Source apportions of groundwater in arid climate using stable isotopes

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Abstract. The isotopic composition ($\delta^{18}O$ and δD) of groundwater may alter upon interaction with the aquifer body through solid-water reactions and mixing of different water sources. The challenge of identifying groundwater sources in arid environment becomes even more complicated when effects of high atmospheric temperature and rapid evaporation are considered. We have analyzed groundwater collected from carbonates and Quaternary clastics aquifers for ($\delta^{18}O$ and δD) in Al Ain region, UAE. The results indicate range of $\delta^{18}O$ and δD from -1.8 to -2.5 ‰ and -7,4 to -15.6 ‰, respectively. Water samples collected from an open pit and dug well show enrichment in the heavy isotopes. These observations suggest that evaporative effect enhances enrichment of the heavy isotopes, but interactions in the aquifers body may contribute to the adjustment of the fractionation to modulate the evaporation enrichment effect.

Keywords: Groundwater, stable isotopes, carbonates, clastic, UAE

1. Introduction

Tracing the recharge sources of groundwater in arid regions is vital for the estimation of available water for consumption at present and in the future. With the expectation of even a drier climate and fluctuating rainfall in arid regions (IPPC, 2014), the prospect for the already overexploited aquifer systems is not promising. This situation, together with rather scattered information on the recharge possibilities of aquifers (meteoric and/or juvenile sources), has further made accurate evaluation of groundwater overturning recharge difficult. A good example of the stressed groundwater resources is found in the United Arab Emirates (UAE) which is facing significant challenges. Groundwater of the region plays an important role in the agricultural and domestic practices. The country witnesses economic development with population growth imposing significant increase in the demand and created a stressful impact on the natural water resources. The impact on groundwater is depletion of the quantity in the main aquifers and deterioration of the quality (Murad and Krishnamurthy, 2008; Murad and Mirghni, 2012). This situation has led to suing tools that provide identification of sources (meteoric and/or juvenile) and mechanisms (shallow or deep infiltration) of groundwater recharge. In addition, alteration of groundwater chemistry may happen during recharge and storage in the aquifer body. Thus, groundwater chemistry, particularly stable isotopes, can provide insight into recharge sources and mechanisms.

The variability of isotopic ratio of stable oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$ or hereafter δD) results from fractionation processes by atmospheric and aquifers conditions (Gupta and Deshpande, 2005). This variability is used here to identify sources of groundwater and possible mechanisms of recharge in a region characterized by arid climate conditions. The selected region used in the investigation presented here is Al Ain located in the UAE (Fig. 1). The region has dry climate with an average annual rainfall of about 50 mm which mostly occurs during winter months (Murad and Aldahan, 2017). The temperature variability is rather wide reaching on average to 10 ^{o}C in winter and up to 50 ^{o}C in summer, with an annual average of 27 ^{o}C. Most parts of Al Ain region are located < 250 m above sea level with the exception of Jabal Hafit (Hafit Mountain) that is rising at an elevation of 1150 m above sea level. The hydrogeological conditions in the area are partly controlled by recharge from meteoric water through rainfall along the Oman Mountains at the eastern and north eastern boundaries. Migration of juvenile water from deep aquifers may also be a possible recharge pathway.

2. Sampling and analytical techniques

For the purpose of this investigation, groundwater was sampled from 14 drilled wells, 1 dug well, 1 open pit and 2 rainfall (Fig. 1 and Table 1). The dominating lithology of the aquifers is Quaternary alluvial clastic deposits and carbonate rocks. Temperature of the groundwater varied at 29-32 ^{o}C. A thermal spring (water temp at 65 ^{o}C) located in carbonate rocks in Oman was also sampled and is reported here.

The analysis of oxygen and hydrogen isotopes was performed at the Center for Ice and Climate, University of Copenhagen using a laser evaporation-based mass spectrometry (Picarro 2120). Vienna Standard Mean Ocean Water (VSMOW) was used as a standard and the precision for $\delta^{18}O$ is 0.1-0.2 per mil and for δD it is 0.5-1.0 per mil.

Fig. 1 Location map of Al Ain showing the area of clastics aquifer wells (yellow ring) and the area of carbonates aquifer wells (blue ring).

Table 1. Results of isotopic analysis.

