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Evaluation of groundwater chemistry and its impact on drinking and irrigation water quality in the eastern part of the Central Arabian graben and trough system, Saudi Arabia

Faisal K. Zaidi [a, b, *], Saad Mogren [a], Manoj Mukhopadhyay [a], Elkhedr Ibrahim [a]

[a] Department of Geology and Geophysics, College of Science, King Saud University, Riyadh, Saudi Arabia
[b] SGS Research for Natural Hazards, Department of Geology and Geophysics, College of Science, King Saud University, Riyadh, Saudi Arabia

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ABSTRACT

The present study deals with the assessment of groundwater with respect to the main hydrological processes controlling its chemistry and its subsequent impact on groundwater quality for drinking and irrigation purposes in the eastern part of the Central Arabian graben and trough system. Groundwater samples were collected from 73 bore wells tapping the Cretaceous Biyadh and Wasia sandstone aquifers. The main groundwater facies in the area belong to the mixed Ca–Mg–SO_4/Cl type and the SO_4–Cl type. Prolonged rock water interaction has resulted in high TDS (average of 2131 mg/l) and high EC (average of 2725 μS/cm) of the groundwater. The average nitrate (56.38 mg/l) value in the area is higher than the WHO prescribed limits of 50 mg/l in drinking water and is attributed to agricultural activities. The Drinking Water Quality Index (DWQI) shows that 33% of the water samples fall within the excellent to good category whereas the remaining samples fall in the poor to unsuitable for drinking category. In terms of Sodium Adsorption Ratio (SAR), Sodium percentage (Na %) and Residual Sodium Carbonate (RSC) the groundwater is suitable for irrigation however the high salinity values can adversely affect the plant physiology.

1. Introduction

The main sources of water supply in the Kingdom of Saudi Arabia include the non-renewable groundwater sources, renewable surface and groundwater sources, desalinated water and treated wastewater. Of all these available water resources, the non-renewable groundwater reserves in the deep seated sedimentary aquifers constitute the major portion of water supply (MOEP, 2010). The lack of present day recharge and long residence time in these aquifers have often resulted in very high salinity in the groundwater (Al-Bassam and Al-Rumikhani, 2003; Zaidi et al., 2015a). Groundwater studies in the Arabian platform show that the groundwater facies mostly belong to the SO_4–Cl type (Hussain et al., 2008; Zaidi et al., 2015b, 2015c). Prolonged rock-water interaction has also led to reverse ion exchange in many regions resulting in high Ca and Mg concentrations (Zaidi et al., 2015a, 2015c). The formation of non-carbonate salts often imparts permanent hardness to the groundwater in these areas.

The presence of agricultural activities in regions of promising ground water reserves have also led to the increased instances of high nitrate concentration (Ahmed et al., 2005, 2015; Alabdula'aly et al., 2010). High fluoride concentrations have also been reported in many areas in the kingdom (Loni et al., 2015; Zaidi et al., 2015b). Though the elevated fluoride concentrations are mostly associated with geogenic source but more detailed studies are required to ascertain the exact source of fluoride as prolonged usage of water with more than 1.5 mg/l concentrations for drinking purposes could have severe health consequences (WHO, 2011).

Regions of limited groundwater supply like Saudi Arabia, is associated with uncertainty and can be influenced by climatic changes in the future (Chowdhury and Al-Zahrani, 2013). Under such circumstances, groundwater quality assessment gains utmost importance for proper planning and management of the available resources. The present study deals with the evaluation of the groundwater quality with respect to the main processes controlling its major ion chemistry and its suitability for drinking and agricultural purposes in the eastern part of the Central Arabian graben

* Corresponding author. Department of Geology and Geophysics, College of Science, King Saud University, Riyadh, Saudi Arabia.
E-mail address: fzaidi@ksu.edu.sa (F.K. Zaidi).

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and trough system. The study involved the interpretation of the groundwater chemistry using ionic relationships and water facies analysis. Furthermore the drinking water quality in the area was assessed using the DWQI. The suitability of the groundwater for irrigation purposes was assessed using the SAR, Na% and RSC.

2. Study area description

2.1. Physiography and climate

The study area is a part of the Riyadh province in central Saudi Arabia and lies to the south east of Riyadh city between 24°N and 24.5°N and 47°E to 48°E (Fig. 1). The city of Al Kharj lies in the south-western part of the study area. The study area lies in the eastern part of the Central Arabian graben and trough system (Al-Dabbagh, 2014) and the lowest elevations are found in the center corresponding to the west–east trending trough system and is locally known as Wadi As Sahba. Wadi as Sahba is an eastward extension of the Wadi Nisah and the Nisah graben (Powers et al., 1966). The average elevation of the region is approximately 459 m amsl. The major drainage in the region follows the West–East trending trough system and is structurally controlled (Fig. 1). The sub drainage network shows a dendritic pattern and is governed by the topography.

The area experiences a desert type of climate with temperatures ranging from approximately 48 °C in summers to about 3 °C in winters. The average annual rainfall in the region is less than 100 mm and the annual evaporation rates are as high as 2000 mm (Almazroui, 2011).

