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Application of Earth Resistivity, Hydrogeochemistry and Isotope Hydrology Methods for Assessment of Groundwater Recharge in Two Drainage Basins in Northeastern United Arab Emirates

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Abstract: *This study analyzed the water chemistry and isotope hydrology of Wadi Al Wurrayah and Wadi Al Tawiyean basins and assessed the contribution of their dams to groundwater recharge. For this purpose, 49 surface and groundwater samples were analyzed for stable (^{18}O and ^{2}H) and the radioisotope (^{3}H). Results of chemical analysis indicate that the groundwater in the study area is predominantly fresh (TDS < 1,000 mg/L), with salinity ranging from 222 mg/L (TW2) to 935 (TW8), and averaging 500 mg/L. The average values of $\delta^{2}H$ and $\delta^{18}O$ are -4.80‰ and -2.52‰, in Wadi Al Wurrayah, and -3.16‰ and -11.45‰ in Wadi Al Tawiyean groundwater, respectively, suggesting meteoric water origin. The values of $\delta^{2}H$ and $\delta^{18}O$ in Al Wurrayah and Al Tawiyean reservoirs are -1.83‰ and 2.04‰, and -2.25‰ and -2.85‰, respectively, indicating evaporative enrichment. Stable isotopes mass balance showed that the dam reservoirs contribution to aquifer recharge varies between 22% and 43%. The average tritium (^{3}H) value of 3.6 TU in Al Tawiyean basins means that the groundwater < 50 years old. Results of 2D earth resistivity imaging survey determined the location of water filled fractures and thickness of the unconsolidated materials in the wadis.*

Keywords*: Groundwater recharge, Isotope hydrology, Hydrogeochemistry, Two-dimensional earth resistivity imaging, United Arab Emirates*

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I. Introduction

The coastal plain in the northeastern part of the United Arab Emirates (UAE) extends for 70 km between Dibba in the north and the UAE-Oman borders in the south, and varies in width between 4 and 10 km between the Gulf of Oman in the east and the Northern Oman Mountains in the UAE in the west.

There are no permanent streams in the UAE, but many dry wadi channels in the north and east can carry flood water after heavy rainstorms. Streams discharging drainage basins start at the Northern Oman Mountains in the UAE drain either eastward in the Gulf of Oman or westward in the direction of the Arabian Gulf in the northwest and the sand dune fields in the west and southwest. The drainage basins can carry large amounts of water over a very short period of time, forming flash floods that can cause groundwater recharge under favorable lithological and confinement conditions. The Northern Oman Mountains in the UAE are dissected by 70 drainage basins, 58 of which lie within the UAE. The area of these basins vary from 5 km^2 (Wadi Dhannah) and 500 km^2 (Wadi Al Bih). Among these basins, 54 have areas more than 10 km^2, indicating their capability of carrying large amounts of flood water, especially the basins of the southern region which drain low permeability igneous and metamorphic rocks [1, 2, 3].

During the last four decades, the groundwater resources in the UAE have been over exploited to meet the increasing water demand, especially for agricultural purposes. Over-pumping practices has resulted into aquifers' depletion, salt-water intrusion and degradation of groundwater quality. Evidences indicated that groundwater levels have declined sharply in many farming areas. To minimize this impact, the UAE government has built more than 130 detention and retention dams. In addition, several observation wells have been installed to monitor the groundwater levels fluctuations, as well as to detect changes of the groundwater quality. Detention dams are designed to control the flow velocities and to allow appropriate time for the recharge process to take place. While, retention dams are designed to store large quantities of surface water and to raise the hydraulic heads in shallow systems, the stored water can be also used directly for irrigation purposes.

Wadi Al Wurrayah and Wadi Al Tawiyean are two major drainage basins in northeastern UAE with catchment areas of 113 and 119 km^2, respectively. Two earth rock-fill dams were built in Wadi Al Wurrayah in 1997 and in Wadi Al Tawiyean in 1991, with reservoir areas of 490,000 and 3,240,000 m^2 and reservoir storage capacities of 5,200,000 and 18,000,000 m^3, respectively [3].

The objective of the present study is to develop a better understanding of groundwater flow patterns, recharge mechanism, effectiveness of dams in recharging the shallow aquifer system and the amount of groundwater recharge due to construction of two selected dams, namely Al Wurrayah and Al Tawiyean (Fig. 1a). Hydrochemical and isotopic data (^{18}O, ^{2}H and ^{3}H) were used to calculate the contribution of both dams to aquifer recharge. A tentative isotopic mass balance based on stable isotopes of rain water stored by these dams enables quantifying the artificial recharge rate induced by Wadi Al Tawiyean and Wadi Al Wurrayah dams.

1.1 General Setting

The dam of Al Wurrayah, which was established in 1997, is located approximately 5 km northwest of Khor Fakkan town, in the eastern region [4]. This dam was constructed on fractured Semail Ophiolite bedrock, which comprises mineralized assemblages of serpentinite and gabbroic rocks. The catchment area of Al Wurrayah Basin is 113 km^2 (Fig. 1a).

The dam of Al Tawiyean in northern agricultural region was constructed in 1991 on bedrock composed of Jurassic and Cretaceous limestone. The capacity of this dam is about 18 million cubic meters (MCM), and its catchment area covers 119 km^2 [3].

II. Materials and Methods

Two dimensional (2D) Direct Current (DC)-resistivity profiling is conducted by making many measurements at different locations along the profile and at different offsets [5, 6, 7]. The 2D DC-resistivity profiling data are inverted to create a tomogram-like model of resistivity along a section of the subsurface that can be used to determine groundwater potentiality and/or detect and define individual fracture zones.

2.1 Field Work

In the present survey, eight channels Memory Earth Resistivity and induced polarization (IP) instrument and Switch Box manufactured by Advanced Geosciences, Inc. were used. The linear array of each profile consisted of 112 electrodes where the distances were controlled automatically by using an eight channel switch box. Out of forty (40) 2D resistivity profiles with a profile length ranging from 550 to 2,220 m and total length of 93 km, conducted during the period October 2005-December 2007, only eight (8) profiles in Wadi Al Wurrayah and Wadi Al Tawiyean are presented in this study (locations of these profiles are shown in Fig. 1b and c). Several sampling periods were undertaken in the study areas during the period December 2002-January 2008. Eighty three (83) water samples were analysed for major ions and forty two (42) samples were analysed for stable and radioisotopes. Figures 1a show the locations of a few samples presented in this study. The groundwater temperature in degree Celsius (°C), electrical conductivity (EC) in micro Siemens per centimeters (μS/cm), hydrogen-ion concentration (pH) and total dissolved solids (TDS) in milligrams per liter (mg/L) were directly measured in the field because they change after sample collection [8].

