

HYDROGEOCHEMICAL AND ISOTOPIC APPLICATIONS ASSESSMENTS TO THE GROUNDWATER ALONG THE GULF OF AQABA COASTAL PLAIN, SINAI, EGYPT

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ABSTRACT

The Aqaba border line province does not comprise extended aquifers except at two localities in the Quaternary deposits, Dahab and Nuweiba alluvial fans. Hydrochemical and isotopic studies were carried along the coastal plain of the Aqaba Gulf to ascertain the role of rainfall, local paleowater and sea water intrusion as a replenishment sources for available groundwater in this area. The brackish water body has lens-like shape above the sea level. The variation in water types is due to the leaching of terrestrial salts and the impact of marine evaporites and sea spray. Sea water intrusion via over pumping and/or during tide and ebb duration shows an affect; to some extent; on the chemical composition of some localized wells. From the isotopic point of view, it can be concluded that the groundwater in Nuweiba wells appear to have been recharged from continental and Mediterranean precipitation recent precipitation via monsoonal air mass which recharged from Indian Ocean plays a considerable role in recharging of Dahab and Sharm El-Sheikh wells. In Taba wells, seepage of partly evaporated flood water represents the main source of their recharge. The fractured and topographic nature of the investigated area has an effect on the occurrence of groundwater. Establishment of meteorological stations in scattered sites all over Sinai is necessary to collect rainwater and floods samples periodically, to study the modification of the isotopic composition of rainwater by processes which occur before groundwater recharge using environmental isotopes.

1. INTRODUCTION

The Aqaba rift border province is represented by a narrow coastal plain that extending along the western coast of the Gulf of Aqaba; from Taba at the north to Sharm El-Sheikh at the south. It is delineated by the mountainous range of the basement complex to the west and the Gulf shore line to the east (Fig. 1).

Even now the groundwater plays a critical role in satisfying the water requirements in many localities in Egypt. So, the groundwater has been the principal source of water that extensively used for human consumption and agriculture production. It could be said that the groundwater is unique source of water in Sinai. Thus serious development programs are required for idial use of this vital resource. The isotopic geochemical

investigation was undertaken to study the origin and salinity and identify groundwater recharge process.

The development of the study area as a tourist site depends on good management of the available water resources and getting accurate information about the sources of recharge and the salinity of the groundwater supply wells in the area.

The present study is concerned with the distribution of chemical constituents to evaluate the water quality of the different three localities (Sharm El-Sheikh, Dahab fan, Nuweiba fan and Taba) for drinking and agriculture purposes, and the environmental stable isotopes of O and H used in this study are considered as ideal geochemical tracers for water as their concentration is assumed as being not interacted with host rocks of the reservoir.

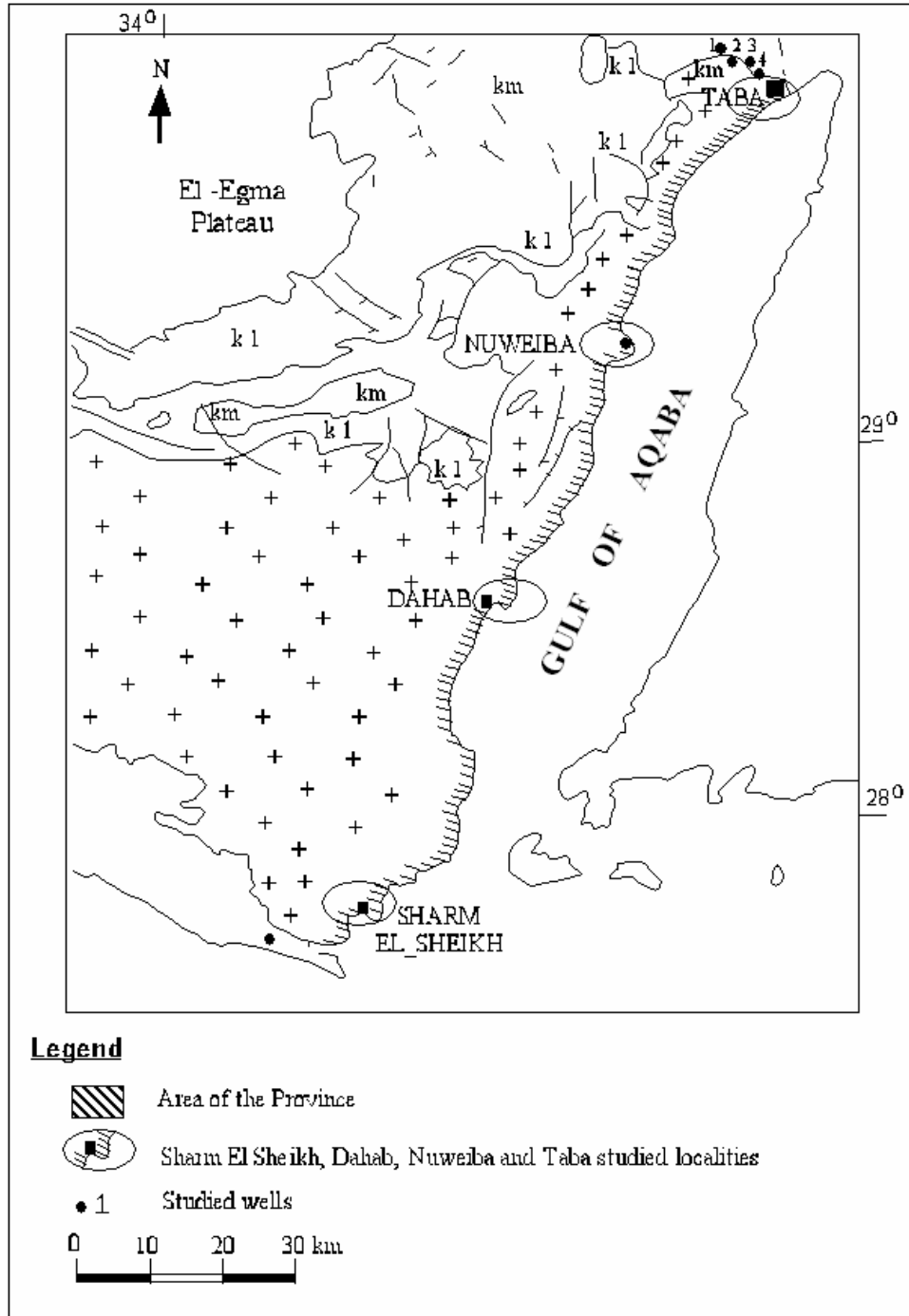


Fig. (1): Location map of the Gulf of Aqaba Border Land Province and Well Location of Sharm El-Sheikh and Taba

1.1. Climatic Conditions

The area under investigation is characterized by west ward High Mountain of basement complex. The air temperature in the area of study ranges from 24 – 42 °C during the summer and 8 – 24 °C in the winter. The temperature drops below zero in the high mountains. Hence the peaks are sometimes covered with a thin snow layer. The area receives a noticeable amount of rainfall mainly in winter. The relative humidity usually ranges from 30% to 60% but it may reach 90% during rainy season. The studied area is subjected to several floods. The local precipitation and flush floods represent the main source of groundwater recharge in the area.

1.2. Hydrogeological Setting

Geological and hydrological setting of the study area and its vicinities were previously studied by many worker, among them are Bendor and Eyal (1987), Diab (1969), Gat and Issar (1974), El Shazly *et al.* (1974), Issar and Gilad (1982), El Kiki *et al.* (1992), El Shamy and El Rayes (1992), Shata (1992), Rachwan (1994), Ghodeif (1995), Abd El Samei (1995), Shendy *et al.* (1997), Tantawi *et al.* (1998), El Sayed (1999), Tantawi (2001) and Salem and Tantawi (2001).

