Preliminary Hydrogeologic Investigations of Nubia Sandstone and fractured Basement Aquifers in the Area between El Shalateen and Halayeb, Eastern Desert, Egypt

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Abstract. El Shalateen-Halayeb triangle is a promising district for tourism and agricultural development. Pre-Miocene rocks (fractured basement and Nubia sandstone) represent the main water-bearing formations in the investigated area. Rainfall and occasionally flash floods represent the main sources of recharge. Groundwater occurrence and movement in basement aquifer is mainly controlled by the structural elements, where interaction between fractures and intrusive dykes reflect a good environment for groundwater entrapment. In fractured basement aquifer, the transmissivity ranges from 2.75 m^2/day to 784 m^2/day. Such wide variation could be attributed to the lateral facies changes as well as the impact of the complicated structural setting. Nubia sandstone is detected as a water-bearing in Abraq, Abu Saafa and EL Dif localities, its transmissivity varies from 2.72 m^2/day to 72.4 m^2/day. Poor potentiality of aquifers is mainly due to high channel gradient, which gives no chance for groundwater replenishment. Regionally, the direction of groundwater flow is mainly restricted by the variable hydraulic gradients from locality to another.

Twenty-three groundwater samples were collected and chemically analysed. Groundwater salinity of basement aquifer varies from 438 mg/l to 10409 mg/l, reflecting a wide variation in groundwater quality from fresh to saline. The groundwater quality of Nubia sandstone aquifer varies from fresh to brackish, where the salinity ranges from 459 mg/l to 1292 mg/l. In basement aquifer, the type Cl–Na is dominant, while in Nubia sandstone aquifer, HCO_3-Na and Cl-Na water types are recognized. In basement aquifer, the groundwater is mostly characterized by permanent hardness (except Nos. 1, 6 & 13 have a perfect temperary hardness). In Nubia sandstone aquifer, the groundwater is mainly characterized by temporary hardness. In basement groundwater, Cl is the most correlated anion with salinity (R^2 = 0.9615), and Na is the most correlated cation with salinity (R^2=0.9153). In Nubia sandstone groundwater, SO_4 is the most correlated anion with salinity (R^2 = 0.7573) and Na is the most correlated cation with salinity (R^2 = 0.8578). Groundwater quality was evaluated for different uses and some recommendations were given.

Introduction

Rising populations in Egypt are putting increased pressure on existing fresh Nile water supply. Arid and semi–arid regions are subjected to sustainable development, so they are vulnerable to drought and rapidly rising water demands. Groundwater management in such regions needs an implemented policy emphasizing optimal utilization of water resources. The main objective of this study is to evaluate groundwater resources quantitavely and qualitatively.

Meteorologically, Eastern Desert lies within the Egyptian arid belt. The investigated area is characterized by scarce rainfall and occasional flash floods, so, floodwater control should be taken into consideration.

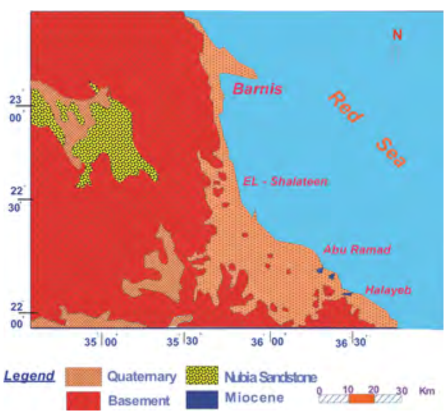

Fig. 1. Geological map of Barnis – Halayeb district.

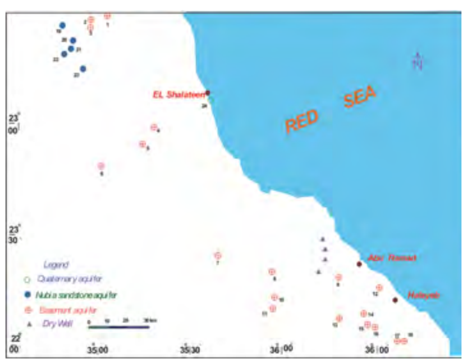

Fig. 2. Water points distribution withinthe investigated area.

Hydrographically, the investigated area is distinguished into three great basins facing Red Sea to the east. The first is Barnis basin (3000 km^2), the second is EL Shalateen – Abu Ramad Basin (2300 km^2) and the third is Halayeb Basin (2500 km^2). Geologically (Fig. 1), the investigated area is occupied from the western side by basement rocks. Nubia sandstone outcrops close to water divide. Tertiary volcanic rocks are extruded at the foot slope of Red Sea mountainous shield. Isolated patches of Miocene sediments outcrops due west of Abu Ramad and Halayeb area, (alternating limestone and marl of Gebel EL Rusas Formation). Quaternary deposits form deltas of Wadis as well as Wadi fill of main channels.

Groundwater Occurrences

Twenty-three water points were selected to evaluate groundwater resources in the study area (Fig.2, and Table 1). Eighteen of them are tapping fractured basement aquifer and five get their water from Nubia sandstone aquifer in the upreaches of Wadi Hodein.

Hydrogeologic conditions of the basement aquifer

Fractured basement aquifer is composed of older granitoids, younger granites, gneisses, migmatites, schists, metasediments, gabbro, diorites and quartazites. These rocks are highly weathered and strongly fractured, jointed as well as faulted, giving a great chance for accumulation and movement of groundwater. Depth to water varies from 1 m at Mahareka well (No. 10) to 27 m at Gomidlum well (No. 8). Water level ranges between + 40 m at Meisah well (No.7) and + 326.5 m at Salalat Osar well (No.13). Groundwater occurrence and movement in fractured basement are mainly controlled by the orientation, size and density of the intrusive dykes, which act as a doming factors for percolated water as in EL Gahelia well (No.1). Interaction between fractures and intrusive dykes reflects a good environment for groundwater entrapment (Aggour and Sadek, 2001).

