Uranium in groundwater and environmental impact in arid climate

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Abstract

Data on radionuclides concentration in groundwater are essential for both quality assurance and better understanding of recharge sources. In the investigation presented here, results of ^{238}U and ^{235}U analysis in groundwater across some parts of the United Arab Emirates (UAE) are discussed. The data are evaluated with respect to distribution in different aquifers, sources and effect of climate conditions. The data indicate a wide range of concentration (^{235}U= (0.12–508) ng L^{-1} and ^{238}U (26–69237) ng L^{-1}), but most of the groundwater samples have values below the permissible limit set by the WHO for drinking-water. Carbonate rock aquifers contain the highest concentration of radionuclides concentration, whereas clastic aquifers show the lowest values. Sources of the radionuclides in the groundwater are mainly attributed to natural interaction of groundwater within the rocks and sediments, but anthropogenic addition, particularly from use of fertilizers may also be a secondary source. The arid climate of the UAE may have enhanced accumulation of the isotopes in the aquifers due to limited water recharge.

Keywords: Uranium-238, Uranium-235, aquifer, arid region, United Arab Emirates.

1. Introduction

Characterizing the quality and radioactivity of groundwater is essential in order to secure the use of this valuable resource, particularly in arid regions. The investigation presented here provides a step towards establishing radionuclide environmental baseline data in groundwater of the United Arab Emirates (UAE). The UAE is entering a nuclear era in 2018 with the start of its first nuclear power station. So it is vital to establish a base line of the natural radionuclides concentration in the groundwater for both future monitoring of all types of radioactivity as well as for groundwater quality assurance. The UAE occurs in southeastern part of the Arabian Peninsula and is crossed by tropic of cancer, where the annual precipitation rarely exceeds 100 mm (Murad & Aldahan, 2017). Therefore, groundwater recharge is poor and radioactivity may accumulate in the aquifers with time. Here we present results for uranium isotopes concentration in groundwater collected from wells in different areas in the UAE. The data are further used to evaluate water quality, expected sources of the uranium and environmental implications.

2. Material and Methods

Groundwater samples from 40 wells, 13 in clastic and 27 in carbonate aquifers were collected from various locations in the UAE (Fig. 1). Most of the sampled wells supply recreational and agricultural water. The clastic aquifers represent Quaternary (last 3 million years) gravelly and silty sandstone to sand dunes. The carbonate aquifers are older (> 200 million years old) and are mainly composed of fossiliferous carbonates with subordinate chert and shales (Thomas *et al*., 2014). Temperature, pH and total dissolved solids (TDS) were measured in the field using WTW-COND-3301 instrument. The determination of uranium was performed using ICP-MS in Technical University of Denmark. 100 ng/ml indium ($InCl_3$) as internal standard was added to the sample to a final concentration of 2 ng/ml, the solution was then diluted by 10 times using 3% HNO_3 (high pure grade). Standards of uranium were prepared using similar methods as that of the samples with 3% HNO_3 by dilution of NIST uranium standard solution (NIST-SRM-4321c). Blanks were prepared using the same method with addition of HNO_3 and indium standard solution. The concentrations of the target analytes (^{235}U, ^{238}U) and internal standard (^{115}In) were measured using ICP-MS system (X SeriesII, Thermo Fisher Scientific, Waltham, MA) equipped with an Xt-skimmer cone and a concentric nebulizer under hot plasma conditions. The detection limits, calculated as three standard deviations (3σ) of the processing blank, were 0.37 mBq/L for ^{235}U and 0.95 mBq/L for ^{238}U. Measurement of Ca was performed using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). HCO_3 was measured using high performance ion liquid chromatography (HPILC). Measurements error calculated at (1σ) was <5%, while the detection limit was in the range of 0.01 to 0.2 mg/L.

3. Results

The results of the measurements (Table 1) indicate that the pH of the groundwater spans between 8 and 8.6 for the clastic and between 7.1 and 8.8 for the carbonate aquifers. TDS of the groundwater vary with less limited range (247–5310) mg L^{-1} in the clastic than in the carbonate aquifers (143–8700) mg L^{-1}. The groundwater had temperature at (30–36) °C in the clastic and (29–49) °C in the carbonate aquifers. The general concentration of ^{235}U and ^{238}U in all groundwater samples are (0.12–508) ng L^{-1} and (26–69237) ng L^{-1} respectively. The concentrations of ^{235}U and ^{238}U in the specic aquifers are (0.12– 54) ng L^{-1} and (26–7114) ng L^{-1} respectively in the clastic aquifers. The range of concetration is rather different in the carbonate aquifers where the ^{235}U varies at (4–508) ng L^{-1} and the ^{238}U at (429–69237) ng L^{-1}.

