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Hydro-geochemical review of groundwater and rain waters from Al Jabal Al Akhdar, Northeast Libya

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Highlights

- **Tritium and Carbon radioisotopes used in estimating the groundwater, surface water, springs and rain recharge rates, and origin of the water. Shallow and deep aquifers and the karstic systems are used extensively for environmental studies.**
- **Values of δ^2H and $\delta^{18}O$ indicate increase in aridity, as deuterium excess is reduced due to evaporation effects.**
- **Mixing of fresh water with the seawater indicates that the stable isotopes are enriched due to evaporation.**
- **High contents of bicarbonate ions suggesting most carbon in solution derives from the reservoir limestone.**

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ABSTRACT

Groundwater recharge and age dating using stable and carbon isotopes in northern Cyrenaica have been performed during the seventies of the last century. Twenty-eight groundwater samples (springs and wells), as well as sixty rain water samples, were collected from four hydrogeological units in Al Jabal Al Akhdar that have been analyzed in order to determine the composition of the stable isotopes (δ^2H, $\delta^{18}O$, ^{14}C, and ^{13}C). Tritium is used herein to determine if there is any direct infiltration of modern water to the existed aquifers in the study area. The range of compositions for each rainwater sample is: δ^2H (–28.3‰ to 0.3‰) and $\delta^{18}O$ (–5.32‰ to 0.33‰) for Benghazi rain samples whereas δ^2H (–35‰ to –22.6‰) and $\delta^{18}O$ (–6.5‰ to –4.43‰) for Al Marj rain samples which show apparently oceanic and continental effects on the studied samples to the Global Meteoric Water Line (GMWL). The Miocene water samples have δ^2H and $\delta^{18}O$ values indicated an increasing in aridity as the deuterium excess is reduced due to evaporation effects. Given this result, the isotopic values indicate that the groundwater pumped from wells in Benghazi – Al Marj region resulted from the mixing of at least two groundwater systems. Seawater intrusion should be considered in the Ayn Zayanah-Al Coeffiah karstic system. Additionally, the δ^2H /$\delta^{18}O$ ratios show that most of the Ayn Zayanah spring discharges contain evaporated waters due to enrichment in isotopic values.

1. Introduction

Libya has very low precipitation values due to its location in an arid climate. However, Al Jabal Al Akhdar is located in northeast Libya (Fig. 1), which is receiving the largest annual precipitation. In particular, the coastal plain of the eastern part of Libya receives about 250 to 650 mm of annual precipitation. On the other hand, evaporation rates are likewise high, ranging from 1530 to 1710 mm/year in the north, and significantly increases towards the south. The potential evapotranspiration is minimum at the center of the northern slope of Al Jabal Al Akhdar reaching values of 1200 mm in Shahhat area and 1600 mm in the central south of Cyrenaica (Group Etude' de France en Libya, 1972). According to Ar-Lab (1978 and 1982), the evaporation at Al Makhili was recorded as 2871 to 3174 mm/yr, whereas in Msus area ranging between 3535 to 4050 mm/yr.

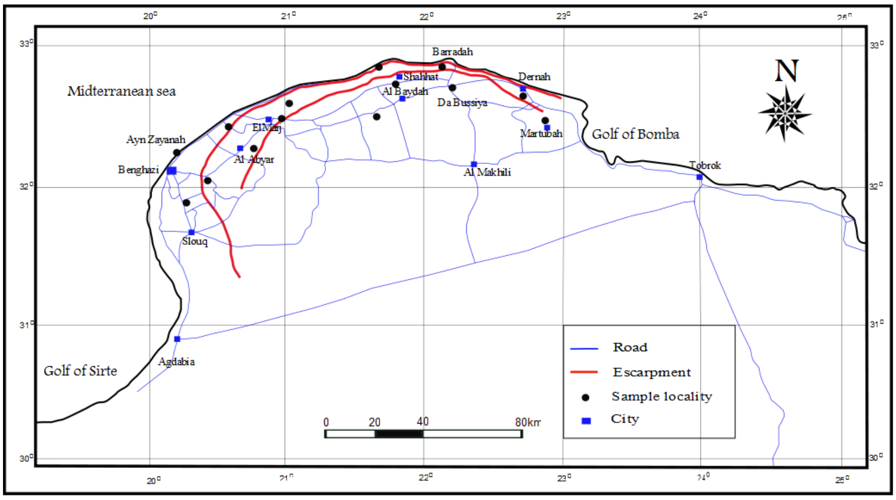

Fig.1. Location map of the study area, Al Jabal Al Akhdar, NE Libya

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Because of low precipitation fall over all the country and increase in population, the main source for water is the groundwater. In addition, as a result of excessive pumping, seawater intrusion has taken place in the Ayn Zayanah-Al Coeffiah aquifers. The purpose of this work is to re-evaluate the interaction between the precipitation and the recharge, as well as proving whether the groundwater receives modern water or not. Several unpublished studies and reports have been performed by some researchers, such as Group Etude' de France en Libya (Group Etude' de France en Libya 1971, 1972; Pallas, 1978; Franlab, 1976; Italconsult, 1977) on groundwater concerns. However, Anonymous (1975-76), Gonfintianii (1977) and Bahadur (1978) are the only works dealt with isotopic analyses of groundwater in Al Jabal Al Akhdar.