Sinai Peninsula forms a well defined geographic entity which is isolated from neighboring continental areas by two ocean tongues and their continuation in the rift valley. It contains a range of elevations up to 2500 m and is made up of two different geological regions, namely the southern mountainous part which is mainly built of crystalline rocks and the northern plateau and coastal regions consisting of sedimentary rocks. The coastal plain is fragmented due to tectonic activity which formed the two gulfs. The coastal plain along the Gulf of Aqaba is narrow and short alluvial fans reach it. The alluvial materials are coarse and very permeable. Water which infiltrates from the

floods or from the under flow in the wadis rapidly discharge into the gulf.

The alluvial processes play a major role in the formation and evolution of the alluvial fans fringing the gulf. The fans store water percolated and drained by the drainage net crossing the basement province. The Quaternary deposits represent the main aquifer. Older formations occupy the mountain-foot slopes as erosional remnants. The alluvial fans are built up of the erosional products of the wadi's surface its drainage net dissects different sedimentological deposits and basement rocks. The main wadis course fan out to fringe of the Aqaba Gulf forming the Nuweiba and Dahab alluvial fans. The alluvial deposits, which form the water bearing formation are heterogeneous in composition and form a coastal aquifer along the Aqaba Gulf. The water bearing formation is composed of sands (ranging in size from fine to coarse) and gravels (boulders of carbonates and basement rocks) embedded in silty and clayey matrix. This composition characterizes the heterogeneous nature of the aquifer lithology and shows that the aquifer is unconfined type. The water table configuration confirms with the general topography of the study area, and the water body forms a lens-like shape of slightly brackish quality overlying the deeper saline groundwater. The relatively fresh water thickness above the mean sea level ranges from zero to about three meters.

According to electric and gamma logs data, El Kiki *et al.* (1992) differentiated Dahab district to three zones (A, B, C), and Nuweiba to four zones (A, B, C, D). The higher resistivity zone in both areas is zone A, followed by the other zones respectively.

1.3. Sampling and Measurements

The water samples were collected from 37 hand dug wells (Figs. 1, 2, 3). One sample from Sharm El Sheikh Nubian sandstone, 11 from Dahab alluvial fan, 18 samples from Nuweiba alluvial fan, and 4 samples from

Taba area (two from wadi deposits and the other two from basement rocks) beside one surface sample from Aqaba Gulf. Groundwater is available at depth of about 2-4 m below the land surface which it is deeper in other wells to about 6-10 m below the land surface).

The groundwater samples were subjected to chemical and isotopic analyses (^{18}O and ^2H). The cations (Na^+ , K^+ , Ca^{++} , Mg^{++}) and anions (Cl^- , HCO_3^- , and SO_4^{--}) were determined using standard methods (Crompton, 1992). The oxygen-18 and deuterium were measured using a mass

spectrometer. Oxygen-18 was determined in the form of carbon dioxide after equilibrating with water samples in a special preparation line (Epstien and Mayeda, 1953). Deuterium was produced from the water samples by reduction over heated Zn, under vacuum (Coleman *et al.*, 1982). The isotope composition of oxygen-18 and deuterium are expressed as part per million deviation ($\delta\text{‰}$) of the ratio of $^{18}\text{O}/^{16}\text{O}$ or $^2\text{H}/^1\text{H}$ against SMOW (Standard Mean Ocean Water) according to the following equation:

$$\delta = [(R_{\text{samples}} - R_{\text{standard}}) / R_{\text{standard}}] \times 1000 \quad (1)$$

where R is the ratio $^{18}\text{O}/^{16}\text{O}$ or $^2\text{H}/^1\text{H}$

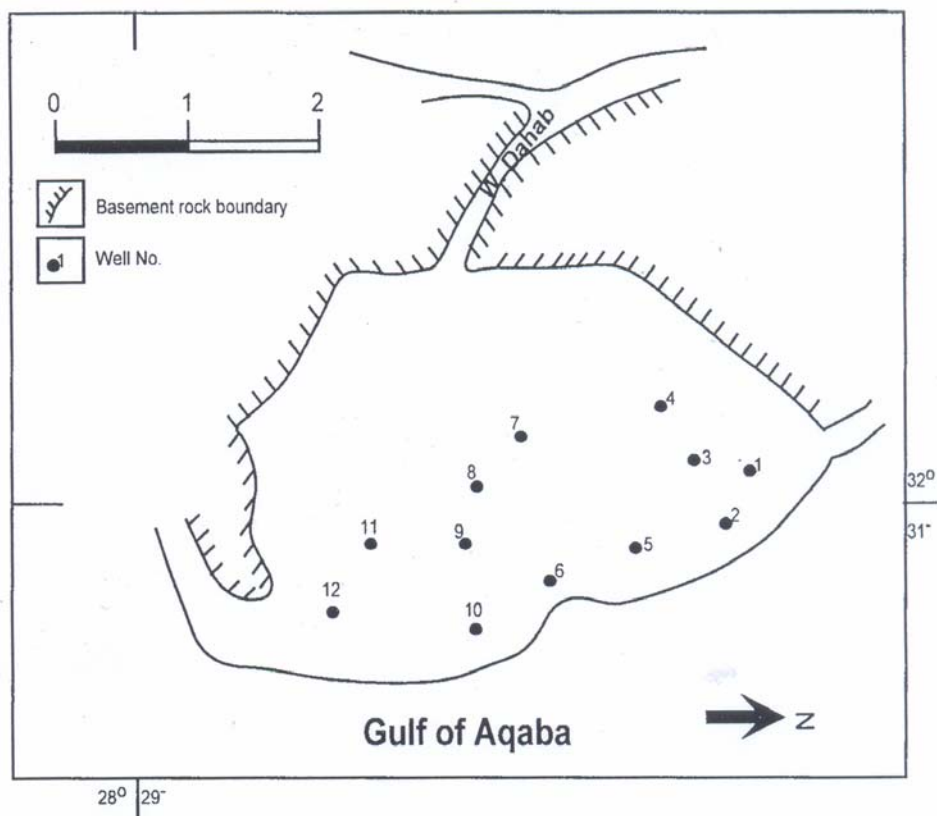


Fig. (2): Location map of Dahab Wells.

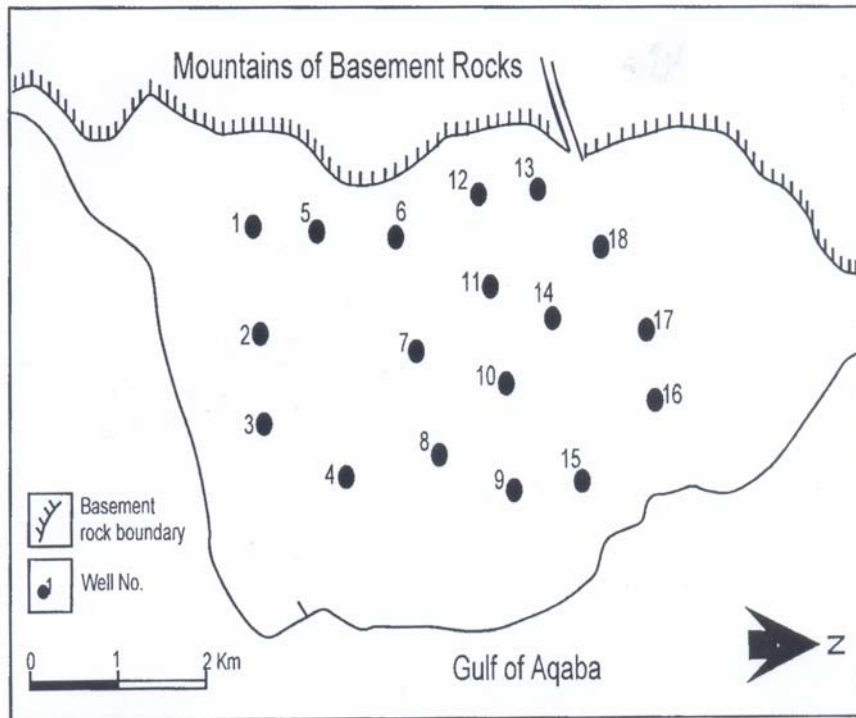


Fig. (3): Location map of Nuweiba wells.