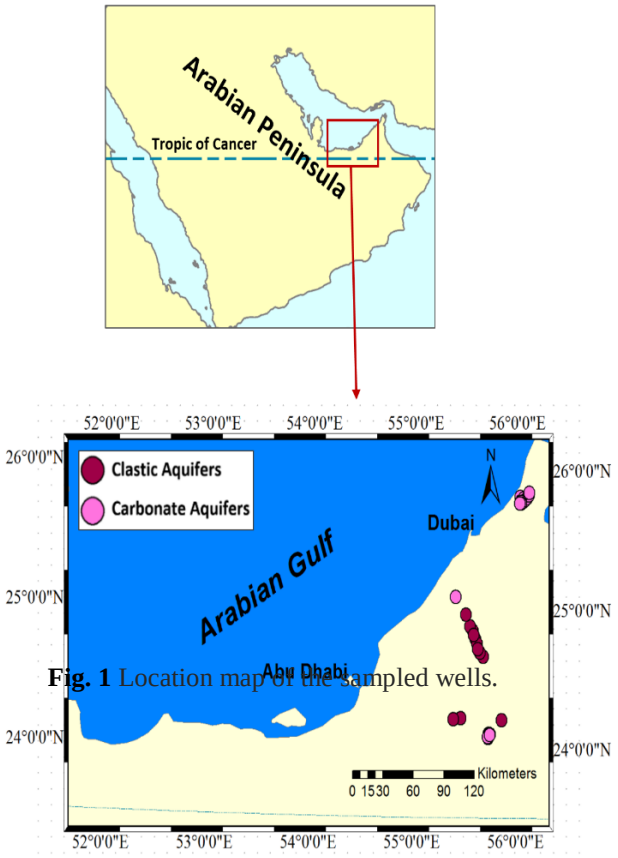

Fig. 1 Location map of the sampled wells.

4. Discussion

4.1. Uranium distribution in the aquifers

The uranium isotopes distribution patterns in the groundwater analyzed here indicate higher concentrations in the carbonate aquifers with averages ((^{235}U=42 and ^{238}U=5762) ng L^{-1}; Fig. 3) than in the clastic aquifers ((^{235}U=18 and ^{238}U=2400) ng L^{-1}). This trend might be due to availability of more uranium in the carbonates. The correlation between ^{235}U and ^{238}U shows strong positive value (R=0.99) confirming the natural abundance of uranium in the analyzed samples.

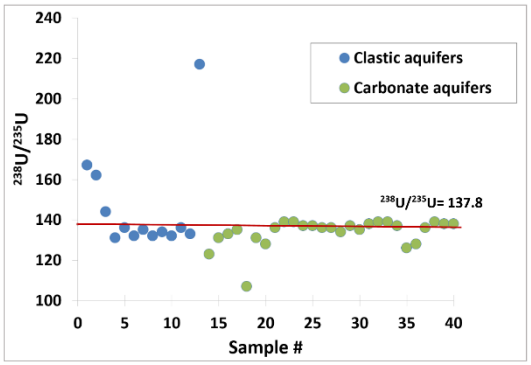

Fig. 2 The isotopic ratio of $^{238}U/^{235}U$ in the groundwater samples compared with the natural isotopic abundance as shown by the line.

reaching 217 in a sample collected from the clastic aquifers (Fig. 2). The source of this uranium isotope anomaly is not clear but it may relate to addition of uranium released from the use of fertilizers. Phosphate fertilizers can contain some uranium (Hodge, 1994) and part of that may have isotopically fractionated to enrich the ^{238}U in the groundwater. Another possible source of the anomalous $^{238}U/^{235}U$ value in Fig. 2 is weathering of uranium-rich shallow deposits. In the carbonate aquifers, one sample (sample 18, Table 1) had low isotopic abundance ratio ($^{238}U/^{235}U$=107). The source of the low ratio might relate to uranium fractionation at high temperature due to thermal waters at depth (Brennecka *et al*., 2010).

