Chemical characteristics of groundwater in Ardabil region, Iran

Kamran Pazand
Department of Mechanical Engineering, East Tehran Branch, Islamic Azad University, Tehran, Iran, and
Kaveh Pazand
Young Researchers and Elite Club, Science and Research Branch, Islamic Azad University, Tehran, Iran

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Abstract

Purpose – The chemical analysis of wells in the Ardabil area, Ardabil Province NW of Iran, was evaluated to determine the hydrogeochemical processes and ion concentration background in the region. The purpose of this study is to analyze the hydrochemical quality of groundwater in Ardabil aquifer in order to assess the suitability of the waters for different uses.

Design/methodology/approach – The chemical analysis of 75 water wells in the Ardabil area, was evaluated. Over the entire area, the dominated hydrochemical types are: Na-Cl, Na-HCO3-Cl-Mg, Ca-SO4, Ca-Mg-SO4-Cl and Ca-Mg-HCO3. The abundance of the major ions is as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > Cl^- > HCO_3^-$ and major ion concentrations are below the acceptable level for drinking water. Most of groundwater samples fell in the soft water category. All of groundwaters belong to the excellent category and can be used safely for irrigation.

Findings – The chemical analysis of 75 water wells in the Ardabil area, Ardabil Province NW of Iran, was evaluated to determine the hydrogeochemical processes and ion concentration background in the region. Over the entire area, the dominated hydrochemical types are: Na-Cl, Na-HCO3-Cl-Mg, Ca-SO4, Ca-Mg-SO4-Cl and Ca-Mg-HCO3. The abundance of the major ions is as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > Cl^- > HCO_3^-$ and major ion concentrations are below the acceptable level for drinking water. Most of groundwater samples fell in the soft water category. All of groundwaters belong to the excellent category and can be used safely for irrigation.

Originality/value – The chemical analysis of 75 water wells in the Ardabil area, Ardabil Province NW of Iran, was evaluated to determine the hydrogeochemical processes and ion concentration background in the region. Over the entire area, the dominated hydrochemical types are: Na-Cl, Na-HCO3-Cl-Mg, Ca-SO4, Ca-Mg-SO4-Cl and Ca-Mg-HCO3. The abundance of the major ions is as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > Cl^- > HCO_3^-$ and major ion concentrations are below the acceptable level for drinking water. Most of groundwater samples fell in the soft water category. All of groundwaters belong to the excellent category and can be used safely for irrigation.

Keywords Groundwater, Ardabil, Hydrochemical

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Introduction

Nowadays, in the current world, a sustainable socioeconomic development of every community depends much on the sustainability of available water resources. Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries. Poor groundwater quality has attracted worldwide attention particularly because of increasing dependence on groundwater as a source of water for securing the quality of life (Pazand and Javanshir, 2013). Water of adequate quantity and quality is required to meet growing household, industrial, and agricultural purposes (Rashid *et al.*, 2019). Therefore, water quality and its management have received more attention in developing countries (Jalali, 2006). The quality of groundwater at any point below the surface reflects the combined effects of many processes along the groundwater flow path (Pazand and Hezarkhani, 2012). Chemical reactions such as weathering, dissolution, precipitation, ion exchange, geological structure and mineralogy of the watersheds and aquifers and the geological and various biological processes commonly take place below the surface (Pazand and Sarvestani, 2013). Hydrogeochemical study is a useful tool to identify these processes that are responsible for groundwater chemistry (Jeevanandam *et al.*, 2007). The interaction of all factors leads to various water types. Intense agricultural and urban development have placed a high demand on groundwater resources in Ardabil regions and also these resources at greater risk to contamination therefore Increased knowledge of geochemical evolution of groundwater in these regions could lead to improved understanding of hydrochemical systems in such areas, leading to sustainable development of water resources and effective management of groundwater resource for Ardabil city and its suitability for irrigation purposes. Despite the importance of water resources, little is known about the natural that govern chemical composition of available water or other factors that presently affect them in the Ardabil area. Therefore, groundwater hydrogeochemistry of the regions remains poorly understood. The aim of this study is to analyze the hydrochemical quality of groundwater in the Ardabil aquifer in order to assess the suitability of the waters for different uses.

Study area

The study area is situated in the Ardabil region of the northwestern part of Iran and lies between longitudes 48° 06′ 25″ and 48° 44′ 02″ E and latitudes 38° 01′ 53″ and 38° 29′ 55″ N (Figure 1).