2. RESULTS AND DISCUSSION

The results of chemical analysis for both major cations and anions, and isotopic analysis of stable isotopes oxygen-18 and deuterium of the selected wells in the study areas are listed in table (1). The hydrochemical parameters are given in table (2).

2.1. The chemical characteristics of the groundwater

2.1.1. Groundwater Quality

The pH measurements range between slightly acidic (6.8) to slightly alkaline (8.4). The slightly acidic water is located mainly in Nuweiba and Taba areas, while the alkaline ones has been recorded in most of the water

points in the coastal plain of the Gulf.

2.1.1.1. Salinity Distribution

In the concerned areas, the salinity of the investigated wells varies from (1000 – 2000 mg/l), (2000 – 4000 mg/l) and (>4000 mg/l), this reflecting slightly brackish to saline water type. The high saline water is located close to coastal line.

Chemical water types

a- $\text{Na} > \text{Mg} > \text{Ca} / \text{Cl} > \text{SO}_4 > \text{HCO}_3$ such sequence is noticed in samples Nos. 1 and 36

b- $\text{Na} > \text{Ca} > \text{Mg} / \text{Cl} > \text{HCO}_3 > \text{SO}_4$ as in samples Nos;

2,4,5,7,8,9,10 and 13 Dahab samples

32, 33, 34 and 35 Taba area

17, 21 and 26 Nuweiba fan

c- $\text{Na} > \text{Ca} > \text{Mg} / \text{Cl} > \text{SO}_4 > \text{HCO}_3$ in samples Nos.

3 and 12 Dahab
16,18,19,20,22,23 and 24 Nuweiba
d- $\text{Ca} > \text{Na} > \text{Mg} / \text{Cl} > \text{SO}_4 > \text{HCO}_3$ This category is marked in sample No. 11 in Dahab sample Nos. 14, 15, 25, 27, 28, 29 and 30 in Nuweiba
e- $\text{Ca} > \text{Na} > \text{Mg} / \text{SO}_4 > \text{Cl} > \text{HCO}_3$ Sample No. 24 Nuweiba area

2.1.1.2. Salt assemblages

Two assemblages of salt combination are defined in groundwater samples according to the methods proposed by Collins (1923). The salt contents are recorded as:

a- NaCl , MgCl_2 , MgSO_4 , CaSO_4 , $\text{Ca}(\text{HCO}_3)_2$ as in sample 1 Sharm El-Sheikh

as in sample 11 Dahab

as in samples 14, 15, 16, 22, 24, 27, 28, 29, 30 Nuweiba

as in sample 36 Gulf of Aqaba
b- NaCl , MgCl_2 , CaCl_2 , CaSO_4 , $\text{Ca}(\text{HCO}_3)_2$ as in samples 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13 Dahab

as in samples 17, 18, 19, 20, 21, 24, 25, 26, 31 Nuweiba

as in samples 32, 33, 34, 35 Taba

The presence of MgCl_2 and CaCl_2 in water samples is contributed to marine source caused by leaching or mixing with saline water.

2.1.2. Geochemical evolution

Taking into consideration chemical properties mentioned in groundwater quality section, the evolution of coastal aquifer along the Gulf of Aqaba can be summarized as follow:-

The mineralization of the investigated groundwater samples changes along the coastal plain and salinity increases towards the gulf. Sea water intrusions, at least at the periphery of the Quaternary aquifer is expected especially under extensive water exploitation from the drilled wells. Distance from the sea shore line, permeability of the aquifer and recharge conditions are factors controlling sea water wedging (El-Kiki F., *et*

al., 1992).

The TDS contents of groundwater samples varies widely from 1165 to 7100 mg/l along the S-N profile passing the area of study from Sharm El-Sheikh at the south to Taba at the north. The groundwater presents various chemical facies.

2.1.3. Chemical evolution

The chemical evolution of the investigated groundwater samples may be resulted from:

1. Three types of water / rock interaction and reaction:
 - a. Leaching of marine sediments rich in halite, gypsum and anhydrite.
 - b. Ca/Na exchange reaction with clay minerals is indicated by an excess Na and deficit in Ca as in Dahab site where the presence of CaCl_2 salt is attributed to extensive activities of Base Exchange due to very slow groundwater flow rates and discharge along deep saline water.
 - c. Dissolution / precipitation reaction of carbonates in coastal sabkhas.
2. Sea aerosols and air borne dust spreading along the coastal plain, which alter the slightly brackish water of Cl-Na type to brackish water of Cl-Mg type nearby the gulf shore. Chemically, the brackish water seems to be as a result from binary mixing between fresh water (rain and floods) and marine water rich in Cl, Na and Mg due to excessive withdrawal of saline water. The mixing ratio depends on the relative contribution of each source. The chemical composition of groundwater tapping the coastal plain areas in Sinai Peninsula is mainly controlled by aerosols originating from beach sands

(aragonite of recent reef debris) and anhydrite and Mg-calite).
sabkha sediments (halite, gypsum,

Table (1): Results of the chemical analyses of the groundwater samples in the investigated areas.

S.No.	Sample Location	Aquifer Material	pH	TDS	Units	Cations				Total Cations	Anions				Total Anions	Ionic Balance	180 %	D %	d*
						Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K		HCO ₃	Cl	SO ₄	SO ₄					
Sharm El Sheikh																			
1	El Sheikh	Nubia	7.9	1685	ppm epm epm%	140 7 25.83	102 8.50 31.36	258 11.22 41.39	15 0.38 1.42	271.10	110 1.80 6.18	650 18.31 62.76	435 9.06 31.06	29.18	-3.685	-5.70	-38.0	7.60	
Dahab Fan																			
2	1 D	Alluvium	7.65	5550	ppm epm epm%	450 22.50 37.70	105 8.75 14.66	621 27.00 45.24	56 1.44 2.41	59.69	371 6.08 10.20	1764 49.69 83.37	184 3.83 6.43	59.61	0.067	-3.15	-20.3	4.90	
3	2 D		7.80	5180	ppm epm epm%	498 24.90 39.24	136 11.33 17.86	590 25.65 40.43	61 1.56 2.47	63.45	322 5.28 8.30	1822 51.32 80.69	336 7.00 11.01	63.60	-0.120	-3.21	-18.8	6.88	
4	3 D		7.50	3550	ppm epm epm%	289 14.45 38.51	57 4.75 12.66	405 17.61 46.92	28 0.72 1.91	37.53	390 6.39 16.47	1118 31.49 81.12	45 0.94 2.41	38.82	-1.699	-3.36	-20.5	6.38	
5	4 D		8.00	3470	ppm epm epm%	291 14.55 38.20	56 4.67 12.25	420 18.26 47.94	24 0.62 1.62	38.09	303 4.97 12.45	1221 34.39 86.24	25 0.52 1.31	39.88	-2.295	-3.24	-18.3	7.62	
6	5 D		8.30	6250	ppm epm epm%	396 19.80 35.72	112 9.33 16.84	582 25.30 45.64	39 1.00 1.80	55.44	459 7.52 12.98	1777 50.06 86.37	18 0.38 0.65	57.96	-2.221	-3.19	-19.8	5.72	
7	6 D		8.40	7100	ppm epm epm%	531 26.55 33.46	129 10.75 13.55	937 40.74 51.34	51 1.31 1.65	79.35	322 5.28 6.82	1822 51.32 66.28	1000 20.83 26.90	77.44	1.219	-2.66	-17.9	3.38	
8	7 D		7.8	3730	ppm epm epm%	468 23.4 40.54	105 8.75 15.16	565 24.57 42.56	39 1.00 1.73	57.72	488 8.00 14.08	1712 48.23 84.89	28 0.58 1.03	56.81	0.792	-3.16	-17.4	7.88	
9	8 D		7.70	4410	ppm epm epm%	354 17.70 35.64	86 7.17 14.43	551 23.96 48.23	33 0.85 1.70	49.67	381 6.25 12.32	1563 44.03 86.86	20 0.42 0.82	50.69	-1.018	-3.15	-18.6	6.60	
10	9 D		7.90	5270	ppm epm epm%	401 20.05 36.59	95 7.92 14.45	587 25.52 46.58	51 1.31 2.39	54.80	547 8.97 15.47	1725 48.59 83.81	20 0.42 0.72	57.98	-2.819	-2.09	-13.3	3.42	
11	10 D		7.60	4400	ppm epm epm%	627 31.35 36.83	326 27.17 31.92	587 25.52 29.98	42 1.08 1.27	85.12	264 4.33 5.33	1744 49.13 60.45	1335 27.81 34.22	81.27	2.313	-3.23	-13.8	12.04	
12	11 D		7.20	3770	ppm epm epm%	455 22.75 33.54	204 17.00 25.06	613 26.65 39.29	56 1.44 2.12	67.84	361 5.92 9.00	1667 46.96 71.37	620 12.92 19.63	65.79	1.531	-3.38	-19.7	7.34	
13	12 D		8.10	5140	ppm epm epm%	299 14.95 33.54	75 6.25 14.02	521 22.65 50.82	28 0.72 1.61	44.57	449 7.36 16.78	1260 35.49 80.94	48 1.00 2.28	43.85	0.810	-3.27	-21.4	4.76	