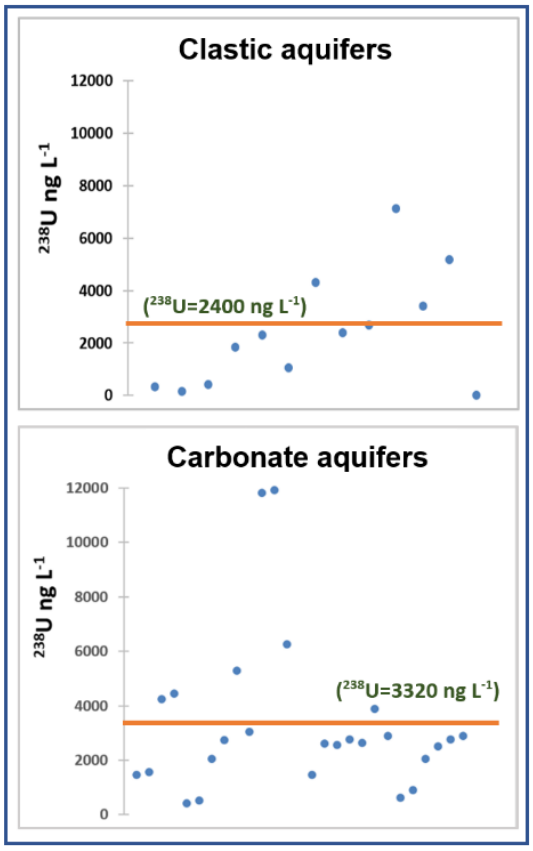

Fig. 3 Uranium distribution in the groundwater of the clastic and carbonate aquifers, the red line represents average value.

Table 1. Location and groundwater data including pH, temperature, TDS, ^{235}U, ^{238}U, $^{238}U/^{235}U$, HCO_3 and Ca (NM = Not Measured)

Sample #	Sample ID	UTM (E)	UTM (N)	pH	Tempe. °C	TDS (mg L^{-1})	^{235}U ng L^{-1}	^{238}U ng L^{-1}	$^{238}U/^{235}U$ isotope ratio	HCO_3 mg L^{-1}	Ca mg L^{-1}
Clastic aquifers											
1	AD-1	353302	2680076	8.6	32	1955	2	333	167	NM	NM
2	AD-2	344134	2679008	8	36	5310	1	162	162	NM	NM
3	AD-3	336559	2678041	8.2	35	4270	3	433	144	NM	NM
4	Kh-1	366369	2727640	8.1	32	1040	14	1837	131	NM	NM
5	MQ-1	358665	2741848	8.4	32	1190	17	2310	136	NM	NM
6	FQ-1	362995	2731012	8.1	34	1230	8	1059	132	NM	NM
7	US-1	355953	2748498	8.1	30	1250	32	4311	135	NM	NM
8	GS-1	353131	2751866	8.3	32	1320	18	2378	132	NM	NM
9	Yh-1	359981	2738171	8.4	32	1500	20	2671	134	NM	NM
10	MQ-2	356807	2745234	8.4	31	1860	54	7114	132	NM	NM
11	FQ-2	360970	2733806	8.1	31	2610	25	3402	136	NM	NM
12	Mm-1	349424	2761392	8.1	31	2830	39	5176	133	NM	NM
13	GWW-Jaw,2	384216	2677310	8.5	33	247	0.12	26	217	NM	NM
Carbonate aquifers											
14	GWW-58	372788	2665600	8.8	47	6080	12	1475	123	NM	NM
15	ADD0911078	373094	2665913	8.2	49	6100	12	1576	131	NM	NM
16	GWW-47	371506	2666511	8.1	33	6940	32	4251	133	NM	NM
17	ADD0911076	372277	2666541	8.1	35	7040	33	4448	135	NM	NM
18	GWW-F1	370885	2663116	8.2	33	7200	4	429	107	NM	NM
19	GWW-F	370657	2663966	8	35	7300	4	525	131	NM	NM
20	ADD0911080	372642	2665702	8.5	45	8700	16	2041	128	NM	NM
21	R-KH05	404577	2851081	7.5	36	1800	20	2729	136	132	163.3
22	R-KH06	404555	2851588	7.2	35	1690	38	5293	139	123	179.1
23	R-KH07	405098	2851144	7.6	37	1596	22	3050	139	134	184.5
24	R-KH13	405233	2851739	7.3	35	2730	86	11798	137	152	129.1
25	R-KH14	405789	2852053	7.7	36	2200	87	11915	137	132	472.9
26	R-KH21	402764	2854872	7.3	32	3955	46	6264	136	132	57.5
27	Rw-1	339214	2775281	7.4	29	4150	508	69237	136	NM	NM
28	R-KH08	408561	2853735	8	33	238	11	1472	134	131	51.1
29	R-KH10	403377	2850866	7.7	36	351	19	2601	137	124	125.8
30	R-KH11	403196	2851429	7.8	36	1564	19	2563	135	136	135.3
31	R-KH12	405935	2850976	7.1	36	2142	20	2764	138	150	162.8
32	R-KH15	406728	2853143	8.1	35	2238	19	2644	139	137	226.0
33	R-KH16	406153	2853900	7.5	34	900	28	3897	139	140	66.5
34	R-KH17	407252	2852160	7.8	36	1294	21	2881	137	104	291.9
35	R-KH18	409690	2854120	7.5	34	143	5	629	126	110	92.2
36	R-KH19	411196	2855958	7.9	38	155	7	894	128	114	44.8
37	R-KH20	411668	2858249	7.9	34	229	15	2040	136	128	57.0
38	R-KH01	403711	2850942	8.4	35	1510	18	2508	139	139	128.6
39	R-KH02	403589	2849530	7.8	36	858	20	2767	138	99	73.8
40	R-KH03	402635	2849717	7.1	35	6400	21	2891	138	143	13.2