The area has a cold temperate climate and annual precipitation being approximately 350 mm with a mean altitude of 1,345 m.a.s.l. The most important economic activity of the area is agriculture. During the Late Eocene–Oligocene, the study area was cut by several intrusive bodies. Late Eocene–Oligocene plutonic activity has been documented (Khain, 1975; Pourhosseini, 1981) and consists of alkaline and calc-alkaline volcanic rocks and related intrusives (I-type) and was formed by subduction of the Arabian plate beneath central Iran during the Alpine orogeny (Stockline and Nabavi, 1973; Berberian and King, 1981). Large variations in lithology exist throughout the region. The bedrock is made up of Eocene volcanic (andesite, basalt and tuff), Cretaceous marly limestones and Pliocene sandstone – conglomerates. The central parts of the study area are Quaternary deposits that mainly characterized by silty-muddy layers alternating with sandy and sometimes gravel lenses (Khodabandeh and Aminifazl, 1997).

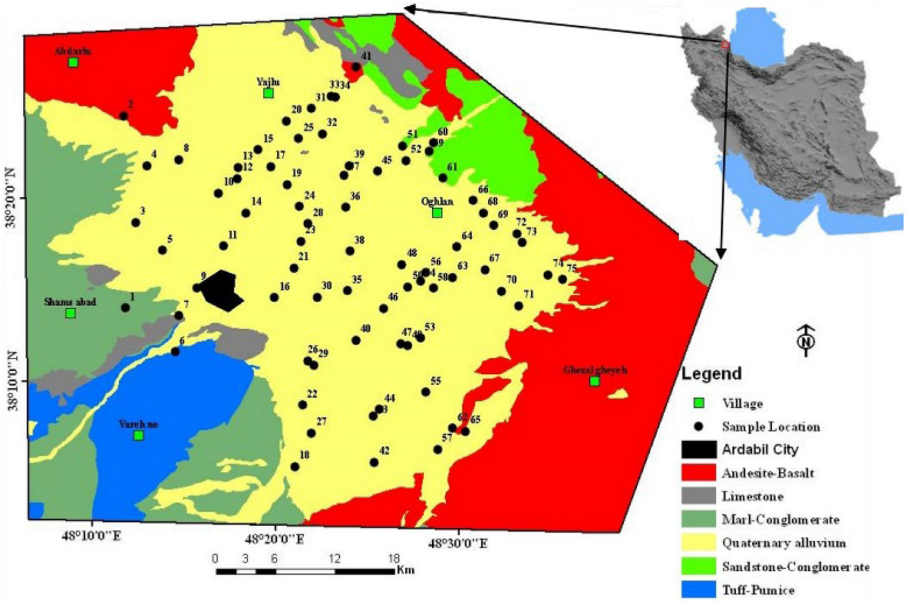

Figure 1.
Geology map and sample location of the study area

Materials and methods

In all, 75 groundwater samples were collected from the Ardabil area during September 2007 (Figure 1). The selected wells are used for agricultural and domestic purposes. 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 prior to their filling with groundwater samples to minimize the chance of any contamination. The water samples of bore wells were collected after pumping out water for about 10 min to remove stagnant water from the well. Immediately after sampling, pH, Eh, dissolved oxygen concentration and electrical conductivity (EC) were measured in the field using a multi-parameter portable meter (HATCH, Germany). At each site, the pH electrode was calibrated using two buffers (Merck, Germany) that bracketed the measured pH and that was thermally equilibrated with the water sample.

Samples were analyzed in the laboratory for the major ions employing standard methods. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined titrimetrically using standard EDTA. Chloride (Cl^{-}) was determined by the standard $AgNO_3$ titration method. Carbonate CO_3^{2-} and bicarbonate (HCO_3^{-}) were determined by titration with HCl. Sodium (Na^{+}) and potassium (K^{+}) were measured by flame photometry, sulfate SO_4^{2-} by spectrophotometric turbidimetry (Rowell, 1994). Total dissolved solids (TDS) were determined gravimetrically at 105–110°C (Table 1).

Results and discussion

Groundwater chemistry

The pH of the groundwater in the study area ranges from 6.22 to 8.32 with an average value of 7.66. Only few samples have pH values less than 7 (Figure 2). All other samples have values more than 7, indicating the alkaline nature of the samples.