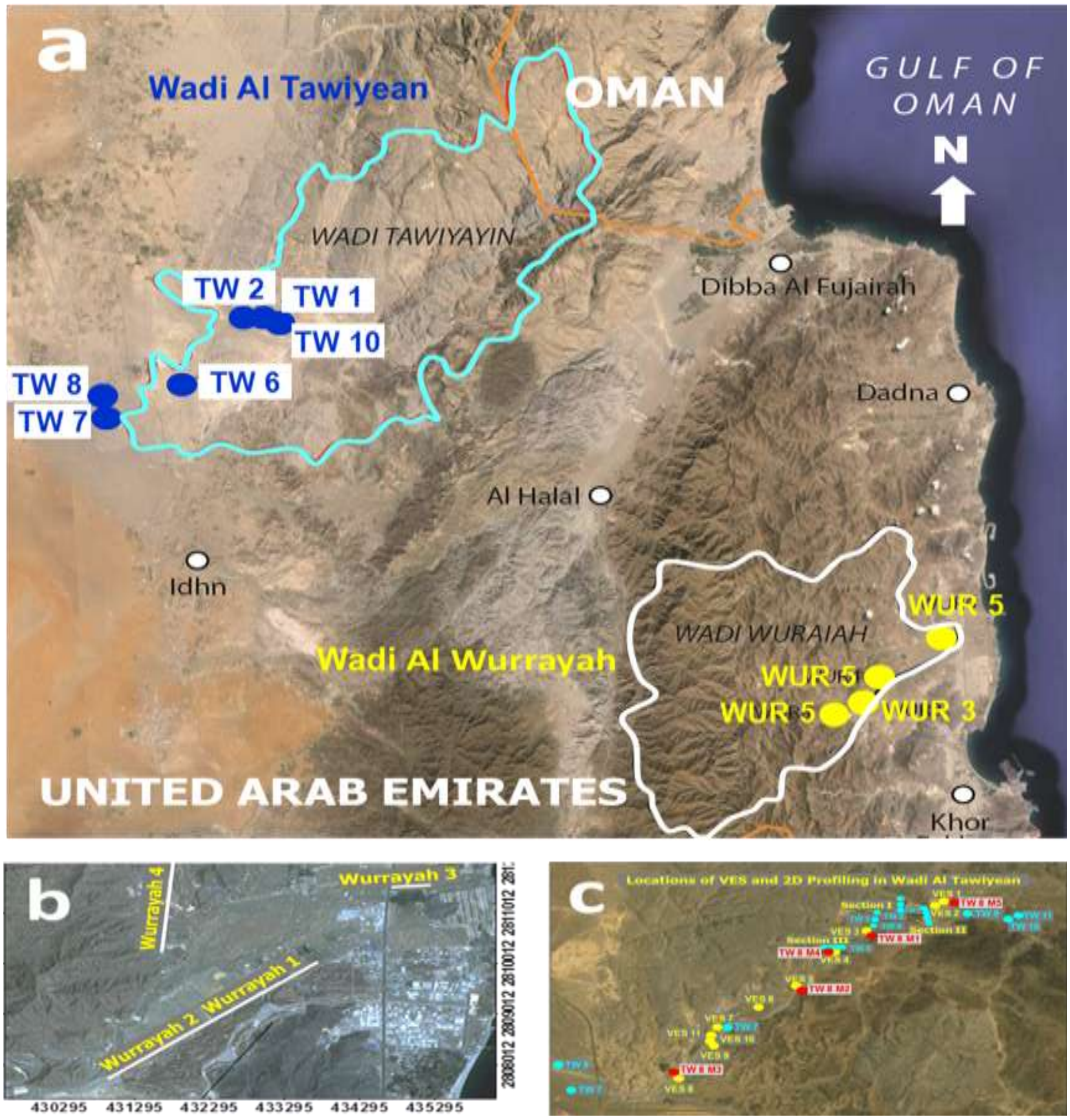

Fig. 1a Location map of Wadi Al Wurrayah and Wadi Al Tawiyean and groundwater monitoring wells sampled for the present study; b and c are location maps of 2D earth resistivity profiles in both wadis.

2.2 Laboratory analyses

The chemical analysis of the collected water samples was conducted in the Ministry of Electricity and Water (MEW) laboratories in the UAE. Standard analytical techniques described in [9, 10, 11, 12, 13], were applied. Chemical analysis of major cations and anions was performed using titration methods, ion chromatography [14], atomic absorption spectrophotometry (AAS) [15] and inductively coupled plasma-atomic emission spectrometry (ICP-AES) [16]. For measurement of TDS, a 100 mL of well-mixed water sample was filtered through a standard glass fiber. The filtrate was evaporated to dryness in a weighed dish and dried to a constant weight at 180°C. The increase in dish weight represented the TDS [12]. For determination of alkalinity, soluble carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions were measured by titration of 50 mL water sample against 0.02 N HCl solution using phenolphthalein and methyl orange indicators [13]. Ion chromatograph, model Dionex-2020i, was used for the analysis of the anions; chloride (Cl^-), nitrate (NO_3^-) and sulphate (SO_4^{2-}). The Dionex-2020i ion chromatograph is a dual-channel, high-performance chromatographic system featuring two precision analytical pumps, a dual-channel advanced chromatography module with optional column heater and two conductivity detectors. The operating conditions were 10-40°C temperature range and 1,900 psi (129 atm.) maximum pressure. A calibration curve was prepared for each anion using aliquots anion concentrations higher than detection limits. The detection limits in mg/L of Cl^-, NO_3^- and SO_4^{2-} were 0.03, 0.13 and 0.03, respectively. Prior to the determination of total metal concentrations by AAS or ICP-AES, each water sample was acidified with nitric acid (8 ml/L Analar grade), boiled for 4-5 minutes to ensure complete solubility of metal ions [13], and then filtered. Filtrate was used for both AAS and ICP-AES measurements. Atomic absorption spectrophotometry (AAS) was used for the determination of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) ions by measuring their absorbance at the maximum wavelengths, against reagent blank [15]. Determination of stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) was performed in Syria by means of a Finnigan Mat DELTA^{Plus} mass spectrometer. The tritium (^{3}H) determinations were also performed (after electrolysis) in Syria, by using a liquid scintillation counter (Quantulus 1220). Measurement accuracy for $\delta^{18}O$ and $\delta^{2}H$ are ±0.1, ±1.0‰, respectively, and ^{3}H is ±1 tritium unit (TU).