Nuweiba Fan

Alluvium

S.No.	Sample Location	Aquifer Material	pH	TDS	Units	Cations			Total Cations	Anions			Total Anions	Ionic Balance	180 %	D %	d*	
						Ca ⁺⁺	Mg ⁺⁺	Na ⁺		K	HCO ₃ ⁻	Cl ⁻						SO ₄ ⁻⁻
14	1 N		7.30	3990	ppm epm epm%	497 24.85 41.52	142 11.83 19.77	505 21.96 36.69	47 1.21 2.01	59.84	556 9.11 16.26	956 26.93 48.05	960 20.00 35.69	56.04	3.280	-3.11	-16.8	8.08
15	2 N		8.30	5885	ppm epm epm%	317 15.85 41.52	83 6.92 18.12	335 14.57 38.15	33 2.22	38.18	498 8.16 22.45	575 16.20 44.55	576 12.00 33.00	36.36	2.438	-2.52	-14.3	5.86
16	3 N		8.32	5935	ppm epm epm%	411 20.55 36.68	107 8.92 15.91	575 25.00 44.62	61 1.56 2.79	56.03	703 11.52 20.81	1131 31.86 57.52	576 12.00 21.67	55.38	0.581	-2.20	-17.3	0.30
17	4 N		8.40	6480	ppm epm epm%	574 28.70 38.11	180 15.00 19.92	667 29.00 38.50	102 2.62 3.47	75.32	742 12.16 16.47	1873 52.76 71.45	428 8.92 12.08	73.84	0.988	-2.55	-18.4	2.00
18	5 N		7.2	3570	ppm epm epm%	411 20.55 37.36	113 9.42 17.12	551 23.96 43.56	42 1.08 1.96	55.00	381 6.25 11.60	1195 33.66 62.54	668 13.92 25.86	53.82	1.080	-3.08	-18.8	5.84
19	6 N		7.20	3500	ppm epm epm%	502 25.10 37.43	134 11.17 16.65	667 29.00 43.24	70 1.79 2.68	67.06	566 9.28 14.15	1505 42.39 64.64	668 10.92 21.22	65.59	1.110	-2.30	-18.2	0.20
20	7 N		7.25	4010	ppm epm epm%	433 21.65 36.71	112 9.33 15.83	613 26.65 45.20	52 1.33 2.26	58.97	547 8.97 15.93	1292 36.39 64.67	524 10.92 19.40	56.28	2.335	-3.52	-22.0	6.16
21	8 N		7.90	5000	ppm epm epm%	622 31.10 43.21	121 10.08 14.01	667 29.00 40.29	70 1.79 2.49	71.98	708 11.61 16.68	1777 50.06 71.94	380 7.92 11.38	69.58	1.694	-0.92	-10.1	-2.74
22	9 N		7.70	4450	ppm epm epm%	431 21.55 37.88	123 10.25 18.02	544 23.65 41.58	56 1.44 2.52	56.89	468 7.67 14.19	1014 28.56 52.83	856 17.83 32.98	54.07	2.541	-3.45	-20.0	7.60
23	10 N		7.60	4240	ppm epm epm%	419 20.95 37.01	150 12.50 22.08	505 21.96 38.78	47 1.21 2.13	56.61	410 6.72 12.41	1027 28.93 53.42	888 18.50 34.16	54.15	2.222	-2.05	-15.0	1.40
24	11 N		7.00	3860	ppm epm epm%	1529 76.45 40.09	389 32.42 17.00	1817 79.00 41.42	111 2.85 1.49	190.71	1152 18.89 10.36	4994 140.68 77.16	1092 22.75 12.48	182.31	2.252	-1.35	-11.1	-0.30
25	12 N		7.20	3450	ppm epm epm%	1758 87.90 43.62	405 33.75 16.75	1771 77.00 38.21	111 2.85 1.41	201.50	556 9.11 4.69	4806 135.38 69.61	2400 50.00 25.71	194.50	1.768	-1.51	-12.4	-0.32

Sharm El Sheikh

Dahab Fan

Sample Number	SAR	Hydrochemical Formula	Ion Dominance	Water Type	Hypothetical salts									
					NaCl	Na ₂ SO ₄	NaHCO ₃	MgCl ₂	MgSO ₄	Mg(HCO ₃) ₂	CaCl ₂	CaSO ₄	Ca(HCO ₃) ₂	
1	4	Cl (e) SO ₄ (e) HCO ₃ (e) (Na + K) (e) Mg (e) Ca (e)	Na > Mg > Ca Cl > SO ₄ > HCO ₃	Na - Cl	43			20	11			20	6	
2	7	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	48			14				21	7	10
3	6	Cl (e) SO ₄ (e) HCO ₃ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	43			18	4			20	8	11
4	6	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	49			12				20	2	17
5	6	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	50			12				24	1	13
6	7	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	48			17				21	1	14
7	9	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	50			14				23	1	12
8	6	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	44			15				26	1	14
9	7	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	50			14				33	1	12
10	7	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	48			15				21	1	16
11	5	Cl (e) SO ₄ (e) HCO ₃ (e) Ca (e) Mg (e) (Na + K) (e)	Ca > Mg > Na Cl > SO ₄ > HCO ₃	Ca - Cl	31	2		30					32	5
12	6	Cl (e) SO ₄ (e) HCO ₃ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	41			25				5	20	9
13	7	Cl (e) HCO ₃ (e) SO ₄ (e) (Na + K) (e) Ca (e) Mg (e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	53			13				15	2	17

Table (2): Cont.

Sample Number	SAR	Hydrochemical Formula	Ion Dominance	Water Type	Hypothetical salts							
					NaCl	Na ₂ SO ₄	NaHCO ₃	MgCl ₂	MgSO ₄	Mg(HCO ₃) ₂	CaCl ₂	CaSO ₄
Nuweiba Fan												
14	5	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) Ca ^(e) (Na + K) ^(e) Mg ^(e)	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	38	32		10	10	42	26	16
15	4	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) Ca ^(e) (Na + K) ^(e) Mg ^(e)	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	40			5	13		20	22
16	7	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	47			11	5		17	20
17	6	Cl ^(e) HCO ₃ ^(e) SO ₄ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	42			20		9	12	17
18	6	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Mg > Ca Cl > SO ₄ > HCO ₃	Na - Cl	46			17			26	11
19	7	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Mg > Ca Cl > SO ₄ > HCO ₃	Na - Cl	46			17		2	21	14
20	7	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Mg > Ca Cl > SO ₄ > HCO ₃	Na - Cl	47			16		2	19	16
21	6	Cl ^(e) HCO ₃ ^(e) SO ₄ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	42			14		15	11	17
22	6	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	44			9	9		24	14
23	5	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	41			12	10		24	13
24	11	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) (Na + K) ^(e) Ca ^(e) Mg ^(e)	Na > Ca > Mg Cl > SO ₄ > HCO ₃	Na - Cl	43			17		17	13	10
25	10	Cl ^(e) SO ₄ ^(e) HCO ₃ ^(e) Ca ^(e) (Na + K) ^(e) Mg ^(e)	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	39			17		14	26	4

HYDROGEOCHEMICAL AND ISOTOPIC APPLICATIONS ASSESSMENTS TO THE GROUNDWATER ALONG THE GULF OF AQABA COASTAL PLAIN, SINAI, EGYPT

Table (2): Cont.