2. Geological settings

Al Jabal Al Akhdar anticlinorium is a part of the northern African-Arabian active margin that had been evolved following the opening of the Neotethys. This area is classified into the mobile province in the north (referred as Al Jabal Al Akhdar) and more stable Cyrenaica Platform province in the south by some workers (e.g. El Werfalli *et al*., 2000; El Hawat and Abdulsamad, 2004). Anketell (1996) delineated the Cyrenaica Fault System (CFS) that forms the boundary between Al Jabal Al Akhdar and Cyrenaica Platform into the North Cyrenaica Fault System (NCFS), which runs parallel to the coast of Cyrenaica offshore, and the South Cyrenaica Fault System (SCFS), which forms the southern limit of Cyrenaica Platform. The mobile area upfaulted at some regions in form of Cretaceous inliers including Jardas al Abid; Uwaliyah; Jardas al Jarari; Marawa; and the recently discovered Ras al Hilal anticline (El Amawy *et al*., 2011) with major SWS–ENE trending anticlines, where the older Cretaceous rocks are cropping out (Fig. 2). The exposed Upper Cretaceous rocks are strongly folded and faulted as indicated by the angular unconformity in Jardas area, whereas, the Paleocene, Eocene, Oligocene and the Miocene rocks are slightly folded. The rare exposures of Al Uwayliah Formation were the result of this tectonic event as reflected in unconformities (Faraj *et al*., 2016) (Fig. 2). The successions of the Al Jabal Al Akhdar are summarized in Fig. 3.

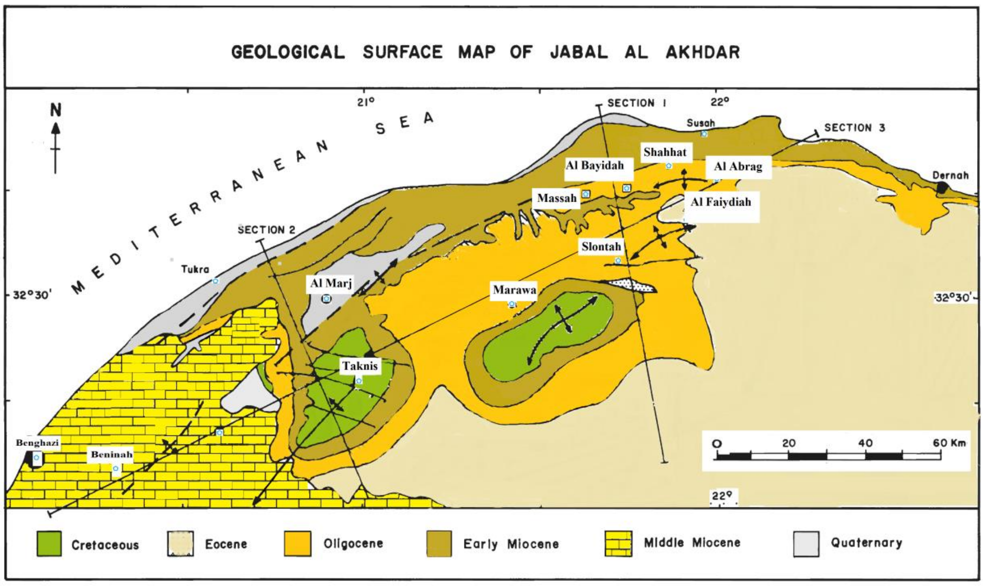

Fig. 2. The tectonic map shows the exposed rock units with Upper Cretaceous inliers (modified from El Werfalli *et al*., 2000).

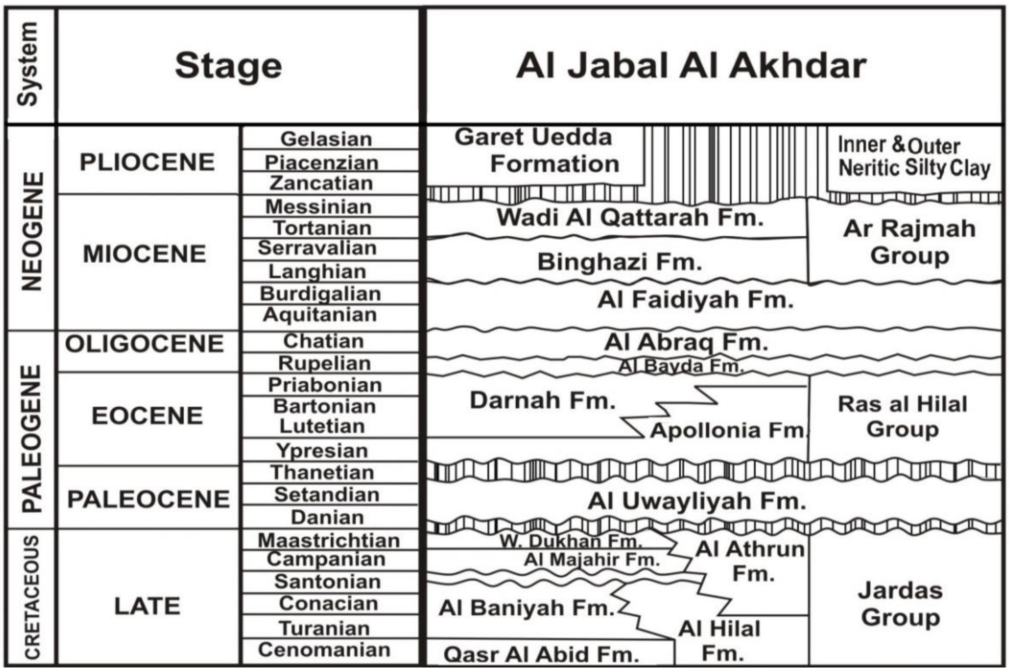

Fig. 3. Stratigraphic chart of the exposed rock units at Al Jabal Al Akhdar area (after El Hawat and Abdulsamad, 2004).