III. Results and Discussion

3.1 Two-dimensional (2D) earth resistivity methods

The geophysical data presented in this study were collected from the main channels and outlets of wadis. The locations of the 2D resistivity profiles are shown in Figures 1b and 1c. By using an iterative smoothness-constrained least-squares inversion method [17, 18], apparent resistivity data collected by the 2D DC-resistivity system were inverted to model the subsurface resistivity, which approximates the true subsurface resistivity distribution [5]. The interpretation results are discussed for Wadi Al Wurrayah and Wadi Al Tawiyean.

The water-bearing units in eastern coast area of the UAE can be classified into the Quaternary aquifer (upper aquifer), which consists of alluvial gravels, and the bedrock aquifer (lower aquifer), which is composed of fractured ophiolites. The upper aquifer is directly recharged from rainfall and the lower aquifer is indirectly recharged through the upper aquifer. Thus, it is important to determine the physical setting of the aquifer systems and their lithological variation. The location and orientation of fracture zones are also important for modeling the groundwater flow. Surface geophysical methods are regarded as rapid and inexpensive tools that could be used, in addition to drilling, for determining the locations and orientations of fractured zones in bedrock. Surface geophysics can be used in conjunction with geologic, hydrologic and borehole-geophysical investigations to optimize well drillings [19, 20, 21, 18], or as a stand-alone method for fracture detection [22]. In this study, the 2D earth resistivity imaging techniques were used to evaluate groundwater potentiality and quality in the gravel and ophiolite aquifers.

3.1.1 Wadi Al Wurrayah

Four 2D earth resistivity profiles were conducted in Wadi Al Wurrayah (Fig. 1b). Profiles Al Wurrayah-1 and Al Wurrayah-2 are located along the main wadi near its outlet area. Their interpretation results are very similar and indicate the presence of two layers; the upper one is the unconsolidated sediments vary in thickness from less than 50 m in the west to more than 100 m in the east. The upper 30 m of this layer is dry and the lower portion is saturated with slightly fresh water (Figures 2a and 2b). This layer overlies the ophiolite layer which is strongly fractured up to the depth of penetration (256 m) in some places and probably saturated with fresh to slightly brackish water in these areas. Profile Al Wurrayah-3 is located in the northern side of Al Wurrayah alluvial fan (Fig. 1b).

The interpretation results indicate the presence of one layer, with an average thickness of 100 m. The layer is mostly dry with some lenses of clay materials and/or saline water (Fig. 2c). The ophiolite layer is not detected in this cross-section but is expected to be at a depth greater than the depth of penetration. Due to accessibility problem the profile was only extended to 560 m. Profile Al Wurrayah-4 is located in the northern side of the main wadi near its outlet area (Fig. 1b). The interpretation results indicate the presence of two layers; the upper one is unconsolidated sediments vary in thickness from 20 to 50 m. This layer is mostly dry in the middle part of the profile and partially saturated with fresh water at both ends of the profile (Fig. 2d). This layer overlies the ophiolite layer which is strongly fractured up to the depth of penetration (500 m) in western part of the profile.

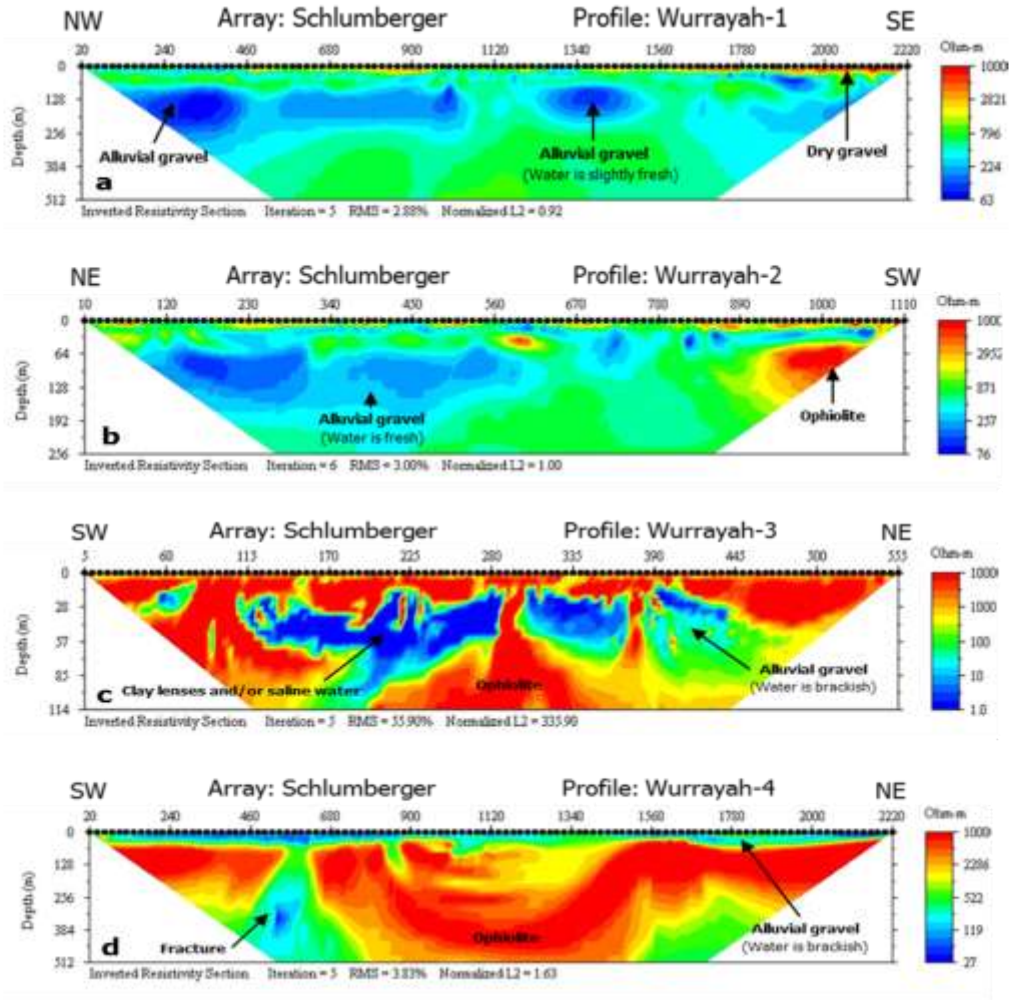

Fig. 2 Two-dimensional (2D) DC-resistivity models for profiles Wurrayah-1 to Wurrayah-4 in Wadi Al Wurrayah (see Fig. 1b for profile locations).