Among the cations, the concentrations of Na^+, Ca^{2+}, Mg^{2+} and K^+ ions ranged from 1 to 36.9, 1–20, 0.5–9.1 and 0–0.8 mg/l with a mean of 7.36, 3.45, 1.81 and 0.13, respectively. Their concentrations represent on average 57.69, 27.07, 14.21 and 1.03% of all the cations, respectively. Thus, the order of abundance is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Major anions show a very wide range of variations. Among the anions, the concentrations of HCO_3^-,Cl^- and SO_4^{2-} ions lie in between 0.4 and 15, 0.5 and 93.8 and 0.31 and 35.8 mg/l with a mean of 4.52, 4.79 and 4.91 mg/l, respectively. The order of their abundance is $SO_4^{2-} > Cl^- > HCO_3^-$, contributing on average, 34.51, 33.71 and 31.78% of the total anions, respectively. If halite dissolution is responsible for sodium, Na/Cl ratio should be approximately equal to 1, whereas ratio greater than 1 is typically interpreted as Na released from silicate weathering reaction (Meyback, 1987; Kabir *et al.*, 2014; Pazand, 2020). In the present study, Samples (except number 60) having Na/Cl ratio greater than 1 (Figure 3) hence silicate weathering was the probable source of sodium.

Water types

The piper diagram in Figure 4 constructed using Rock Ware Scientific Software shows the relative concentrations of the different ions from individual water samples .Based on dominant cations and anions, four water types were found in the water samples: Na-Cl, Na-HCO_3-Cl-Mg, Ca-SO_4, Ca-Mg-SO_4-Cl and Ca-Mg- HCO_3. Na-Cl type represents 57.33% of the total number of water samples analyzed, while Ca-Mg-HCO_3, Ca-SO_4, Ca-Mg-SO_4-Cl and Na-HCO_3-Cl-Mg represents 17.34%, 12%, 8%, and 5.33% of the total number of water samples analyzed, respectively.

Groundwater quality and assessment

The analytical results have been evaluated to ascertain the suitability of groundwater of the study area for drinking and agricultural uses based on the WHO (2004) standards. A natural chemical composition of groundwater results from two main processes: the first is the atmospheric salts that come from marine aerosols, dust and concentration by evaporation of dissolved salts in precipitation, and the second are the interaction of groundwater with the formation minerals (Pazand *et al.*, 2011). A hydrogeological environment is a conceptual model of morphological, geological and climatic parameters that determine the main groundwater flow features in given area. Understanding the quality of groundwater is as important as its quantity because it is the main factor determining its suitability for drinking, domestic, agricultural, industrial and touristic purposes (Pazand *et al.*, 2011). Total dissolved solids (TDS) in the study area vary from 189 to 4,634 mg/l. The groundwater in the study area falls under fresh (TDS < 1,000 mg/l) to brackish (TDS > 1,000 mg/l) types of water (Freeze and Cherry, 1979). In comparison with the drinking water standards, it was observed that 25% samples analyzed have TDS concentrations greater than 1000 (WHO, 2004)

Table 1.
Summary statistics of chemical compositions of major ions in the groundwaters of Ardabil area

Parametr	EC ms/cm	pH	TDS	SO_4	Cl	HCO_3 (mg/l)	K	Ca	Mg	Na
Average	1110	7.75	728	3.86	2.1	4.1	0.1	2.9	1.7	5.8
Min	271	6.26	189	0.31	0.5	0.4	0	1	0.5	1
Max	6620	8.32	4634	35.8	93.8	15	0.8	20	9.1	36.9
Std.Deviation	1001.27	0.4	701	5.56	11.08	2.27	0.13	2.59	1.32	6.44