3. Methodology

Since 1972, General Water Authority (GWA) or their consultants collected groundwater, surface water, and rain samples from different regions in Al Jabal Al Akhdar. Samples were analysed to determine the composition of the stable isotopes (δ2H and δ18O, tritium and carbon) that are used to estimate the groundwater recharge rates and the origin of the water. Chemical measurements of pH, water temperature (˚C), and Specific Conductance (SC) have been measured in the field.

4. Isotopic analyses and recharge

4.1 Stable Isotopes

One of the important application of isotopic is studying the groundwater recharge. A number of researchers have used environmental ^3H, ^{14}C, D and ^{18}O, while others have used artificial isotopic tracers to magnitude the moisture movement in unsaturated soils. Recently, Mass spectrometry (MS) is used to measure the ratio of the rare isotope to the common isotope ($^2H/^1H$ and $^{18}O/^{16}O$) instead of measuring the concentration of ^2H and ^{18}O individually. The variations in many isotopic abundances are relatively small, therefore, stable isotope ratios are reported relative to a standard as δ values in units of parts per thousand (per mil, and written as ‰) (Craig, 1961). Moreover, the values for water are reported relative to VSMOW (Vienna Standard Mean Ocean Water). A stable isotope has a general expression:

$$\delta_s = \left(\frac{R_s}{R_{std}} - 1\right) \times 1000 \quad (1)$$

where Rs (s=sample) and Rstd (std=standard) are $^2H/^1H$ or $^{18}O/^{16}O$ of the sample and standard, respectively. When δ has a negative value means, the sample is depleted in the heavy and it is isotopically light relative to the standard isotope (Al Faitouri and William, 2015). The relationship between δ^2H and $\delta^{18}O$ in precipitation worldwide is called the Global Meteoric Water Line (GMWL) Craig (1961) and is represented by the following equation

$$\delta^2H = 8\delta^{18}O + 10 \quad (2)$$

4.2 Stable Isotopes Results

The stable isotope results are presented in Tables (1&2) and the location of these samples is indicated in Fig. 1. Role of stable isotopes of the water molecule has been reviewed for the solution of the problem connected with the arid zones Bahadur (1978). A number of isotopic studies were performed by different consultants at different times in different areas in northern Cyrenaica (Bahadur *et al.*, 1980). The results are summarized below. Group Etude' de France en Libya (1972) has established that there is an altitude effect for ^2H and ^{18}O from the mean annual stable isotopic concentrations for precipitations at Benghazi.

Table 1

Stable Isotope compositions of groundwater samples in per mil (GWA, 1982).

Sample No	Location		^{18}O $^0/_{00}$ SMOW	D $^0/_{00}$ SMOW	d	δD/$\delta^{18}O$	^3H (T.U.)	^{14}C % NBS	^{13}C $^0/_{00}$ PDB
1	Dabusiah	Springs in Miocene limestone aquifer	−5.8	−26.4	20.0	4.6	<1		
2			−5.8	−26.6	19.8	4.8	<1		
3			−5.3	−23.7	18.7	4.5	2±1		
4			−5.5	−26.2	17.8	4.8	2±1		
5			−5.3	−26.4	16.0	5.0	4±2		
6								62.2±1.2	−9.68
7			−5.1				10±2		
8			−3.1	−16	8.8	5.2	5±2		
9	Ayn Zayanah		−2.8	−13	9.4	4.65	5±2		
10			−1.5	−12.8	−0.8	8.5	2±1		
11			−2.3	−13	5.4	5.7	<1		
12			−2.4	−12.4	6.8	5.2	7±2		
13			−2.5		20.0		6±2		
14					0.0			38.8±2.1	−8.25
15	Baradah		−5.0	−22.8	17.2	4.6		94.3±1.5	−28
16	Shahat	Wells in Miocene limestone aquifer	−5.7	−27.4	18.2	4.8	14±2		
17	Marawa				0.0			9.7±0.7	−6.79
18	Salanta		−5.8	−28.1	18.3	4.8	6±2	35.5±1	6.97
19			−5.4		43.2		<1		
20	Al haniah				0.0			62.2±1	−9.64
21	Militaniah				0.0			4.6±0.9	−0.99
22	Abyar				0.0			4±0.6	−5.92
26			−4.9	−24.6	14.6		2±1		
27			−5.0	−24.3	15.7				
28	Beninah		−4.5	−23.3	12.7	5.2	<1		
29			−4.7	−24.5	13.1				−7.04
30			−4.4	−14.9	20.3	3.4	2±1		
31			−4.7	−24.5	13.1	5.2	5±2		
32	Al Marj		−4-4		35.2		3±2		
33					0.0			43.21±1.1	−8.06
34			−4.6	−23.6	13.2	5.21	5±2		

