	0.17	0.17	-0.20	0.18	0.79	-0.03	-0.01	-0.02	0.02	-0.31	-0.38	0.38	0.06	0.18	-0.36	0.27	0.60	0.01	0.23	0.29	0.25	-0.23	1.00					
Sn	0.08	-0.12	0.14	0.12	0.07	0.23	0.20	0.23	0.28	0.09	0.23	-0.12	0.01	0.19	0.02	0.62	0.22	0.07	0.01	0.04	0.09	-0.10	-0.10	0.13	0.13	1.00				
V	0.02	0.08	-0.04	-0.05	0.06	0.12	-0.19	-0.03	-0.15	0.01	-0.03	0.07	0.23	0.39	-0.01	-0.11	0.04	0.18	-0.14	0.04	0.08	-0.01	0.08	0.11	0.04	-0.21	1.00			
W	0.12	0.14	0.02	0.02	0.25	0.21	-0.20	0.30	0.34	0.23	0.26	0.11	0.15	0.09	0.18	0.22	0.22	-0.18	-0.12	-0.08	0.18	0.07	0.27	0.03	-0.14	0.30	-0.01	1.00		
Zn	0.08	0.08	-0.15	-0.13	-0.28	-0.29	0.04	-0.21	-0.27	-0.15	-0.25	-0.08	-0.04	0.24	0.37	-0.23	0.16	0.02	0.27	-0.19	0.22	0.64	0.62	0.28	0.07	-0.05	0.10	0.14	1.00	

Table 3 | ICP-MS analysis of rock contents of rock and sediment

Rock	As	Cd	Co	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn	Zr
Volcanic rock of southern area	81.8	1	16.1	230	41,843	1,181	11.3	13	46	178	49	67
	74.7	1.09	18.8	86	41,616	1,269	7.2	9	21	212	62	78
	66.8	1.76	7.9	87	43,653	3.33	33.9	2	1,806	13	43	212
	62.9	1.61	21.4	39	47,216	1,480	15.8	10	19	175	85	169
	58.5	0.7	2.7	13	25,579	867	3.4	3	22	13	41	128
	46.6	4.4	2.8	20	20,470	764	4.1	1	28	16	34	271
	35	2.81	3.4	26,20	20,822	831	38.2	4	44	35	44	179
	29.2	1.56	20.7	7	46,011	2,134	0.5	36	23	146	197	212
	27.4	0.88	5.4	11,988	30,876	220	8.6	3	16	26	19	175
	23.5	2.05	8.9	131	22,300	739	38.2	5	38	15	85	283
	18.4	2.04	4.6	7	27,054	705	0.6	11	17	21	41	342
	17.4	0.68	3	23	24,993	670	3.9	4	20	23	33	94
	17.4	0.69	3.8	150	14,033	100	10.2	2	15	60	16	61
	16	1.38	0.66	56	21,930	568	15.5	2	99	7	24	298
	6.4	0.16	1.3	33	13,159	307	2.3	2	475	8	42	21
1.9	2.72	2.5	27	21,161	606	3.3	1	44	15	41	180	
Granite	0.06	0.06	2.3	9	6,527	500	0.5	0.66	1	14	9	6
Volcanic rock of northern area	1,104.3	1.74	1.6	90	75,600	2.5	7.4	3	413	17	10	305
	1,070.2	1.34	2.1	13	54,586	2.5	18	3	661	39	17	121
	1,063.6	1.5	6	185	86,256	2.5	7.5	4	538	46	19	253
	740.1	0.98	2.8	15	35,424	2.5	8	2	77	35	53	165
	332.8	2.86	10	96	23,312	252	2.9	1	40	38	14	199
	284.4	0.76	8.3	79	66,829	2.5	8.8	6	102	38	12	147
	275.1	0.17	124.8	1,849	2,773	10,000	97.3	20	3,787	225	336	18
	264.3	0.48	1.2	16	18,836	2.5	5.3	3	36	26	9	110
	257.5	3.17	40.8	35	44,976	717	3.7	15	24	162	112	196
	234.2	1.34	26	36	38,410	218	6.2	17	30	154	54	283
	141.7	0.36	3.3	25	100,000	940	26	4	72	41	31	56
	136	1.16	15.5	24	29,007	21	36.6	7	29	40	12	209
	Sediment of central area	5.1	<0.1	4	4	7,420	174	0.45	15	27	30	18
11.2		0.91	16.9	35	37,007	702	0.78	62	23	131	93	99
19.2		0.93	13.2	28	30,524	913	1.71	52	22	101	74	78
13.2		0.81	16.3	34	34,819	673	2.98	62	22	164	86	89
16.7		0.54	12.9	27	31,453	939	1.65	35	21	93	67	71
12.3		0.86	12.5	30	30,288	659	1.01	49	21	102	82	77
10.8		0.41	10.3	22	21,912	487	1.54	37	21	62	71	67
9.3		0.98	11.9	28	27,155	552	0.79	51	21	98	69	81
20.1		0.9	12.7	31	30,054	865	2.71	48	20	98	68	76
16.7		0.71	20.1	44	38,490	1,115	1.1	88	20	127	132	97

unweathered rocks of volcanic rocks can be considered as the primary source for lead and arsenic mobilizing to groundwaters. This study identified Pb and As as priority pollutants, which calls for further attention and investigation. Based on the distribution of Pb concentration, several wells used for drinking water purposes must be closed or treated with appropriate water remediation technologies.

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