Sample Number	SAR	Hydrochemical Formula	Ion Dominance	Water Type	Hypothetical salts									
					NaCl	Na ₂ SO ₄	NaHCO ₃	MgCl ₂	MgSO ₄	Mg(HCO ₃) ₂	CaCl ₂	CaSO ₄	Ca(HCO ₃) ₂	
26	6	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₄₀ Ca ₆₀ Mg ₄₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	47			13				5	14	21
27	5	Cl ₄₀ SO ₄₀ HCO ₂₀ Ca ₄₀ (Na + K) ₄₀ Mg ₄₀	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	40			12	2				30	16
28	4	Cl ₄₀ SO ₄₀ HCO ₂₀ Ca ₄₀ (Na + K) ₄₀ Mg ₄₀	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	39			5	14				15	17
29	3	SO ₄₀ Cl ₄₀ HCO ₂₀ Ca ₄₀ (Na + K) ₄₀ Mg ₄₀	Ca > Na > Mg SO ₄ > Cl > HCO ₃	Ca - SO ₄	23			8	1				56	12
30	5	Cl ₄₀ SO ₄₀ HCO ₂₀ Ca ₄₀ (Na + K) ₄₀ Mg ₄₀	Ca > Na > Mg Cl > SO ₄ > HCO ₃	Ca - Cl	41			9	8				22	20
31	7	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₆₀ Ca ₆₀ Mg ₆₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	50			29				14	2	14
Wadi Taba														
32	4	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₄₀ Ca ₆₀ Mg ₆₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	47			11				6	5	31
33	7	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₆₀ Ca ₆₀ Mg ₆₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	58			9				2	9	22
34	8	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₆₀ Ca ₆₀ Mg ₆₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	52			9				3	14	22
35	9	Cl ₆₀ HCO ₂₀ SO ₄₀ (Na + K) ₆₀ Ca ₆₀ Mg ₆₀	Na > Ca > Mg Cl > HCO ₃ > SO ₄	Na - Cl	54			8				6	11	21
Gulf of Aqaba Coast														
36	59	Cl ₄₀ SO ₄₀ HCO ₂₀ (Na + K) ₄₀ Mg ₄₀ Ca ₄₀	Na > Mg > Ca Cl > SO ₄ > HCO ₃	Na - Cl	75			12	7				5	1

2.1.4. Geochemical Classification

A genetic classification diagram (Fig. 4) was suggested by Sulin (1948). This diagram consists of two equal quadrants. The plotted chemical analysis of water samples in the upper right quadrant indicated marine origin ($MgCl_2$ and $CaCl_2$ salts). On the other hand those plotted in the lower left one reflect water of meteoric or continental origin ($NaHCO_3$ and Na_2SO_4). Water having $Na/Cl < 1$ are plotted in the upper quadrant, while those having $Na/Cl > 1$ are located in lower quadrant. In the area of study, the plotted samples are related to $MgCl_2$ and $CaCl_2$ water types which reflect the invasion of marine

origin. $MgCl_2$ water type represents recent marine water whereas $CaCl_2$ one is related to old marine.

The geochemical ground trilinear Piper diagram (1953) was also used to define the character of ground water through the relationship among the alkalis ($Na+k$), the alkali earths ($Ca+Mg$), the alkalinity (CO_3+HCO_3) and the salinity ($Cl+SO_4$). This diagram (Fig. 5) shows that, the chemical

Properties of the studied samples are dominated by primary salinity (marine origin). These samples extended toward the vertex of both $Ca + Mg$ and $Cl + SO_4$ characterising the advanced mineralization with $Cl - Mg$ and $Cl - Ca$ water types.

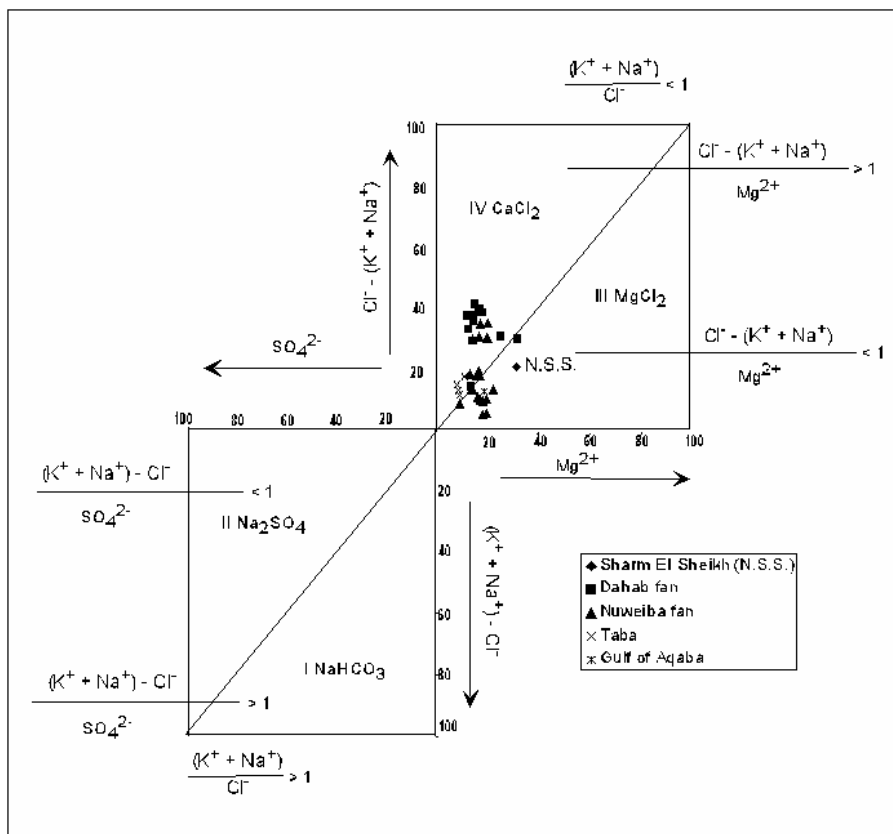


Fig. (4): Plotting of the studied data on Sulin diagram.