The range of compositions for each of the sampled unit are: δ^2H from −28.3‰ to 9.9‰ and $\delta^{18}O$ from −5.32‰ to 2.12‰ for Benghazi rain samples; δ^2H from −35‰ to −22.6‰ and $\delta^{18}O$ from −6.5‰ to −4.43 ‰ for Al Marj rain samples. The water samples collected from springs, wells in the Miocene limestone aquifer and Benghazi region, have values of δ^2H and $\delta^{18}O$ as shown in Tables (1 & 2). Fig. 4 to 7 indicate the effect of an increase in aridity as the deuterium excess is reduced due to evaporation.

Table 2

Stable isotope compositions of rain water samples in per mil (GWA, 1982)

S .No.	Location	$\delta^{18}O^0/_{00}$ SMOW	$\delta D^0/_{00}$ SMOW	d	$\delta D/\delta^{18}O$	^3H(T.U.)	^{14}C % NBS	^{13}C % PBD
1	Ayn Zayanah	2.12	−9.90	−26.86	-4.670			
2		−2.64	−12.60	8.52	4.773			
3		−2.87	−14.10	8.86	4.913	2.7±2		
4		−2.92	−13.4	9.96	4.589			
5		−2.54	−12.3	8.02	4.843			
6		−2.90	−13.1	10.10	4.517			
7		−4.98	−23.3	16.54	4.679	0.47±0.15	17.4±1	−7.59
8		−518	−25.4	16.04	4.903	0.36±0.15	17.7±0.9	−8.17
9		−3.82	−19.00	11.56	4.974			
10		−4.89	−22.1	17.02	4.519	0.36±0.2		
11		−0.33	−0.30	2.34	0.909			
12		−2.88	−12.00	11.04	4.167	2.4±0.3	26.9±3.2	−4.91
13	Beninah & Hawari	−4.96	−25.3	14.38	5.101	0.38±0.19	15.7±0.9	−7.95
14		−5.06	−25.2	15.28	4.980			
15		−4.54	−25.1	11.22	5.529			
16		−4.70	−25.2	12.40	5.362			
17		−5.26	−26.2	15.88	4.981	0.37±0.26		
18		−4.08	−22.8	9.84	5.588		4.4±0.6	−3.25
19		−4.83	−25.3	13.34	5.238			
20		−4.99	−28.3	11.62	5.671			
21		−4.93	−26.5	12.94	5.375			
22		−4.99	−26.5	12.94	5.375			
23		−4.66	−26.0	11.28	5.579		8.4±0.7	−5.43
24		−4.36	−23.1	11.78	5.298		11.6±0.8	−6.06
25		−4.53	−24.4	11.84	5.386			
26		−4.88	−27.6	11.44	5.656		6.2±0.6	−3.98
27		−4.94	−27.2	12.32	5.506		8.2±0.6	−5.78
28	Al Marj & Abyar	−4.63	−21.8	15.24	4.708		41.7±1.2	0.54
29		−4.96	−25.3	14.38	5.101		6.3±0.7	−4.38
30		−5.63	−29.4	15.64	5.222		10.8±0.8	−5.52
31		−4.56	−24.8	11.68	5.439		16.2±3.5	−7.45
32		−4.58	−23.6	13.04	5.153			
33	Beninah & Hawari	−4.81	−26.5	11.98	5.509			
34		−5.24	−28.6	13.32	5.458			
35		−4.68	−25.8	11.64	5.513			
36		−4.88	−27.8	11.24	5.697			
37	Al Marj & Abyar	−4.65	−26.1	11.10	5.613		12. 2±0.8	−6.59
38	Beninah & Hawari	−5.32	−26.4	16.16	4.962			
39		−4.46	−23.8	11.88	5.336			
40		−4.32	−25.8	8.76	5.972			
41		−4.44	−25.9	9.62	5.833			
42	Al Marj & Abyar	−5.44	−28.9	14.62	5.313			
43		−4.67	−25.4	11.96	5.439			
44		−5.06	−26.4	14.08	5.217			
45		−5.18	−26.8	14.64	5.174			
46		−4.77	−24.5	13.66	5.136			
47		−6.50	−35.00	17.00	5.385			
50		−5.28	−28.10	14.14	5.322			
51		−5.52	−28.40	15.76	5.145			
52		−5.21	−28.10	13.58	5.393			
53		−5.26	−27.30	14.78	5.190			
54		−5.20	−28.10	13.50	5.404			
55		−4.64	−25.80	11.32	5.560			
56		−4.43	−23.80	11.64	5.372			
57		−4.43	−23.80	11.64	5.372			
58	Ayn Zayanah	−5.05	−22.60	17.80	4.475			
59		−4.75	−22.70	15.30	4.779			
60	Beninah & Hawari	−4.86	−24.30	14.58	5.000			