Sample	$\delta^{18}O$ ‰	δD ‰	d-excess ‰	Aquifer
SH1	-1,8	-11,2	3,12	clastics
SH2	-1,8	-7,4	7,16	clastics
SH3	-1,76	-10,9	3,18	clastics
SH4	-1,8	-11,1	3,3	clastics
SH5	-1,3	-8,4	2,32	clastics
SH6	-1,8	-9,7	4,3	clastics
SH8	-1,8	-11,2	2,8	clastics
Open pit SHA	5,4	16,7	-26,42	clastics
Dug well SHB2	0,02	4,7	4,54	clastics
Al10	-1,8	-14,3	0,14	carbonates
Al12	-1,5	-13,2	-1,16	carbonates
Al13	-2,5	-15,6	4,35	carbonates
Al15	-2	-14,7	1,32	carbonates
Al16	-2,4	-15	4,19	carbonates
Al17	-2,3	-15,4	2,95	carbonates
Al 24	-1,8	-13,9	0,45	carbonates
Hot spring Oman	-4,23	-20,8	15,0	carbonates
Rain Al Ain 2011-02-21	0,81	21,4	14,8	
Rain Al Ain 2012-12-09	-2,55	2	22,4	

3. Results and discussion

Results of the $\delta^{18}O$ and δD values of the groundwater samples show considerably narrow magnitude of variations between the wells drilled in the clastics and those in the carbonates aquifers (Table 1). In the clastics aquifer, the $\delta^{18}O$ values range between -1.3‰ and -1.8‰ while the values are little negative in the carbonates aquifer (-1.8‰ to 2.5‰). For the δD, the range of variability is comparable between the rock types (from -7.4‰ to -11.2‰ in the clastics), while higher values appear in the carbonates aquifer (δD from -13.2‰ to 15.4 ‰). The range of the isotopic variability in the carbonate rocks seems comparable to earlier measurements from the same area (Murad and Mirghni, 2012). The consistency of the data for a period of many years suggest that despite the extensive exploitation of groundwater in the area, the source isotopic characteristics did not change. Earlier isotopic data on the groundwater of the clastics aquifer are not available, but the comparable level of the $\delta^{18}O$ and δD (Fig. 2) also indicates consistent source as that of the carbonates.

The isotopic data apparently reflect comparable source of groundwater both to the clastics and carbonates aquifers in the studied areas. The most likely source is shallow meteoric water as the studied area lies at the foot of Jabal Hafit (Hafit Mountain) and is not far away from the Oman Mountains. Rainfall on the mountainous region, which may reach up to (300 mm/y), represents the main source of recharging. This consideration is also exemplified by comparing the isotopic data of the groundwater with the UAE local meteoric water line (LMWL), figure 2. The deviation of the groundwater samples from the LMWL is shown by significant enrichment in the heavier isotopes. The enrichment is larger for hydrogen compared with oxygen and apparently relates to effect of temperature. The temperature effect is manifested by two fractionation processes; 1) evaporation at different steps affecting the rainfall before entering and at the top of the aquifers and 2) thermal fractionation within the aquifer due to geothermal heat. The first process (evaporation) seems to induce fractionation patterns where preferable enrichment in the heavier isotope occurs in the groundwater. This evaporative effect has been suggested to even produce disequilibrium in the oxygen-hydrogen isotope pairs where hydrogen isotopes are less sensitive to the evaporative process (Mook, 2001). However, excessive evaporation may occur in the studied area, due to the rather dry air, leading to even further fractionation as shown by the data of the dug well and open pit (Fig. 2 and Table 1). At the same time, the rain $\delta^{18}O$ and δD (Table 1 and Fig. 2) plot at the LMWL and above it confirming the partial evaporative enrichment. The evaporative fractionation seems to affect deuterium in a smaller magnitude, due the large fractionation equilibrium, and thus indicates less depletion than in oxygen.

The thermal fractionation effect that happens in the aquifer due to geothermal heat is best illustrated by the carbonates groundwater. The groundwater temperature in wells drilled in the carbonates aquifer was at 29-32 ^{o}C. This rather limited range of temperature did not exert noticeable changes in the $\delta^{18}O$ and δD values. However, as temperature increases to 65^{o}C (the spring water of Oman), large change in the $\delta^{18}O$ and δD is found (Fig. 2). The change seems to deplete the heavier isotopes in the spring water suggesting possible solid-water interaction within the carbonate aquifer body at this high temperatures. Data from diagenetic mineral reaction in the carbonates of Jabal Hafit suggest possible geothermal temperature as much as 120^{o}C at deeper parts (2-3 km) (Sirat *et al*., 2015).