3.1.2 Wadi Al Tawiyean

Vertical electrical soundings (VES) were collected near the existing borehole for which drilling information is available to constrain the interpretation of the VES data and obtain a true resistivity range for each lithologic layer. The 2D resistivity profiles were constructed along the strike direction to intersect the maximum possible number of geologic features and lineaments. Three 2D profiles and eleven VES were collected from different sites in the main channel of Wadi Al Tawiyean (Fig. 1c). The northeast-southwest (NE-SW) trending fault line separates the Gweiza shale Formation, which has a resistivity of less than 50 ohm-meter (Ωm), from the Hawasina limestone Formation, which was detected in profiles 1a as shown in Fig. 3a. The dry limestone has a resistivity range of 500-1,000 Ωm while saturated fractured limestone has a resistivity range of 50-150 Ωm (Fig. 3b). The production wells of the Federal Electricity and Water Authority (FEWA) are located in a zone where the limestone is highly fractured (Figures 3c and 3d).

The correlation of the VES data interpretation results with the boreholes information obviously indicate that the surficial layer which is mainly composed of dry boulder attains high resistivity and extends from the surface to a minimum depth of 2.5 m. In addition to the drilling information, the water table information during the time of taking these measurements was used to divide the Quaternary alluvium into two zones: the first one represents the high resistive unsaturated zone and the second represents the low to moderate resistive saturated zone. The dry massive limestone has the highest resistivity values and the fractured limestone has a moderate resistivity values. Hawasina shale has the lowest resistivity values.

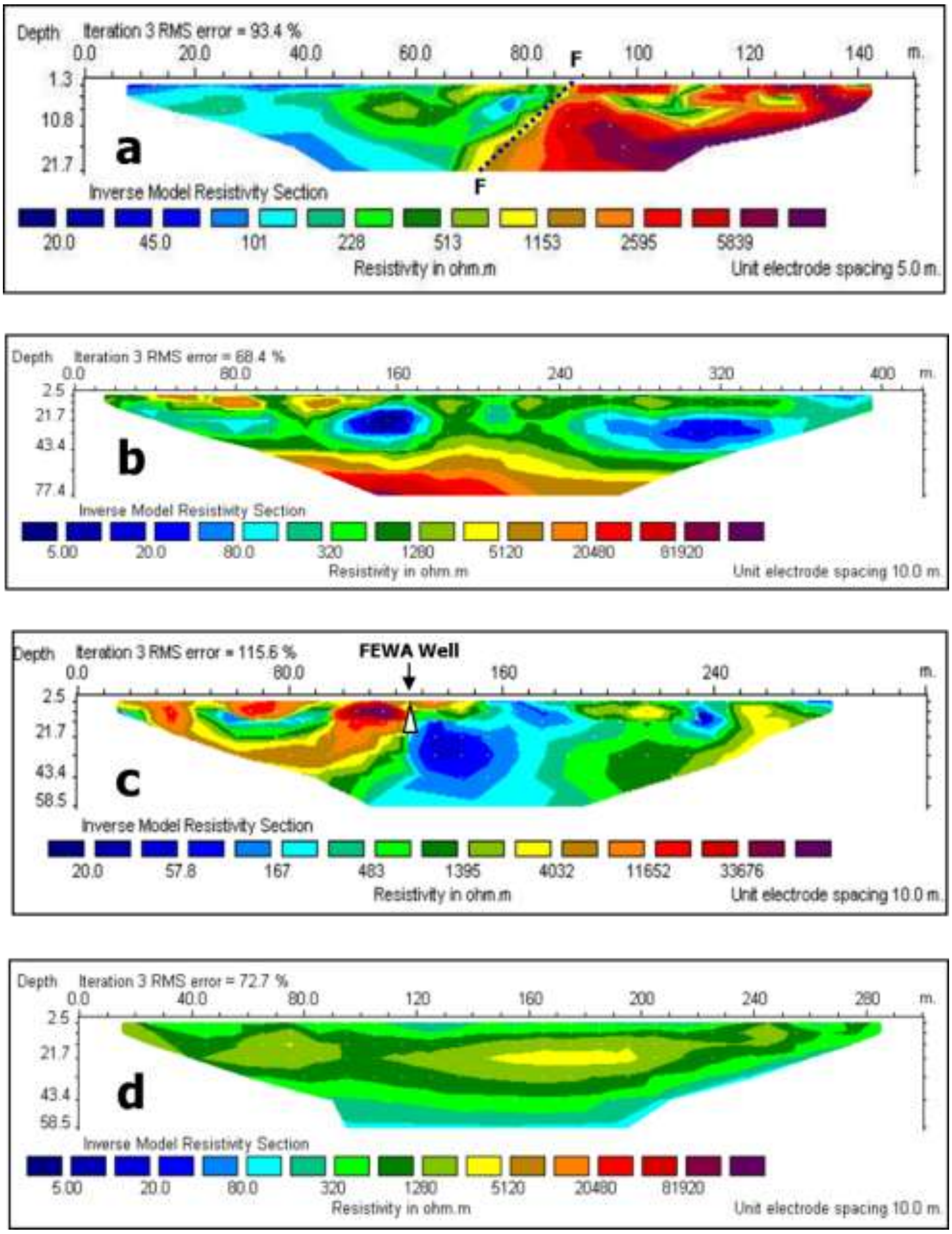

Fig. 3 Two-dimensional (2D) DC-resistivity models for profiles 1a, 1b, 2 and 3 in Wadi Al Tawiyean, see Fig. 1c for profile locations.

The inverted resistivity data together with the available drilling information and water table data of the old and newly-drilled wells indicate the presence of two aquifers in the area of Wadi Tawiyean; the Quaternary (or shallow) aquifer and the fractured limestone (or deep) aquifer. The Quaternary aquifer is regarded as the main aquifer and is composed of unconsolidated coarse sand and gravel.

The Quaternary aquifer is directly recharged from the percolating rainfall. Historical groundwater measurements indicate a significant variation in the response to recharge events and groundwater abstractions from one area to the other mainly depending on its distance from the dam. This indicates that the constructed dam has been playing a major role in enhancing the recharge of the shallow aquifer.

The Quaternary aquifer is well studied and currently is exploited for domestic and agricultural purposes. On the other hand the bedrock aquifer was not tested and needs further detailed study. However, the results of the 2D earth resistivity imaging survey indicate that this bedrock aquifer is probably extending for several hundreds of meters and thus constitutes a deep aquifer with high groundwater potentiality in the areas where it is strongly fractured and karistified.