4.3 Stable Isotopic Interpretation and Discussion

The precipitation samples at Benghazi and Al Marj- Al Abyar show that δD varied from -9.9 to -35‰ and $\delta^{18}O$ from 2.12 to -6.5 ‰ (Table 2). Fig. 4 shows apparently oceanic and continental effects of the sample from the Global Meteoric Water Line (GMWL), which inferred from Eq. 2 or may be due to the origin of moistures that releases from clouds at different elevations. Also, dominant air temperatures at these locations could affect the water. The changes in the isotopic concentrations with time for discharge at Ayn Zayanah water samples show that the water comes from precipitation under altitude and temperature conditions similar to those dominant in Benghazi area (Bahadour *et al.*, 1980). Spring waters show some occurrence of recent precipitation due to changes observed in the stable isotopic concentrations in the direction of changes observed in precipitation collected from the nearby hydrometer logical stations (Fig. 5). The isotopic concentrations of water well data show that the groundwater in the Miocene limestone aquifer of Cyrenaica is a mixed water system (Fig. 6). In addition, Guerre (1984) reported that the contents of δD and $\delta^{18}O$ in different water samples from the Ayn Zayanah karstic network indicate that these are mixed of seawater and fresh water.

Overall, the results of the analyses of 60 samples collected from eastern Libya (from Benghazi region to Al Marj) have been divided into three groups according to the geographical location. The first group includes samples collected from Al Coeffiah area closed to Ayn Zayanah, and related to the study of the spring (sample Nos. 1-12 & 58-59) (Fig. 1). The second group of samples includes those collected from Benghazi plain, mainly from the water wells in the area of Baninah and Hawari (sample Nos. 13-27, 33-36, 38-41, 60) (Fig. 1). The third group includes samples collected from Al Marj Al Abyar area (sample Nos. 28-32, 37, 42-56). Most of these samples plotted just above and on the GMWL, indicating less oceanic and continental effects (Figs. 6 & 7). Particularly, sample (No. 1) does not follow the GMWL and shows the mixing of fresh water with the seawater and indicates that the stable isotopes are enriched due to evaporation. However, the sample (No. 47) shows highly negative δ values of GMWL. The salt presence is most probably due to seawater encroachment as a consequence of intensive exploitation.

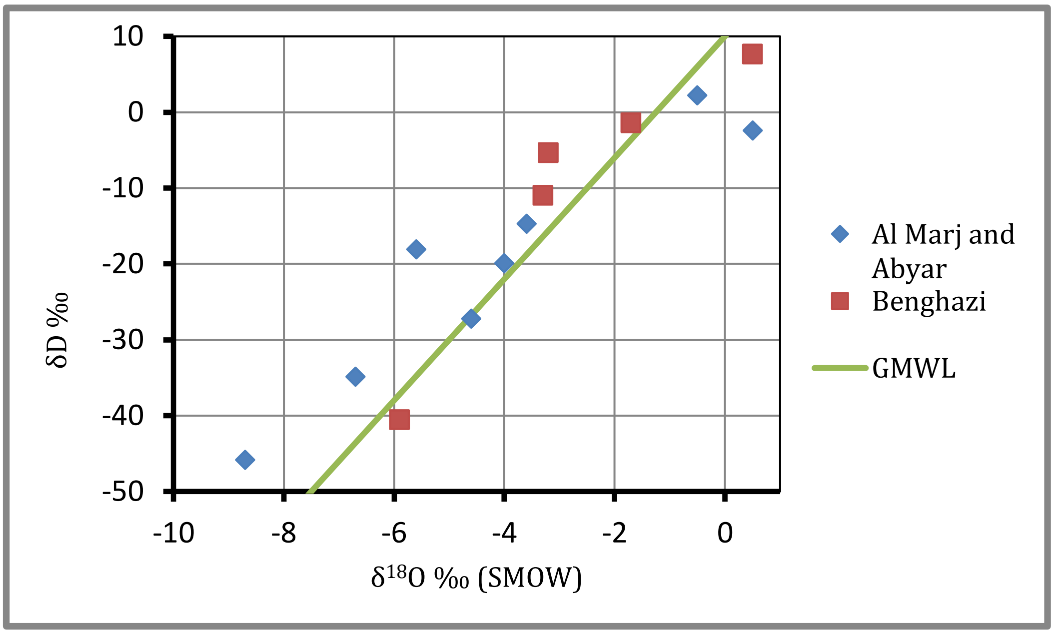

Fig. 4. Compositions of δD vs. $\delta^{18}O$ against the Global Meteoric Water Line (GMWL) from Al Marj, Al Abyar, and Benghazi areas.