2.2. Geology and hydrogeology

The study area is a part of the 560 km long central Arabian graben and trough system (Fig. 2a) represented by an intraplate fault zone which cuts the gently eastward dipping Mesozoic-Cenozoic sedimentary rocks in eastern Saudi Arabia (Powers et al., 1966; Al-Kadhi and Hancock, 1980; Al Kadhi, 1986). Geologically the area comprises of sedimentary Formations which range in age from the upper Jurassic to Quaternary period. The older Formations outcrop in the western part and the younger Formations in the eastern part of the study area (Fig. 2b). The central portion of the study area corresponding to the linear trough system is occupied by the tertiary and quaternary surficial deposits.

The upper Jurassic Arab Formation and the lower Cretaceous Sulay, Yamama and Buwaib Formations are represented by limestones and calcarenite deposits. The lower Cretaceous Biyadh and upper Cretaceous Wasia Formations are represented by sandstones with subordinate shale layers. The Wasia formation unconformably overlies the Biyadh sandstone. Unconformably overlying the Wasia Formation is the upper Cretaceous Aruma Formation represented by limestones and subordinate shales. The lower Tertiary period is represented by the limestones and dolomites of Umm Er Radhuma Formation. The upper Tertiary Kharj Formation and the Quaternary surficial deposits comprises of lacustrine limestone, gypsum, gravel, sand and silt.

The Biyadh and Wasia Formation are one aquifer system in most parts of central Saudi Arabia including the study area (Water Atlas of Saudi Arabia 1984) and are the most prolific source of groundwater supply in the region. Results from pumping tests analyses (MoWE, 2015) show an average transmissivity value of 3.3×10^{-2} m^2/s and storage coefficient values of 5.0×10^{-4} for both the aquifers. Piezometric measurements in 47 wells from Biyadh and Wasia Formations show a west to east groundwater flow direction (Fig. 3a).

The water samples collected from the western part of the study area are from the Biyadh aquifer and those from the eastern part (beyond latitude 47.78125E° as shown in Fig. 2) are from the wells tapping the Wasia aquifer with a transition zone in the central part of the study where the wells are tapping either the Biyadh or Wasia aquifer. The average depth to groundwater level is 113 m and the piezometric level follows the general topography of the area (Fig. 3b).

3. Methodology

Groundwater quality data from 73 bore wells were obtained from the Ministry of Water and Electricity reports on Wasia and Biyadh aquifer in the Kingdom of Saudi Arabia (MoWE, 2015). The data consisted of 12 parameters (pH, EC, TDS, Na. Ca, Mg, K, HCO_3, SO_4, Cl, NO_3 and F). The sampled bore wells tap the Biyadh and Wasia aquifer and are used for irrigation, industrial and public water supply.

Standard procedures were followed during the sampling. Unstable parameters such as pH, TDS and EC were measured in the field using multi-parameter pocket meters (Multi 340i, WTW). The samples were filtered through 0.45 μm pore diameter filters and were preserved using Nitric acid. The samples were stored in cooling boxes at temperatures below 5 °C. Standard analytical techniques were followed to analyze the ionic concentrations.

The saturation indices of the principal mineral phases were calculated using the speciation code PHREEQC 2.8. Ionic relationships and groundwater facies analysis was discussed using

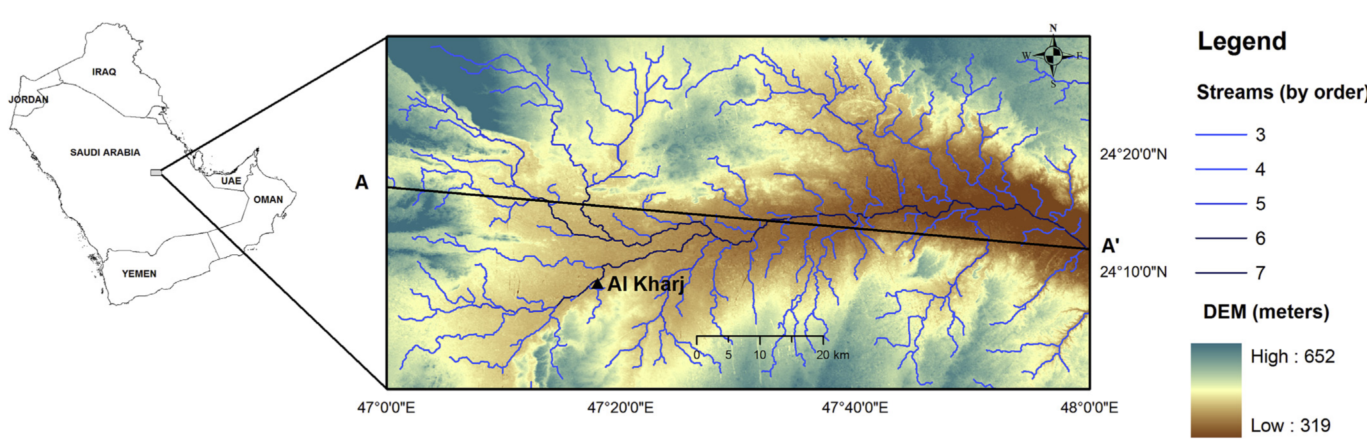

Fig. 1. Location map, DEM and drainage network of the study area.