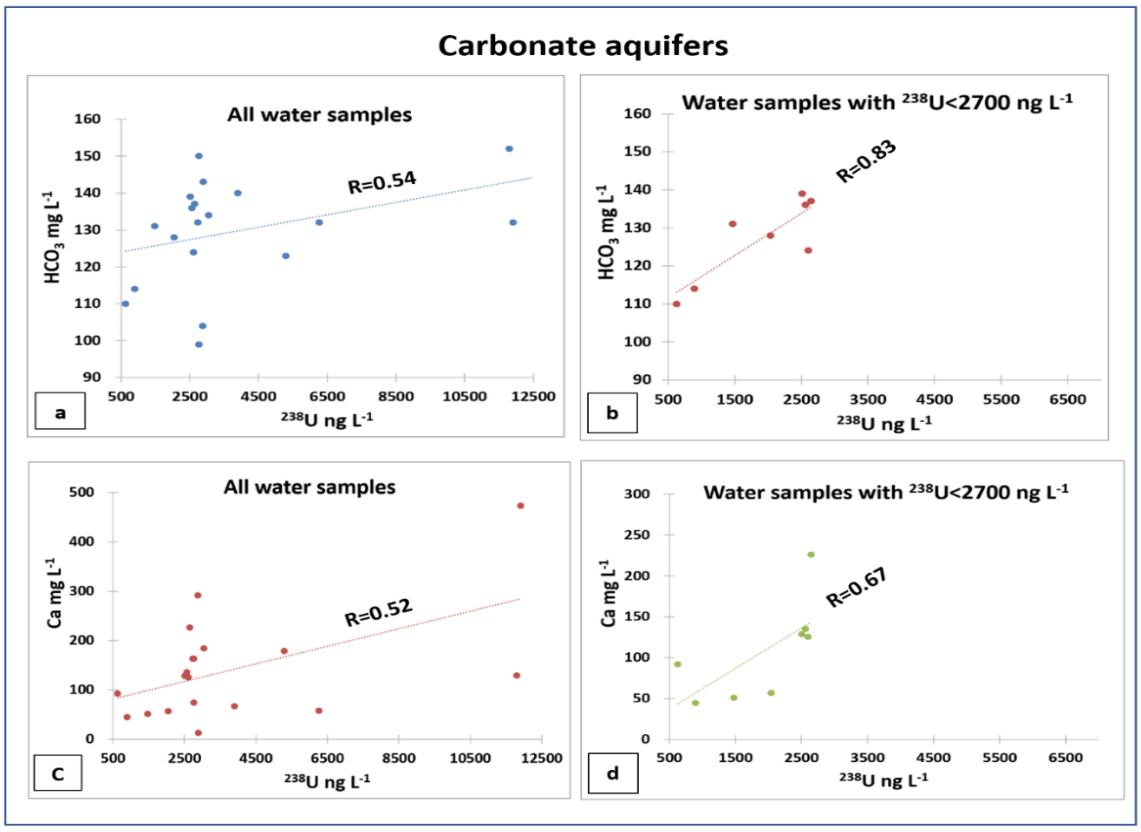

Fig. 4 Scatter plots of HCO_3 , Ca, ^{238}U in the investigated groundwater. R represents the correlation coefficients with the best fit line.