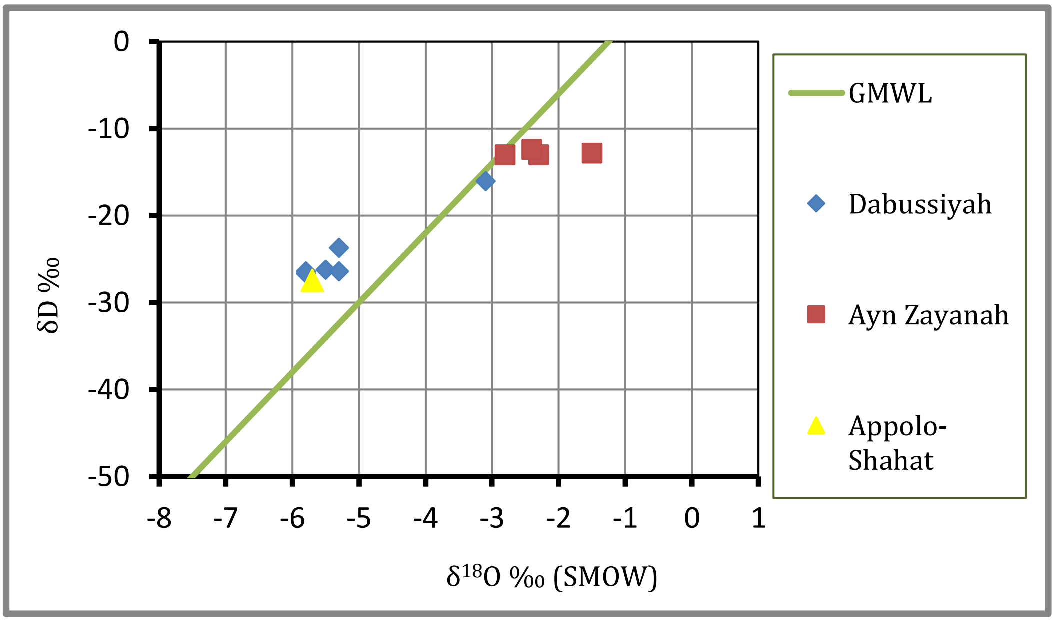

Fig. 5. Compositions δD vs. $\delta^{18}O$ against the Global Meteoric Water Line (GMWL) from Dabussiyah, Ayn Zayanah, and Appolo-Shahhat areas.

The δD and $\delta^{18}O$ relationship between all samples excluding those which contain a high seawater fraction (sample Nos. 2-6, 9, 11 & 12) are affected by evaporation (Fig. 7). The lack of homogeneity of the isotope composition is most surprising within small heavily exploited subsystem as in Baninah well field. The fraction of seawater existing at each site can also be evaluated from the isotopic composition of the three sites in Al Coeffiah area with low conductivity (sample Nos. 7, 8, 58). δD=–23.8‰ and $\delta^{18}O$=–5.07‰ representative of the fresh groundwater component. The δ values given by the seawater sample (No. 11) collected from the Ayn Zayanah indicating that the sample should contain an appreciable fraction of fresh water coming from the Blue Lagoon. Therefore, on the basis of other measurements existing in the literature available, we assume the values of δD= +8‰ and $\delta^{18}O$= +1.5‰ as representative of the seawater component. Moreover, from all the figures above, we can conclude that the groundwater consists of at least two different types of fresh waters that do not mix or only partially mix in somehow. This means that there are two or more fresh water systems present where relative contribution might change from one well to another according to the karstic fissures encountered in drilled wells. Seawater is another component that makes the picture more complicated. Several processes cause water to deviate from local meteoric water lines, e.g. evaporation from surface-water bodies, humidity, temperature, and salt concentration (Gat, 1981). Figs. 4 to 7 also show the intercept and the trends of the meteoric lines that indicate these waters were more or less isotopically light. Some samples will not follow these two groups because they could be mixtures of different types of water. It is clearly seen that the compositions of all samples are quite depleted relative to that of modern precipitation. According to Group Etude' de France en Libya (1976), most of the groundwater in Benghazi Plain are ancient and signified very slow circulation of underground waters. This appears to be contrary to the transmission characteristics of the aquifer systems of the region. The isotope geochemistry of the Miocene limestone aquifer in Al Jabal Al Akhdar for the study of regional recharge and discharge characteristics of the system has been performed by Castany *et al.* (1974). They demonstrated that the isotope geochemistry is helpful for determining the homogeneity or heterogeneity of a groundwater reservoir, and also possible to explore large scale groundwater movement. GWA (1982) had described the results of the analyzed groundwater samples from Al Coeffiah and Benghazi region, using ^{3}H, ^{2}H, ^{18}O and ^{34}S analysis. It was concluded that the samples are having some fraction of recent recharge.

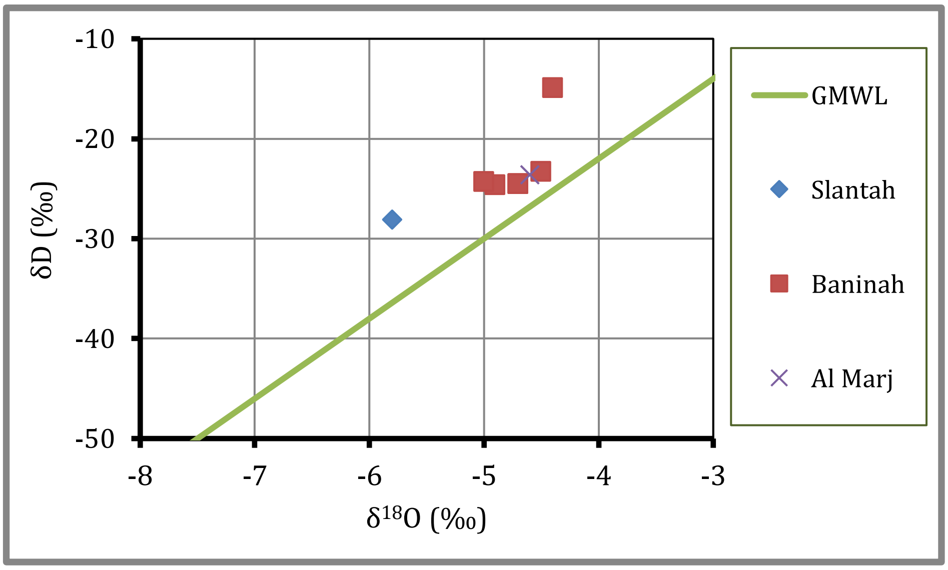

Fig. 6. Compositions of δD vs. $\delta^{18}O$ against the Global Meteoric Water Line (GMWL) from Salantah, Baninah, and Al Marj areas.