3.2 Hydrogeochemistry

3.2.1 Wadi Al Wurrayah Basin

The major ion concentrations and TDS of water samples collected from Al Wurrayah Basin wells are listed in Table 1. The mean TDS value of surface water in the dam reservoir was 119 mg/L. The chemistry of water samples collected from wells tapping the shallow aquifer at longer distances from the dam site (Wur 5) are characterized by high TDS values, whereas those located near the dam (Wur 3) are characterized by low TDS values, indicating a possible recharge from the dam reservoir. This hypothesis is confirmed by the Schoeller-Berkallof diagram (Fig. 4), which shows similar water chemistry of reservoir water and groundwater collected from observation wells. However, the slight difference in Ca^{2+} and Mg^{2+} concentrations between the reservoir (surface water) and the observation wells (groundwater) can be explained by a cation-exchange with the clay minerals present in the shallow aquifer.

Table 1 Results of chemical analysis of water samples collected from Al Wurrayah dam reservoir and the surrounding observation wells. Concentrations are in mg/L.

Site code	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TDS
Wur3	6.2	40.1	23.4	2.0	6.0	109.3	48.3	23.2	6.8	257.4
Wur5	3.5	32.0	25.5	3.5	4.5	83.5	65.5	65.5	29.0	258.5
Wur6	3.7	21.1	49.9	6.2	7.4	92.0	72.3	19.5	3.2	278.5
Wur Dam	16.8	8.7	6.3	1.8	0.0	62.5	21.4	6.6	6.8	119.0

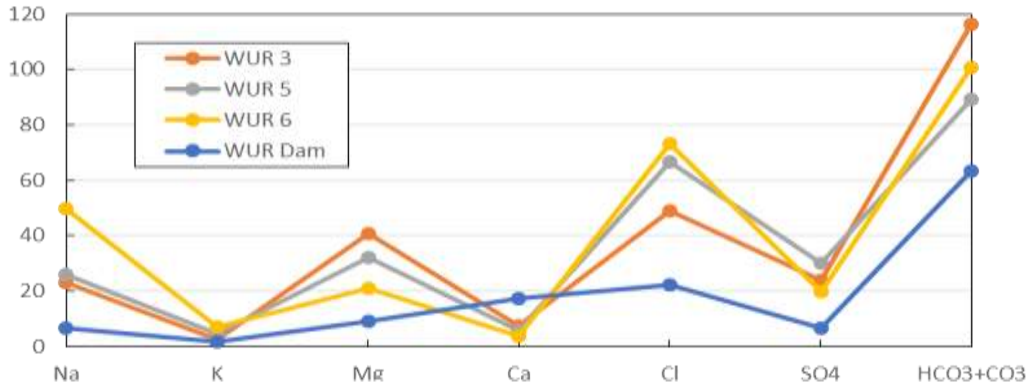

Fig. 4 Schoeller-Berkallof diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Al Wurrayah Basin.

The Piper's [23] diagram (Fig. 5) also supports this hypothesis, and shows the similarity of water types in the reservoir and observation wells, especially those of Wur 3 and Wur 5. The relationship between Cl^- and Na^+ shows that the water samples of observation wells fit the same line of surface water samples from Al Wurrayah dam reservoir (Fig. 6). The position of each groundwater sample along this mixing line is proportional to the distance from the dam site, indicating a possible mixing with water having a similar origin to that in the dam reservoir.

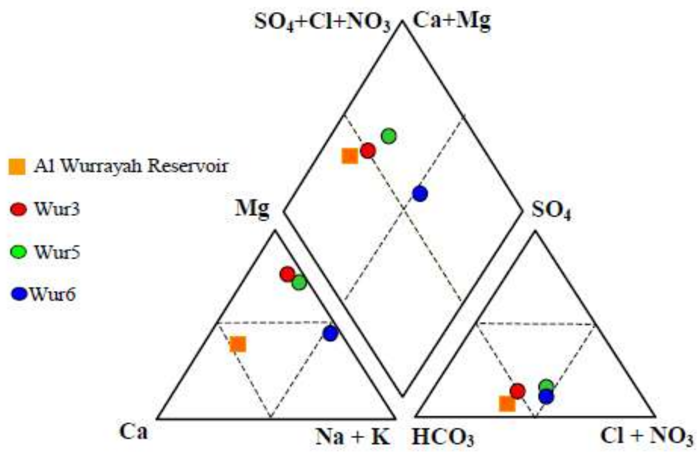

Fig. 5 Piper diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Al Wurrayah Basin.

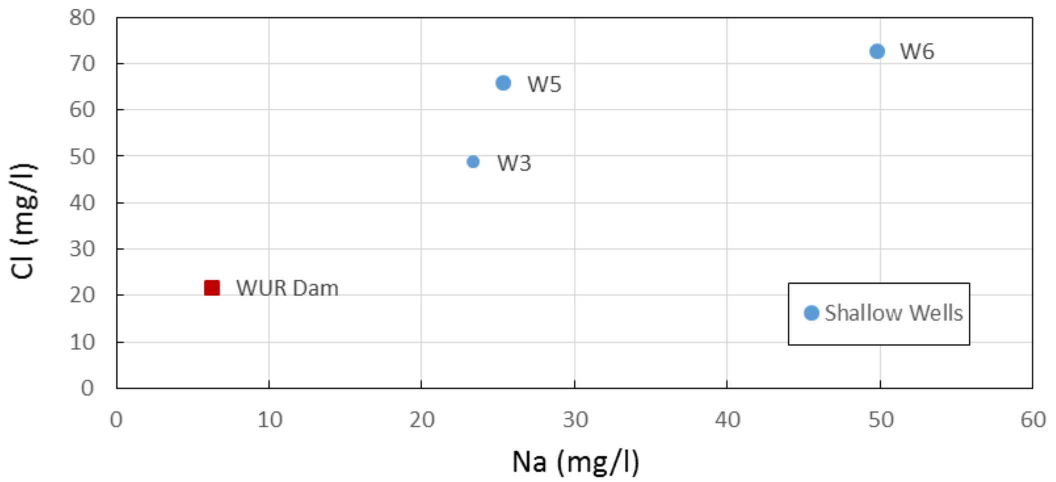

Fig. 6 Relationship between mean Cl^- and Na^+ concentrations of surface water and groundwater samples colleted from Wadi Al Wurrayah Basin

3.2.2 Wadi Al Tawiyean Basin

The mean TDS values, together with major ion concentrations of groundwater samples colleted from Wadi Al Tawiyean Basin are reported in Table 2. The average TDS of surface water in Al Tawiyean dam reservoir was 253 mg/L. Whereas, the salinity value of groundwater samples collected from the shallow aquifer ranges from 222 mg/L (TW 2) to 1,044 mg/L (TW 9) (Fig. 7). The data shows that the TDS of groundwater in the Wells TW 2, TW 6, TW 8 and TW 9, located downstream the dam site, are generally higher than that of the dam reservoir (Fig. 8). The water of these wells is most probably recharged by water coming from the dam reservoir, and suggests the increase of TDS in the direction of groundwater flow. Figure 9 represents the mean hydrochemical properties of collected water from Wadi Al Tawiyean Basin.