The uranium concentration in the carbonate aquifers might not be only sourced from the interaction of groundwater with the bedrocks. This feature is ilustrated by the correlations between bicarbonate and calcium with ^{238}U that show weak-moderate correlation coeffiecients of R=0.54 for and ^{238}U-bicarbonate and R=0.52 for ^{238}U-calcium (Fig. 4 a and c) when all samples are used. The correlation becomes stronger (R=0.83) between samples with ^{238}U < 2700 ng L^{-1} and bicarbontes (Fig. 4b). These samples represent around 30% of the total number of samples, and their uranium content is most likely derived from near surface sediments leaching and may be also fertilizers. In a similar manner, there is small cluster with good correlation (R=0.67) between samples with ^{238}U<2700 ng L^{-1} and bicarbontes (Fig. 4d) in the clastic aquifers. The main part of uranium in the groundwate is, howevere, sourced from bedrocks as also indicated by the high uranium isotopes concentration in other carbonate aquifers in the UAE (Zheng *et al*., 2016).

4.2. Environmental impact

Uranium has been known for its serious renal effect on human health when it exists in drinking water as it causes high calcium excretion and affect the kidney tabules (Kurttio *et al*., 2002). The World Health Organization (WHO, 2011) provided permissble concentration limit for ^{238}U at value not exceeding 30000 ng L^{-1} in drinking water. Uranium concentration exceeding the WHO permissible limit was observed only in one sample out of the anylzed groundwater samples here. The high uranium water sample comes from a well located in the coastal regoin in the carbonate aquifer. The groundwater is used for recreational activities only due to its relatively higher salinity which makes it not suitable for drinking or irrigation. All the other groundwater samples have uranium concetration below 12000 ng L^{-1} which is much lower than the maximum permissible limit. A comparison between uranium concentration presented here (arid region) with concentrations in groundwater of other claimatic regions is shown in Fig. 5. The data reveal inversely proportional relationship between annual precipitation average and uranium concentration in the groundwater (correlation coefficient R = -0.74). The higher precipitation rate might dilute the uranium concentration and thus the highest values in the UAE groundwater.

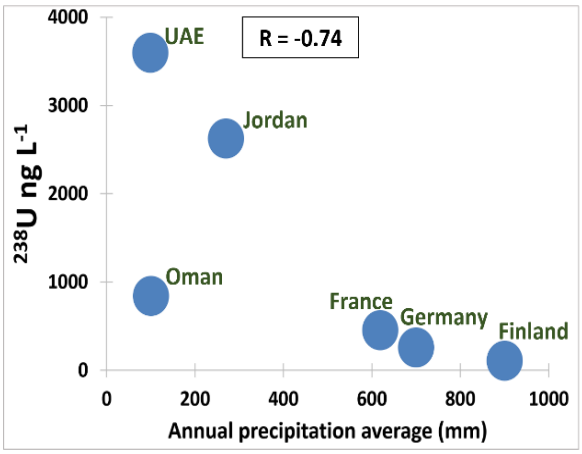

Fig. 5 A diagram showing relationship between groundwater uranium concentration and average annual

precipitation. (Data: from this work Table 1, Alshamsi, 2014; Murad & Aldahan, 2017; NOAA, 2014).

5. Conclusion

The results presented here show that concentrations of uranium isotopes in most sampled groundwater in some parts of the UAE have values below the permissible limit set by the WHO for drinking water. The data indicates that the carbonate aquifers contain the highest concentration of the radionuclides, whereas the clastic aquifers show the least values. The occurrence of uranium isotopes in the groundwater is primarily attributed to interaction between groundwater and rocks and sediments. Anthropogenic source, principally from use of fertilizers, might also have contributed to the radionuclides distribution patterns. The arid climate of the UAE may have enhanced accumulation of the isotopes in the aquifers due to limited water recharge.

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