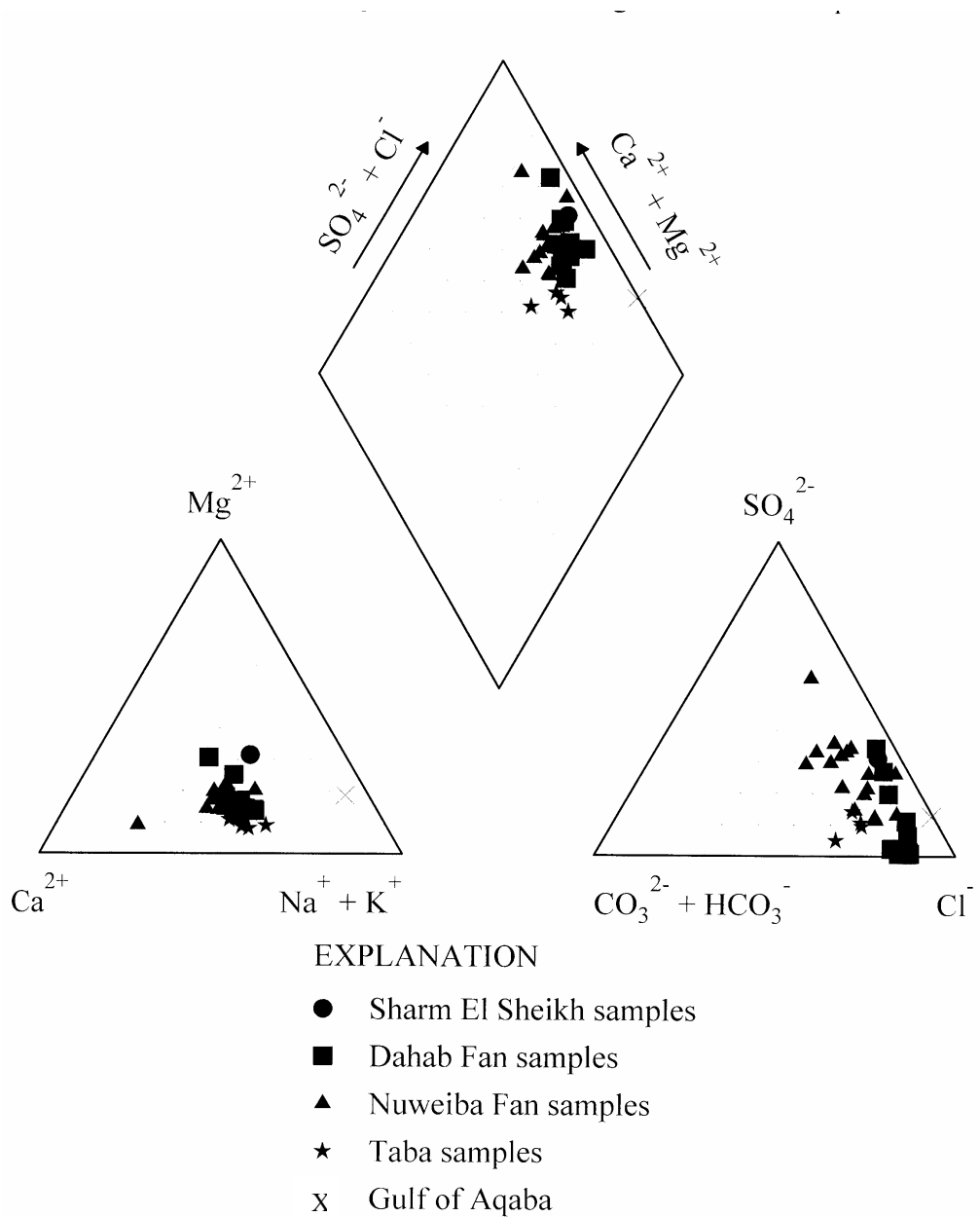


Fig. (5): Piper Diagram of the studied groundwater samples.

2.2. Isotopic Indices and Inter-relation of Different Waters

The stable heavy isotopes of hydrogen (^2H) called deuterium and oxygen-18 have been proved to be a valuable tool in hydrologic studies, because their concentration have not been changed by the interaction with the host rocks of the aquatic reservoir. In this way, water in different environments develops isotopic "fingerprints" with which it can be identified and its origin traced.

2.2.1. Precipitation over Sinai

The continuing depletion of the heavy isotope contents (^{18}O & D) of atmospheric moisture as a result of their preferred rain-out marks the precipitation at different geographic locations, especially as a function of elevation. This variation in isotopic composition have been used to trace the geographical origin of groundwater, and provided that little further change in the composition occurred during the movement of water from the surface to the groundwater table.

The Indian Ocean precipitation falling on Sinai Peninsula which comes from the south direction and causing floods in most cases has specific character different than Mediterranean Sea precipitation by its relatively low isotopic content (Table 3). The monsoonal rain in the Indian subcontinent show deuterium excess (d^*) value of 10‰, there are indication that somewhat lower value of (d^*) -5‰ apply for precipitation in Sinai that originated from the Indian Ocean (Gat, 1983).

2.2.2. Environmental stable isotopes of the investigated groundwater

The stable isotopes data for the groundwater samples in the concerned area (Table 1) are drawn against the Global

Meteoric Water Line (GMWL), the Mediterranean Precipitation Water Line (MPWL) and Paleowater Line (PWL) (Figure 6). Generally, the plotted samples lie between, Global Meteoric Water Line (GMWL) and Paleowater Line (PWL). The $\delta^{18}\text{O}$ and δD values show a wide range of variation from -5.70 to -0.92‰ and from -38.0 to -10.1‰ respectively. Heavy isotope enrichment noticed in the collected samples may be due the residual water accumulated after floods and transport processes of water. Deuterium enrichment appears to be the most promising primary index of evaporation because of the minor impact of variable in kinetic fractionation on total fractionation of this isotope.

Most of the collected groundwater in the studied areas falls between (GMWL) and (PWL). Therefore, this groundwater appears to have been recharged from both monsoonal rains originated from Indian Ocean and continental water. In general, the Dahab water are more depleted in ^{18}O and D in comparing with those of Nweiba and Taba. The Sharm El-Sheikh Nubian well is more depleted in heavy isotopes; $\delta^{18}\text{O} = -5.7$ and $\delta\text{D} = -38$ relative to the other investigated groundwaters. This depletion in its isotopic content could be probably due to receiving a mixture from paleowater of Sinai ($\delta^{18}\text{O} = -6.5 \dots -8.0\text{‰}$ & $\delta\text{D} = -50 \dots -60\text{‰}$ (Gat, 1983) besides present day recharge (monsoonal rains comes from the Indian Ocean) as a recharging source. The isotopic character of the investigated groundwater is different from a locality to another depending on rain intensity (seasonal variations) during the replenishment of groundwater as well as the isotopic fractionation which accompanies the steps in recharge process (i.e. formation of puddles after rain, evaporation effect). In addition to mixing with other water (paleowater and sea water) which seeped to groundwater due to over pumping through faults and cracks, and/or tide and ebb duration nearby the coast may occur.

Table (3): Isotopic content of the rain water after Tantawi *et al.* (1998) and Abdel Samie (1995).

Location	$\delta D\%$	$\delta^{18}O\%$	d*
Rafah	-4.4	-3.4	22.8
Bet Dagan	-35.0	-6.0	13
Saint Catherine	-40.9	-6.43	10.5

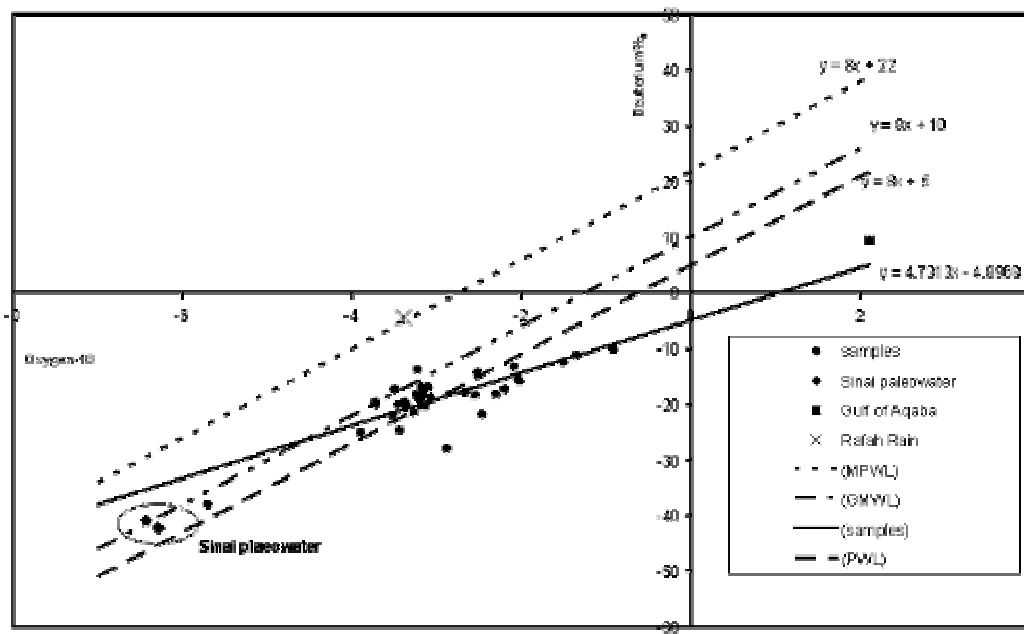


Fig. (6): Oxygen-18 versus deuterium relationship.