Table 2 Results of chemical analysis of water samples collected from Al Tawiyean dam reservoir and the surrounding observation wells. Concentrations are in mg/L.

Site code	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	TDS
TW2	29.2	16.3	12.0	3.0	2.2	137.0	22.2	14.5	8.5	221.8
TW6	48.6	18.6	83.8	4.8	1.4	213.0	81.4	72.2	22.6	504.1
TW8	22.3	12.8	265.8	5.0	5.8	236.2	248.2	126.5	11.2	934.5
TW9	39.3	19.2	200.8	4.8	0.1	234.5	168.9	156.2	27.9	1044.5
TW Dam	6.1	3.6	41.0	1.1	2.0	27.1	37.0	35.6	7.6	253.0

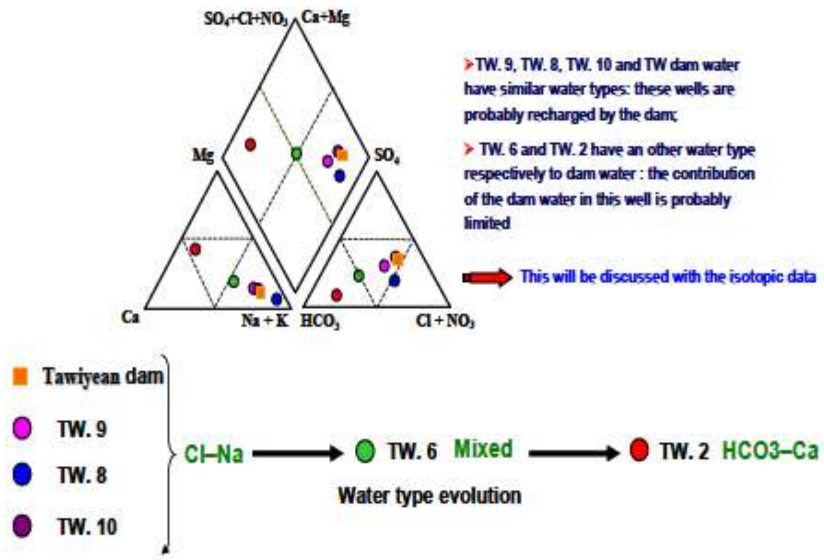

Fig. 7 Piper's (1944) diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Al Tawiyean Basin.

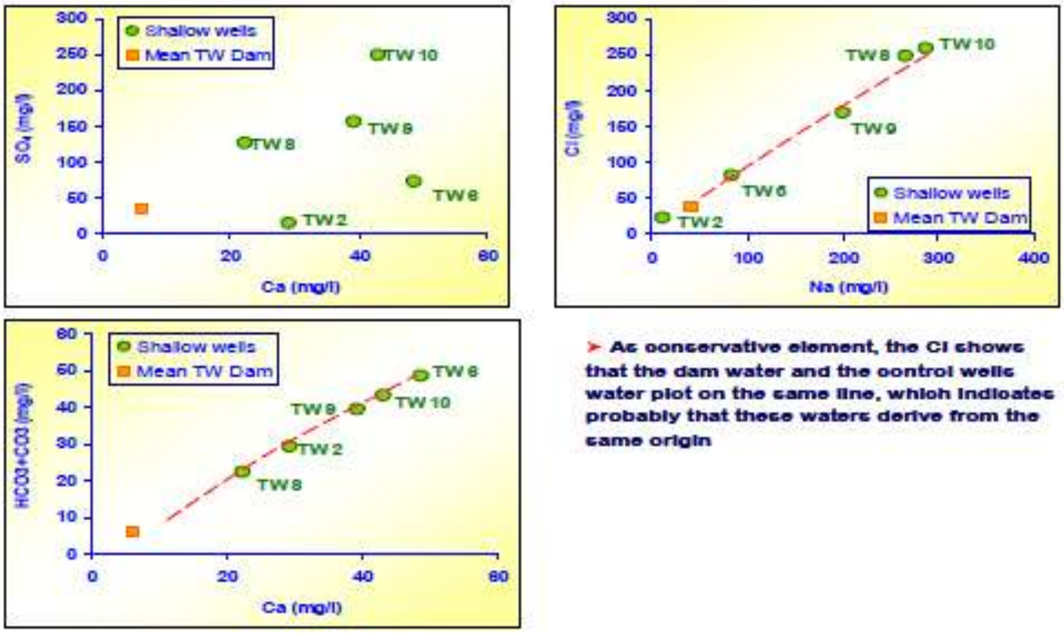

Fig. 8 Relationships between mean major ion concentrations of surface water and groundwater samples collected from Wadi Al Tawiyean Basin**.**

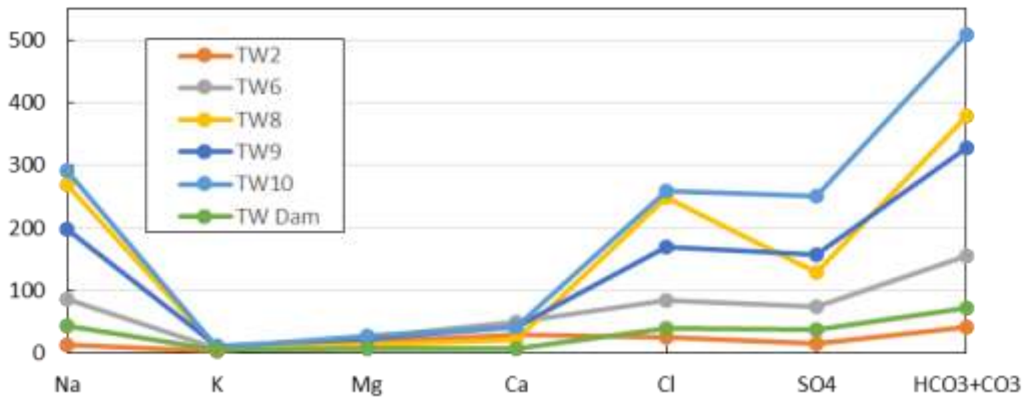

Fig. 9 Schoeller-Berkallof diagram of the mean chemical composition of surface water and groundwater samples collected from Wadi Al Tawiyean Basin.