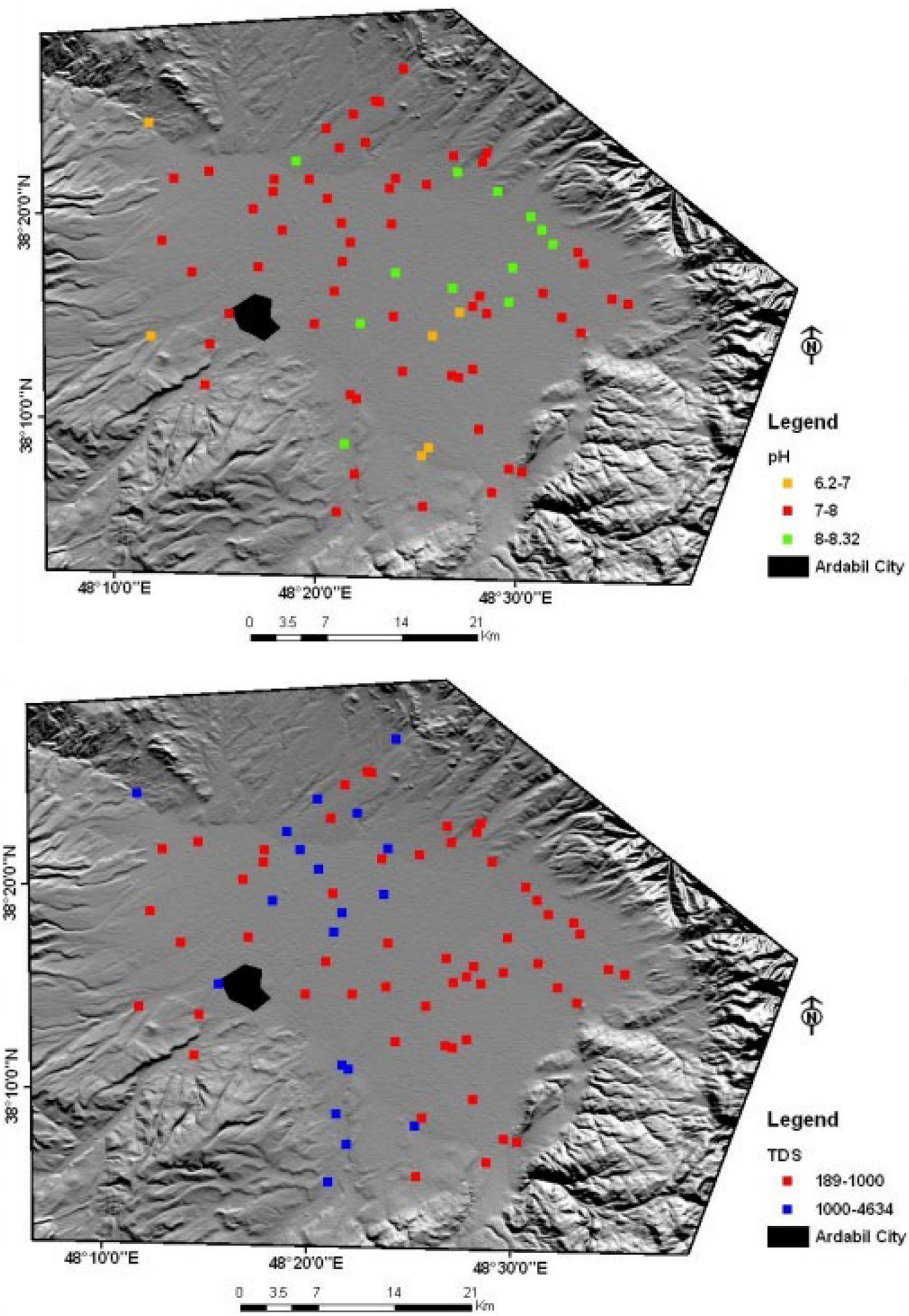

Figure 2. Distribution of pH and TDS in the groundwater from the study area

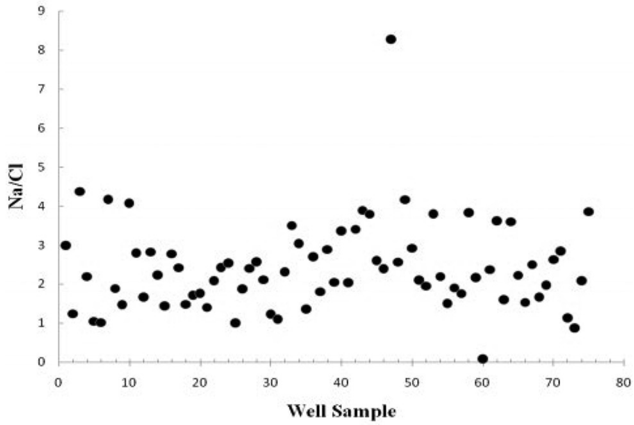

Figure 3. Na/Cl ratio in groundwater from the study area

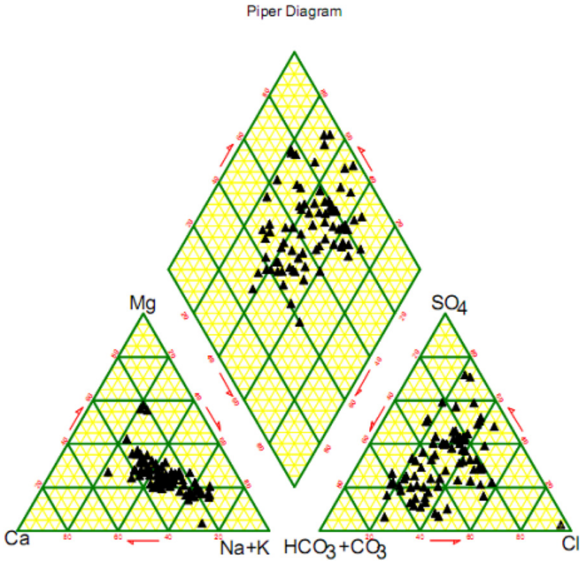

Figure 4. Piper diagram for the groundwater of the studied area

and show a gradual increase in groundwater salinity from the central part to north and south part study area (Figure 2). The electrical conductivity (EC) indicates the amount of material dissolved in water and its values range from 271 to 6620 with a mean of 1274 ms/cm. The recommended value of the EC for potable water is 250 ms/cm. Thus, the EC of the most samples is within the maximum permissible limit. According to the WHO, the range of desirable pH values of water prescribed for drinking purposes is 6.5–9.2. There are only two water samples (well 43 and 46) with pH values outside of the desirable ranges. In all the samples, the concentrations of anion and cations, such as SO_4^{2-}, K^+, Na^+,Ca^{2+} and Mg^{2+} are below the maximum acceptable level (1,492; 200; 1,538; 349; and 133 mg/l respectively) for drinking waters (WHO, 2004). Hardness of water depends mainly upon the amounts of divalent metallic cations, of which Ca^{2+} and Mg^{2+} are more abundant in groundwater. Hardness (H_T) of groundwater was calculated using following equation (Todd and Mays, 2005):

$$H_T = 2.5Ca^{2+} + 4.1Mg^{2+}$$

The hardness values in water samples range from 4.96 to 87.31, the average being 16.07 mg l-1. The degree of hardness in water is commonly based on the classification (0–75) soft, (75–150) moderately hard, (150–300) hard, (>300) very hard and hence groundwaters are soft (Todd and Mays, 2005). All groundwater samples except one sample have H_T lower than 75 and hence groundwater are soft. Sample number 18 has H_T equal 87.31 and therefore is moderately hard. Such water cannot be used for domestic purposes because it coagulates soap lather. Salinity is the total amount of inorganic solid material dissolved in any natural water, and water salinization refers to an increase in TDS and overall chemical content of water (Ritcher and Kreitler, 