2.3. Deuterium Excess (d*)

The deuterium excess (d*) is used to trace the origin of groundwater in the studied areas. It varies from place to place due to the origin and conditions of formation of the water vapour, where over open tropical oceans it rises to $\approx 10\text{‰}$, while in marine areas, i.e. Mediterranean Sea region, it deviates to $\approx 22\text{‰}$, but in more humid and cooler climate prevailing in the Sahara in the past periods it was recorded as $\approx 5\text{‰}$ (Gat and Issar, 1974).

The (d*) parameter is a function of the relative humidity of the air masses overlying the ocean. The deuterium excess (d*) in the collected water samples is computed from the formula suggested by Dansgaard (1964).

$$d^* = \delta D\text{‰} - 8\delta^{18}O\text{‰}$$

The range of these values varies from -4.96 to +12.04‰, reflecting that the rechargability process along the coastal plain of the Gulf of Aqaba is controlled by mixing between various types of water with different isotopic content and consequently (d*) parameter. These types are continental monsoonal rains coming from Indian Ocean in the form of floods and paleowater as shown in figure (7). The negative values of (d*-excess) noticed in samples Nos. 21, 24, 25 (Nuweiba area) and samples Nos. 34, 35 (Taba area) are possibly due to recharge from partly evaporated flood water.

2.4. Chloride – Stable Isotopes (^{18}O & D) Relationship

The relationship between chloride ion as

an index of salinity and $\delta D\text{‰}$ & $\delta^{18}O\text{‰}$ as an index of evaporation (Fig. 8) reveals that, the change noticed in salinity of the investigated groundwater could be attributed to dissolution of terrestrial salts of marine sediments as indicated in Nuweiba area and evaporation process as shown in both Dahab and Taba localities.

2.5. Conclusion and Recommendations

The hydrochemical characters of groundwater in the alluvium formation along the coastal plain of Aqaba Gulf indicate that, there is a distinctive relationship in salinity, ion dominance and hypothetical salt assemblages in the sites of study due to the effect of sea spray and dissolution of marine sediments.

While the isotopic data reveal the origin of groundwater rechargability as a mixture of three water sources (different types of local rain: continental, Mediterranean and Monsoonal rains as well as small contribution of Sinai paleowater).

Establishment of numerous meteorological stations in different localities is necessary to collect several rain events (storm) to draw good isotopic patterns for the precipitation over Sinai because rainwater is considered the main source of recharging groundwater resources in this vital area.

Also, carbon-14 dating is required to study contribution of paleowater in the rechargability of groundwater in Sinai via faults and cracks.

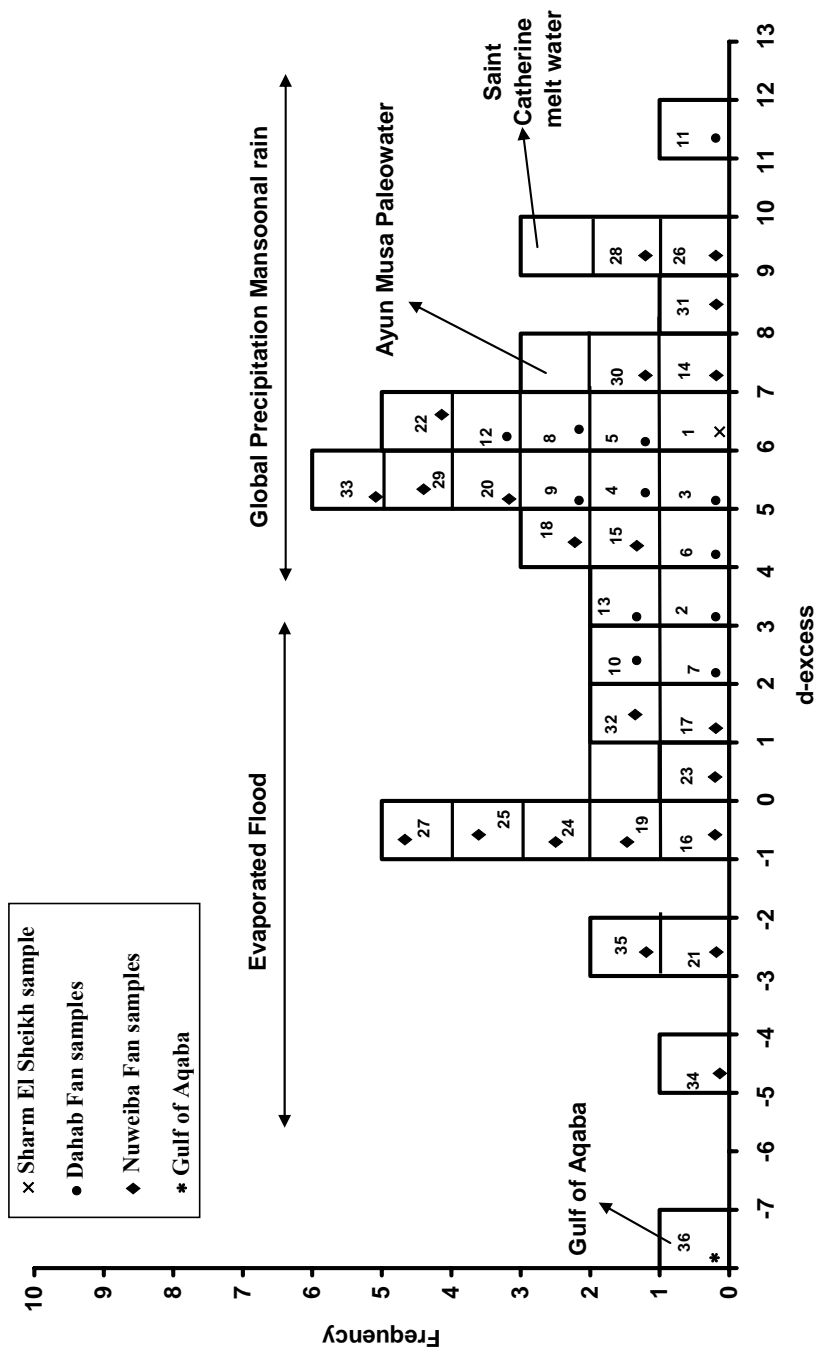


Fig. (7): Relationship between deuterium excess parameter and sources of replenishment in the area of study.