IV. Isotope Hydrology

During this study, the available isotopic data of rainfall samples was used to define the local meteoric water line (LMWL). This line was estimated on a basis of mean isotopic data obtained within another work, realized by [24] between 1984 and 1990 in the UAE. Accordingly, the isotopic rainfall data reveals the existence of the following features (Fig. 10):

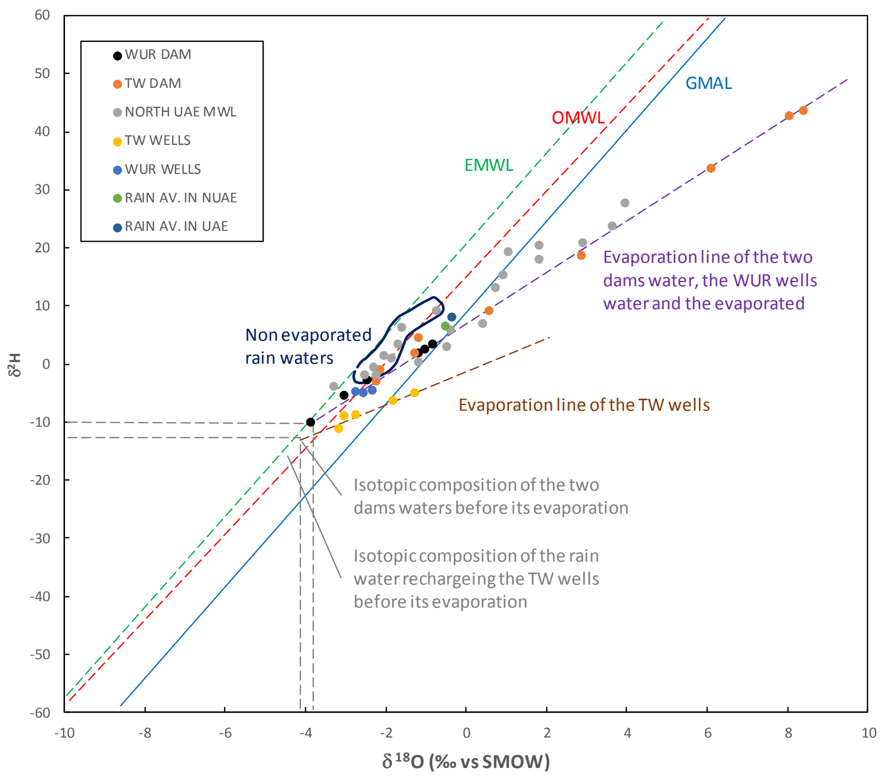

Fig. 10 the ^{2}H-^{18}O relationships of rainfall and shallow groundwater samples collected from wadi Al-Wurrayah and Al Tawiyean Basins.

The deuterium (^{2}H) - oxygen 18 (^{18}O) diagram shows that about 80% of samples fall between the global meteoric water line (GMWL), defined by a deuterium excess (*d*) around 10‰ [25], and the eastern Mediterranean meteoric water line (EMWL), defined by a deuterium excess (*d*) value of the order of 22‰ [26, 27, 28]. The rest of samples reflect the evaporation effect, especially the rain samples collected during winter months.

By considering only the non-evaporated water, mostly responsible for the recharge of the shallow aquifer, the sample representative points fit clearly a line close to that of the eastern Mediterranean meteoric water. This line (^{2}H=8^{18}O+17) reveals that a significant air masses are coming from the northwest, and most probably crossing over the Mediterranean region.

This local meteoric water line is in a good agreement with the Oman meteoric water line (OMWL) defined by the relation (^{2}H=8^{18}O+16), on a basis of rainfall data of significant precipitation amounts (>20 mm), allowing the saturation of air column and minimizing the evaporation from of rainfall droplets [29].

4.1 Wadi Al Wurrayah Basin

During this study, the available isotopic data of rainfall samples was used to define the mean stable isotopes (^{18}O and ^{2}H) concentrations of water samples collected from the observation wells and Al Wurrayah dam reservoir during the period December 2002-June 2003 (Table 3). The Wells Wur 3 and Wur 6 were sampled 14 times, while the Well Wur 5 and Al Wurrayah Reservoir were sampled 6 times.

Table 3 Minimum, maximum and average values of stable isotopes (^{18}O and ^{2}H) of water samples collected from Wadi Al Wurrayah Basin.

Site code	Minimum		Maximum		Average	
	δ^{2}H (‰)	δ^{18}O (‰)	δ^{2}H (‰)	δ^{18}O (‰)	δ^{2}H (‰)	δ^{18}O (‰)
Wur 3	- 5.90	- 2.86	- 3.60	- 2.58	- 4.81	- 2.71
Wur 5	-2.86	- 2.82	- 2.54	- 2.54	- 5.05	- 2.53
Wur 6	- 2.82	- 2.38	- 3.32	- 2.22	- 4.54	- 2.32
Wur Dam	- 3.83	- 3.30	- 3.30	- 0.78	- 1.83	- 2.04

The maximum and average values of stable isotope concentrations of the groundwater in the observation wells are represented in the ^{2}H/^{18}O diagram (Fig. 10). The concentrations of ^{18}O and ^{2}H in the dam reservoir (surface water) and rainwater samples, collected between 1984-1990 from the northern and eastern UAE are shown in Fig. 10. Stable isotopes data of Wadi Al Wurrayah Basin (Fig. 10; Table 3), shows that there is a clear similarity between the trend of evaporated samples of precipitation and the surface water sample collected from the dam reservoir. This trend completely coincides with the groundwater evaporation line of the observation wells, indicating that this water has the same origin, and thus, the groundwater in the observation wells may mostly be recharged from the dam reservoir water. In order to calculate the contribution of recharge coming from the dam reservoir water towards the shallow aquifer in Wadi Al Wurrayah Basin, an isotopic mass balance, using the stable isotopes data and their relationships was applied. Table 4 shows that the contribution of dam reservoir water to aquifer recharge varies between 22% and 43%.

Table 4 the contribution of Al Wurrayah dam reservoir to aquifer recharge, using isotopic mass balance.

Site code	Average $\delta^{18}O$ (‰, V-SMOW*)	Dam reservoir contribution to aquifer recharge (%)
Wur3	-2.71	43.02
Wur5	-2.53	34.1
Wur6	-2.32	22.09

* SMOW = Standard mean ocean water

The result of this isotopic mass balance showed that groundwater in the observation wells represents a mixture of the dam reservoir water and the present-day rains. The computed values indicate the importance of the dam reservoir water in recharging the observation wells tapping the shallow aquifer, especially Wells Wur 3 and Wur 5, which are very close to the dam site (Fig. 1).

4.2 Wadi Al Tawiyean Basin

Water samples collected from the observation wells and from Al Tawiyean dam reservoir during the study period (2002-2003) were analyzed for stable isotopes (^{2}H and ^{18}O). Table 5 illustrates the maximum, minimum, and average values of collected water samples.