1993). Sodium concentration is important when evaluating the suitability of groundwater for irrigation. High concentrations of Na^+ are undesirable in water because Na^+ is adsorbed onto the soil cation exchange sites, causing soil aggregates to disperse, reducing its permeability (Jalali, 2009). SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops (Subramani *et al.*, 2005). SAR is defined as:

$$SAR = \frac{Na}{\sqrt{\frac{ca+Mg}{2}}}$$

The ionic symbols indicate concentrations of the ions in the water in milliequivalents per liter. The calculated SAR ranged from 1 to 11.4. According to the Richards (1954) classification based on SAR values 96% of samples belong to the excellent category (SAR < 10) and 4% remaining samples belong to good category (SAR = 10-18). All of groundwaters can be used safely for irrigation.

Conclusions

Based on hydrochemical characteristic, an attempt was made to evaluated groundwater in the Ardabil basin. The result represent that chemical composition of groundwater are differs according to water types and four water types were found in the water samples that the hydrochemical types Na-Cl and $Ca\text{-}Mg\text{-}HCO_3$ dominate the largest part of the studied area. The major cations in the studied groundwater are in the decreasing order as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The anions are also arranged in decreasing order as $SO_4^{2-} > Cl^- > HCO_3^-$. Groundwater in the study area is generally alkaline in nature.

Assessment of water samples according to exceeding the permissible limits prescribed by WHO for drinking purposes indicated that in all the samples, the concentrations of cations and anions are below the maximum acceptable level for drinking waters. The total hardness indicated that 98.66% of groundwater samples fell in the soft water category. The high ratio of Na+/Cl– indicates a significant contribution from silicate weathering.

According to SAR index, all of groundwaters belong to the excellent category and hence can be used safely for irrigation.

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Corresponding author

Kaveh Pazand can be contacted at: kaveh.pazand@gmail.com