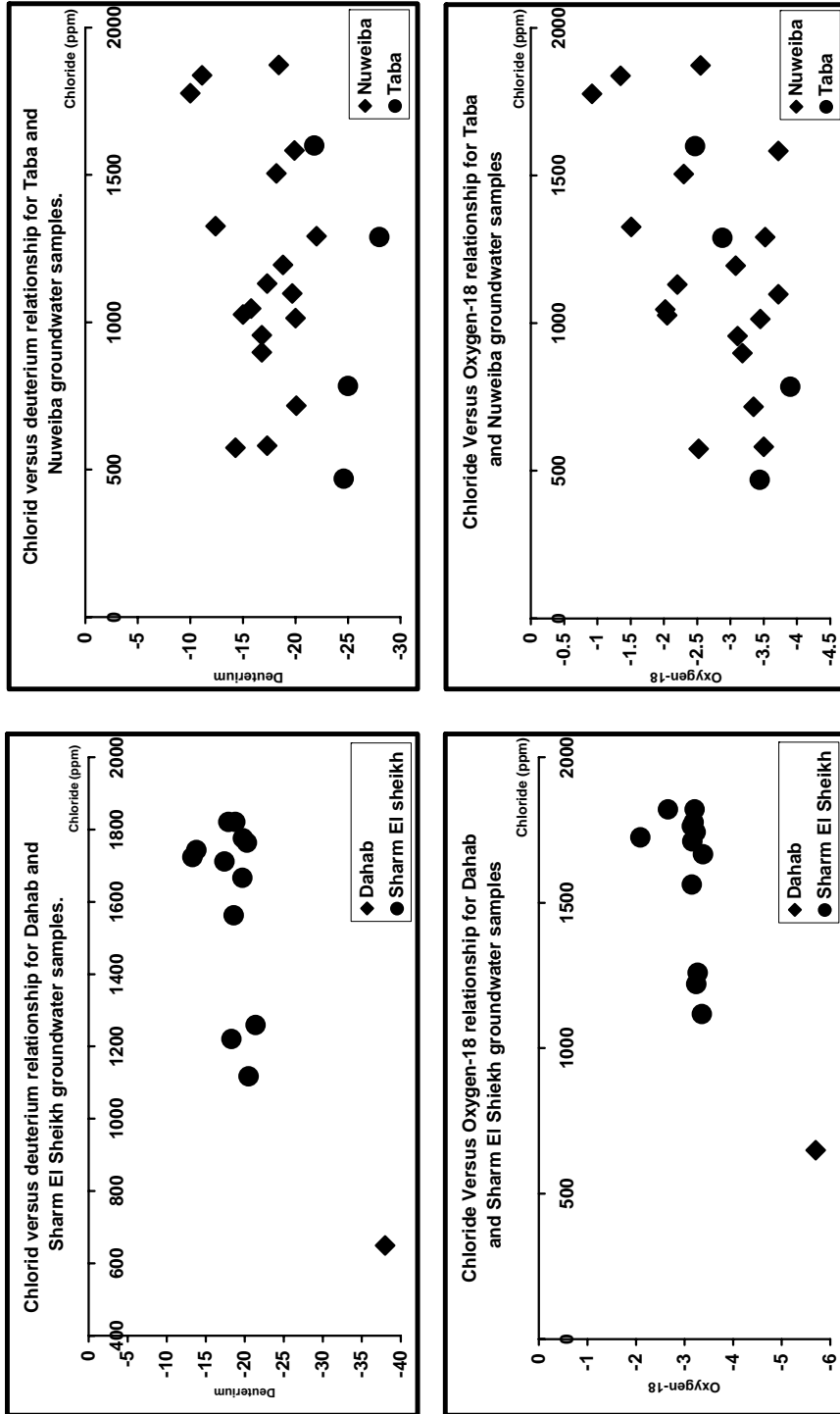


Fig. (8): Chloride versus Deuterium and Oxygen-18 for the studied areas.

REFERENCES

- Abd El-Samei, S.G.: 1995, Isotopic and hydrochemical studies on the groundwater of Sinai Peninsula. Ph.D. Thesis, Chem. Depart., fac. of Sci., Ain Shams Univ., Egypt. 226 p.
- Bentor, Y.K. and Eyal, M.: 1987, the Geology of Southern Sinai, its implication for the evolution of the Arabo-Nubian massif. Israel Acad. Sci. and Humanities 484 p.
- Coleman, M.L.; Shepherd, T. J. Durham, J. J.; Rouse, J.E. and Moore, G. R.: 1982, Reduction of water with zinc for hydrogen isotope analysis. *Analytical Chemistry*, **54**: 993.
- Collins, W.D.: 1923, Graphical representation of analyses. *Industrial Engineering Chemistry*, vol. **14**, p. 394.
- Crompton, T.R.: 1992, Comprehensive Water Analysis. Vols. 1 and 2. Elsevier Science Ltd.
- Dansgard, W.: 1964, Stable isotopes in precipitation. *Tellus* **16**: 436-468.
- Diab, M.S.: 1969, Hydrogeological studies of some springs along the northern parts of the Gulf of Suez. M. Sc. Thesis. Fac. Sci., Ain Shams Univ., Egypt.
- El-Kiki, M.F.; Eweida, A. and El-Refeai, A. A.: 1992, Hydrogeology of Aqaba Rift border province. Proc. 3rd Conf. for Sinai Devel., Ismaillia. pp. 91-100.
- El-Sayed, E.: 1999, Assessment of water resources in Dahab basin, South Sinai, Egypt. *Bull. Fac. Scie., Assiut, Univ., Egypt*, **28 (2)**: 1-32.
- El-Shamy, I.Z.: 1992, Towards the water (management of Sinai Peninsula. Proc. 3rd Conf. Geol. Sinai Develop., Ismalia., pp. 63-70..
- El-Shamy, I. Z. and El - Rayes, A. E. A.: 1992, Hydrogeologic assessment of Saint Catherine area, South Sinai, Proceedings of the 3rd Conference on Geology. Sinai Development, Ismaillia, pp. 71-76. Suez Canal University, Ismaillia, Egypt.
- El-Shazly, E.M.; Abdel-Hady, M.A; El-Ghwaby, M.A.; El-Kassas, I.A.; El-Shazly, M.M.; Salman, A.B.; and El-Rakaiby, M.: 1974, Geology of Sinai Peninsula from ERTS-1 Satellite image. ASTR, Remote Sensing Project, Cairo, Egypt. 20 p.
- Epstein, S. and Mayeda, T.K.: 1953, Variations of oxygen-18 content of waters from natural sources. *Geochimica Cosmochimica Acta* v. **4**, pp. 213-224.
- Gat, J. R.: 1983, Isotopes in hydrology, proc. Of symp., IAEA, Vienna.
- Gat, J.R. and Issar, A.: 1974, Desert isotope hydrology, water source of Sinai Desert. *Geochemica Cosmochemica Acta*. No. **38**, pp. 1117- 1131.
- Ghodeif, K.O.: 1995, Hydrogeological on east Saint Catherine, South Central Sinai, Egypt. M. Sc. Thesis. Suez Canal Univ. Ismaillia, Egypt. 150 p,
- Issar, A. and Gilad, D.: 1982, Groundwater flow system in the arid crystalline province of southern Sinai. *Jour. Hydr. Scie.*, **27 (3)**: 309-325.
- Piper, A.M.: 1953, A graphic procedure in the geochemical interpretation of water analysis. *Am. Geophy. Union Trans.* Vol. **25 No. 6**, Washington, D. C., pp. 914-928.
- Rachwan, Kh.K.: 1994, Geomorphological study, Dahab basin, Sinai Peninsula, Egypt. Ph. D. Thesis Fac. Of Art., Minia Univ., Minia, Egypt. 287 p. (in Arabic).
- Salem, W.M. and Tantawi, M.A.: 2001, Comparative studies of groundwater recharge sources in north and east center parts of Sinai, Egypt, using environmental stable isotopes and hydrogeochemistry. *Isotope & rad. Res.*, **33 (3)**: 349-368.
- Shata, A.: 1992, Watershed management, Development of potential and water resources and desertification control in Sinai. Proc. 3rd Conf. Geol. for Sinai Devel., Ismaillia. pp. 273-280.
- Shendy, E. H.; Geriesh, M. H. and Musa,

- M.M.: 1997, Geophysical and Hydrogeochemical Studies in wadi Saal, southern Sinai, Egypt. *Egypt. Jour. Geol.*, pp. 871-908.
- Sulin, V.A.: 1948, Condition of formation, principals of classification and constituents natural waters. MOSCOW, *Leningrad Acad. Sci. USSR*, 215 p.
- Tantawi, M.A.: 2001, Hydrogeochemical properties and environmental isotopes of groundwater of the Quaternary - Pre Quaternary aquifers in El Arish - Rafah area, northeast Sinai, Egypt. 5th Conf. on Geochem., Alexandria Univ. VII, pp. 185-200.
- Tantawi, M.A.; El-Sayed, E. and Awad, M.A.: 1998, Hydrochemical and stable isotope study of groundwater in the Saint Catherine- Wadi Feiran area, South Sinai, *Egypt. Jour. Afric. Earth Scie.*, **26 (2)**: 19-24.