Table 5 Mean, maximum and minimum values of stable isotopes (^{18}O and ^{2}H) of water samples collected from Wadi Al Tawiyean Basin.

Site code	Mean		Maximum		Minimum	
	$\delta^{2}H$ (‰)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)	$\delta^{18}O$ (‰)
TW2	-3.14	-11.24	-1.84	-5.55	-3.42	-12.70
TW6	-2.75	-8.69	-2.67	-6.65	-2.84	-9.60
TW8	-2.99	-8.07	-2.92	-1.00	-3.11	-11.70
TW9	-1.79	-6.19	-1.42	-4.40	-3.27	-11.80
TW Dam	2.13	16.62	8.43	43.40	-2.25	-2.85

4.3 Temporal Variations of Stable Isotopes

The temporal variations of stable isotope measurements made on groundwater samples collected during the period June 2002-July 2003 do not show any remarkable variations in oxygen-18 or deuterium compositions (Fig. 11).

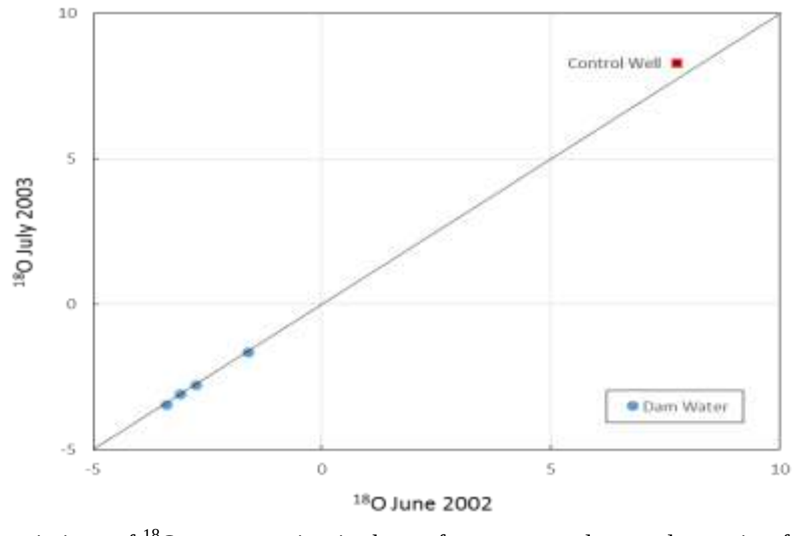

Fig. 11 Temporal variations of ^{18}O concentration in the surface water and groundwater in of Al Tawiyean Basin, between June 2002 and July 2003

However, some changes in the isotopic composition of water in Al Tawiyean dam reservoir were observed between the two sampling periods. The water samples collected from the dam reservoir during June 2003 were relatively more evaporated than those collected from the same reservoir one year earlier. This difference in the stable isotopes composition of reservoir water samples agrees with the hypothesis that there are multiple origins of water, as the hydrochemical data suggests.

4.4 Tritium in Groundwater

The tritium analyses of Wadi Al Tawiyean Basin were performed for the water samples collected during the period 2002-2003. The data of tritium concentrations shows that their influence on the determination of recharge origin was rather limited, especially in this case study, because of the limited range of variations.

This means that the water in the dam reservoir deviates slightly from the recent recharge water, which has similar behavior to that of present-day precipitation (Fig. 12; Table 6). However, the presence of tritium in all groundwater samples proves that the water in the shallow aquifer of Wadi Al Tawiyean Basin is of a recent age, less than 50 years.

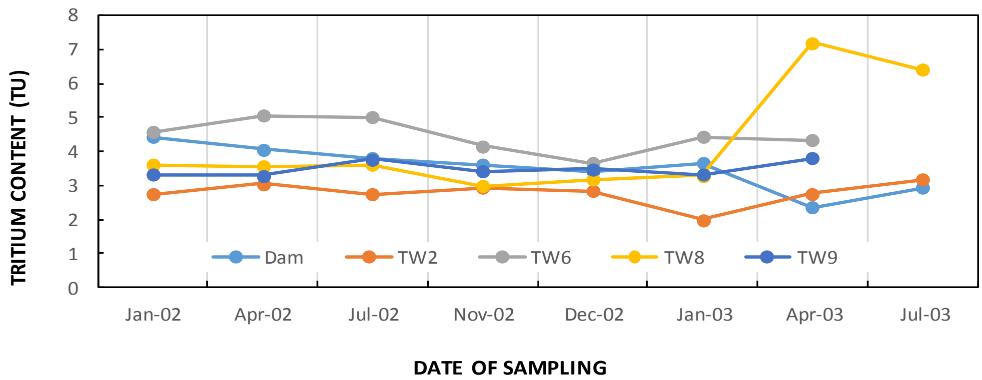

Fig. 12 Variations of tritium (^3H) content in the observation wells and dam reservoir water of Wadi Al Tawiyean Basin.

Table 6 Mean tritium (^3H) values in surface water and groundwater samples collected from Wadi Al Tawiyean Basin.

Site code	^3H content (TU)	Site code	^3H content (TU)
Tw2	2.72	Tw9	3.42
Tw6	4.4	Tw10	2.93
Tw8	4.18	Tw Dam	3.96

V. Conclusions

This study aimed at quantitatively assessing the artificial recharge induced by Al Wurrayah and Tawiyean dams in the UAE. The obtained results allow highlighting the contribution of the above mentioned dams as a source of artificial recharge for the alluvial and ophiolite aquifer systems in northeastern UAE. The hydrochemistry and isotopic data, especially those related to Al Wurrayah Basin, show that there is a significant contribution to aquifer recharge from the dam reservoir site. A tentative mass balance based on stable isotopes of rainfall, surface water stored in the dam reservoirs and groundwater from selected observation wells indicated that the of artificial recharge rate from Al Wurrayah dam reservoir ranges from 20% to 40%. This high recharge rate is related to hydrogeology of the studied areas, which are dominated by intensively fractured igneous and metamorphic rocks. In spite of the high evaporation rate in this part of the country, the estimated amounts of artificial recharge seem to be very important, and prove the retention and detention dams have an important role to play in development and management of water resources in the UAE. The chemical and isotopic data obtained so far from Al Tawiyean Basin did not help to clearly detect any significant recharge from the dam reservoir site. Recent infiltration seems to take place at the observation wells, as learned from the measured tritium content. By considering the scarcity of available data for Wadi Al Tawiyean Basin, it may be concluded that it is still difficult to determine precisely how and when the important infiltrations have took place, as compared with Al Wurrayah dam site.

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