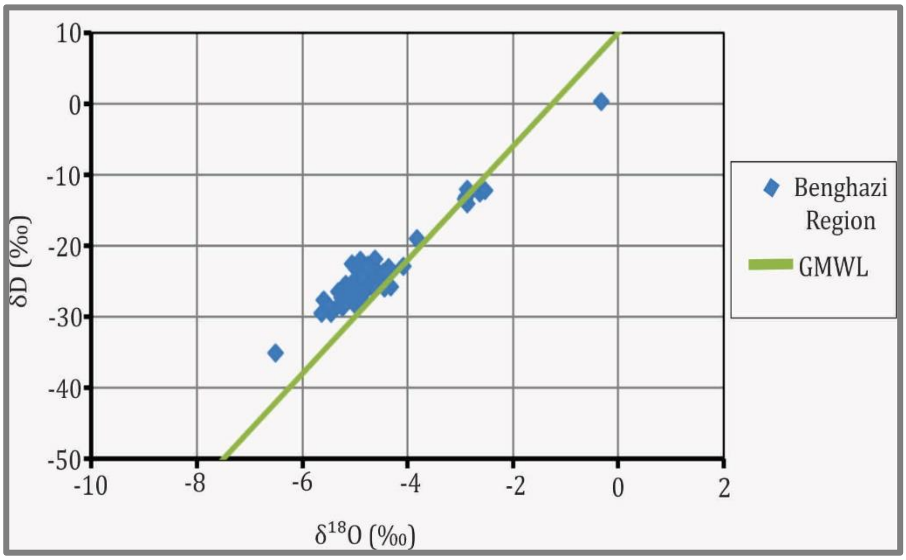

Fig 7. Compositions of δD vs. $\delta^{18}O$ against the Global Meteoric Water Line (GMWL) from Benghazi region.

Fossil groundwater at wells in Miocene aquifers (Fig. 6) are of marine origin and not terrestrial. The water at Baninah had a greater fraction of recent recharge from the precipitation. Investigation of water resources in Benghazi Plain in the area between Sidi Khalifa and Tulmaythah, shown that the groundwater samples collected during the spring season are depleted in $\delta^{18}O$ values by 0.5–0.6‰ from those collected during autumn at the same location thereby indicating that the recharge is occurring in the present environmental conditions. The maximum pollution reported in observed so far in the study area corresponded to an addition of ~20% of seawater to the contemporary fresh groundwater.

5. Tritium Samples Results

The analytical accuracy, as well as the detection limit of the tritium measurements, was approximately ± 0.1 TU (tritium units, 1 TU is equivalent to a $^{3}H/^{1}H$ ratio of 10^{-18}, which represents one atom of tritium in 101 atoms of hydrogen) (Bahadour, 1978). Tritium, which is reported in tritium units (TU), was measured by ^{3}He accumulation method where the samples were vacuum degassed and shelved for 60 days to allow for the growth of ^{3}He from tritium decay. Tritium content of the groundwater, precipitation, and springs in Cyrenaica region are high ranging from <1 T.U. to 70+4 T.U. This high content of tritium indicates that these waters have recent recharge.

The precipitation samples show that the tritium content varied from 32 to 70 TU for Shahhat area and 27 to 59 TU for Benghazi (Bahadour *et al.*, 1980). The corresponding changes in emerging springs in Miocene limestone are less than 1 to 14 TU. Table 1 shows changes in concentration depending on the location as well as the time of sampling. The wells tapping the same aquifer show a variation from less than 1 to 65 TU (Table1), thus demonstration the absence or presence of contemporary recharge respectively. It was recommended that the sampling for ^{3}H at different locations to be monitored at regular intervals of time to determine whether the concentrations are constant and to confirm the presence of more than one groundwater body on a regional scale for delineation of areas and aquifer depths for preferential exploitation of groundwater resources of the area (Bahadour *et al.*, 1980).

The tritium concentrations varied from <1 to 10±1 for Al Dabusiah spring. However, the water samples which have not been mixed with seawater show little content of tritium. On the other hand, Ayn Zayanah with about 1/3 of seawater has an average of 5 TU (Table 1). Thus, one can evaluate a tritium content of 6 to 7 TU for the seawater component. Such a concentration may have been attained by the surface Mediterranean water and therefore the seawater component of Ayn Zayanah should not be older than a few years. The amount of tritium in water from deep aquifers at Baninah wellfield indicates little of modern water but does not necessarily mean the absence of recharge. Analyses of sample collected from a well at Baninah have tritium up to 5±2 TU that is very high and may be due to the limitation of analytical system utilized.