The relative fractionation of the $\delta^{18}O$ and δD in the groundwater compared to the recharge water is also expressed by deuterium excess (Fig. 3). The deuterium excess (*d-excess*), which is a value representing non-equilibrium during fractionation process (Merlivat and Jouzel, 1979), is calculated for the analyzed groundwater samples using the following equation: d-excess= $\delta D - 8\delta^{18}O$ (Dansgaard, 1964). The values of deuterium excess in groundwater samples vary from -26.4‰ to 0.45‰. This wide range of variability suggests a mixture of sources and fractionation processes that are mainly dominated by excessive evaporative effects. Particular water samples that show high evaporative effect are the dug well and open pit (Table 1). Groundwater samples showing near equilibrium loss are most of the samples from the carbonates that may have partially equilibrated by the geothermal heat.

4. Conclusions

The results of $\delta^{18}O$ and δD of groundwater presented here indicates signatures that support a predominant shallow recharge sources for both the clastics and carbonates aquifers. Evaporative and geothermal processes have contributed to the isotopic ratio characteristics of the groundwater. Evaporation effect enrich the recharge water with the heavier isotope while the geothermal heat effect deplete the heavy isotope in the groundwater.

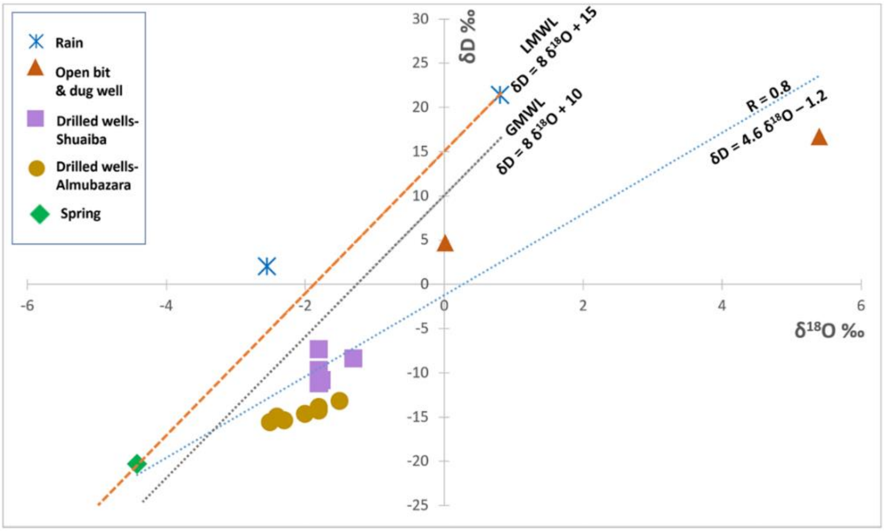

Figure 2. Plot of the isotopic data together with the Global and Local Meteoric Water Lines (GMWL and LMWL) and the linear equations for the relationship between $\delta^{18}O$ and δD.

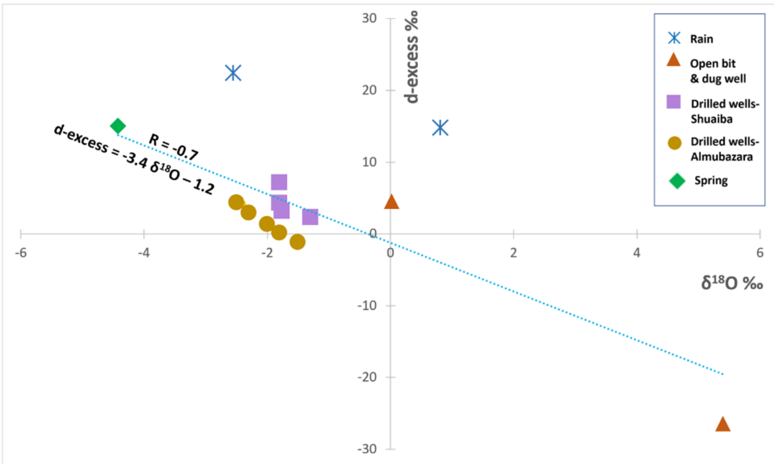

Figure 3. Plot of d-excess and $\delta^{18}O$ for the groundwater samples.

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