6. Carbon Isotopes

Recently, the ^{14}C radioisotope has extensively been used for environmental studies. The main sources of the dissolved carbon in groundwater are (1) *active carbon from the soil zone, from carbon dioxide of soil gases and solid carbonate from the soil*, and (2) *less active carbon of inorganic origin, formed during the production of the bicarbonate*. Moreover, dissolved CO_2 or carbonate is depending on the pH (Fontes and Garnier, 1979).

6.1 Carbon Isotope Results

The ^{14}C activities and $\delta^{13}C$ values were determined on a different type of water: groundwater and springs samples from different sites in Cyrenaica as in Fig. 1, and the results are presented in Tables 1 and 2. ^{13}C analyses are reported as δ values relative to the PDB (Belemite of the PeeDee Formation) standard and ^{14}C abundances are reported as Percent Modern Carbon (PMC).

Carbon isotope analysis shows that the differences in the ages of groundwater samples could not be related to chemical or ^{18}O composition of the samples. In addition, ^{13}C contents of bicarbonate ions are very high, suggesting that most of the carbon in solution derives from the reservoir limestone, which does not contain C. Therefore, it is concluded, that the available data do not confirm the existence of paleo waters in the coastal plain.

In Fig. 7, plots of the $\delta^{18}O$ values against the percent of modern carbon for the wells in which there are both sets of data. It can be seen that the lighter and heavy values of $\delta^{18}O$ are associated with all age of water as shown by Percent Modern Carbon (PMC) – lower PMC, which indicates older water. This comparison suggests that the waters were recently recharged.

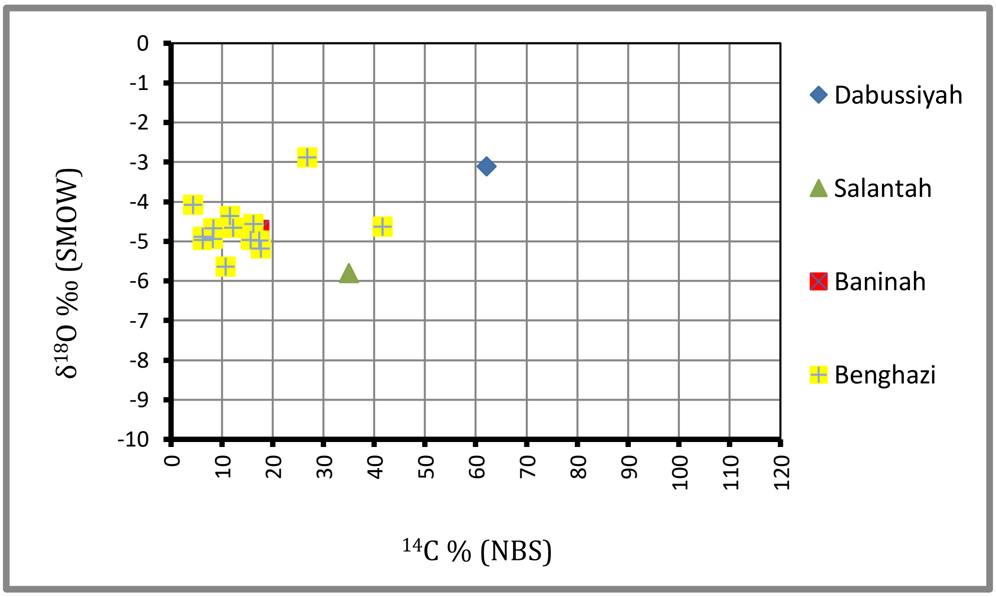

Fig. 8. Comparison of $\delta^{18}O$ vs. ^{14}C from Dabussiyah, Salantah, Beninah, and Benghazi areas. The lighter and heavy values of $\delta^{18}O$ have almost the same values but with different age.

7. Conclusions

- The stable isotopes data from the precipitated samples collected from coastal stations confirmed that the rainfall at these stations is affected by both humid and arid climates.
- Stable isotope composition of this charging water from natural springs show variations with time could be utilized to study the mixing characteristic of different aquifers by time sampling.
- The isotopic values indicate that the groundwater pumped from wells in the Benghazi-Al Marj region results from the interaction and mixing of at least two groundwater systems, to which seawater intruded in the Ayn Zayanah-Al Coeffiah area.
- The changes in stable isotopic concentrations for the spring sample show that they receive the recent recharge. The $\delta D/\delta^{18}O$ ratios show that most of the spring discharges contain evaporated waters due to enrichment in isotopic values, as well as, isotopic data of groundwater, show that they contain waters, which have been differential evaporated.
- The high values of tritium in most of the analyzed samples are linked to the nuclear bomb onwards. The ^{14}C values are not representatives in groundwater from karstified limestone aquifers, due to the influence of carbonate exchange of deeper layers of soil formation. It is the complexity of carbonate chemistry, which has denied the development of single unified criteria ^{14}C dating for all type of groundwater therefore individual aquifer systems should be studied using Carbon isotopes in close corporation with other disciplines as discussed before.
- Tritium results show that there is minor direct infiltration of rainwater. Small tritium content of these waters in Benghazi region, as well as Salantah and Dabussiyah regions, concluded that the contribution of local recent recharge to the karstic system is negligible.

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