Table 1. Hydrogeological data of the investigated aquifers (Jan, 2004).

Well No.	Water Point	Basin	Aquifer Facies	Well Type	Well Diameter (m)	Depth to Water (m)	Total Depth (m)	Ground Elevation (m)	Water Level (m)
1	EL Gahelia well	Wadi Hodein	Basement	Dug Well	3.30	3.30	9.50	+400	—
2	Eiqat-a well	Wadi Hodein		Dug Well	2.00	7.00	—	+134	+ 127
3	Eiqat-b well	Wadi Hodein		Dug Well	1.90	8.50	10.25	+134	+125.5
4	EL Beida- a well	Wadi EL Beida		Dug Well	2.00	4.2	4.4	—	
5	EL Beida-b well	Wadi EL Beida		Dug Well	1.80	3.00	3.8	—	—
6	Madi well	Wadi Madi		Dug Well	1.90	6.7	7.85	—	—
7	Meisah well	Wadi Meisah		Dug Well	2.10	5.90	—	+45.9	+40
8	Gomidlum well	Wadi EL Deib		Dug Well	2.00	27	28	+83	+56
9	Aquamatra well	Wadi Audeib		Dug Well	2.10	4.5	—	+285	+280.5
10	Mahareka well	Wadi EL Deib		Dug Well	1.35	1.00	2.00	+85	+84
11	Shoshab well	Wadi EL Deib		Dug Well	1.50	18.16	19.00	+94	+75.84
12	Sararah well	Wadi Sermatay		Dug Well	1.00	17.00	22.38	+112	+95
13	Salalat Osar well	Wadi Sermatay		Dug Well	1.80	13.50	—	+340	+326.5
14	Sararat well	Wadi Sermatay		Dug Well	1.00	21.2	23.00	+220	+198.8
15	Okak well	Wadi Shandodi		Dug Well	1.20	5.40	—	+320	+314.6
16	Eremit well	Wadi Shandodi		Dug Well	2.15	11.80	—	+300	+288.2
17	Frukit–a well	Wadi Shalal		Dug Well	2.00	17.0	—	+300	+283
18	Frukit – b well	Wadi Shalal		Dug Well	3.15	15.5	17.7	+300	+284.5
19	Ain Abraq	Wadi Abraq	N. Sandstone	Spring	—	Flowing	—	—	—
20	Abu Saafa–a well	Wadi Hodein		Drilled	—	22	310	+270	+248
21	Abu Saafa–b well	Wadi Hodein		Drilled	—	8.17	90	+315	+307
22	Abu Saafa–c well	Wadi Hodein		Drilled	—	13.30	87	+294	+281
23	EL Dif well	Wadi EL Dif		Drilled	—	21.75	134	+241	+219

Abu Ramad area

To understand the hydrogeological setting of the basement aquifer at Abu Ramad area, a hydrogeological cross-section A–A' was constructed (Fig. 3a and 3b). The section crosses Meisah well, Gomidlum well, Aquamatra well and Miocene rocks (marly limestone). All these water points are tapping fractured basement aquifer.

The section reflects the following:

- Faults are dominant in the study area.
- Two geological units are recognized, as a thin layer of Quaternary wadi fill, and the fractured basement rocks.
- It hosts four separate local and limited water-bearing rock units. The first body is located at Meisah well. The second one is located at Gomidlum well. The third one lies at Aquamatra well, while, the fourth water body is located at the eastern side of this section.
- The water level varies from + 40 m at Meisah well to + 280.5 m at Aquamatra well. It is attributed to geographic irregularities.

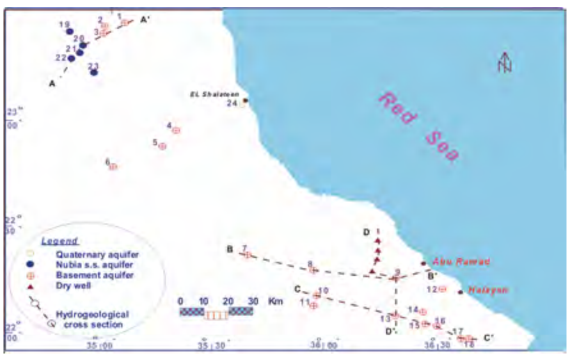

Fig. 3a. Direction of hydrogeological cross sections.

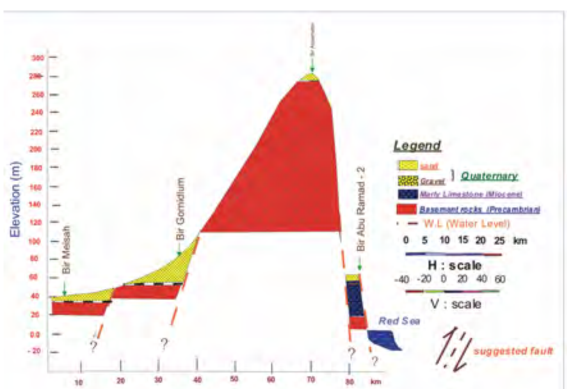

Fig. 3b. Hydrogeological crossection B–B' from west to east (Abu Ramad region).

Halayeb area

To throw the light on the hydrogeologic setting at Halayeb area, a hydrogeological cross-section B-B’ was constructed (Fig.4). It traverses Mahareka well, Salalat Osar well, Okak well, Eremit well and Frukit–a well. Two horizons could be recognized from top to bottom as following:

- The upper one is represented by a thin layer of Quaternary wadi fill deposits, while the lower reflects the water-bearing formation composed of fractured basement rocks.
- Water level varies from + 84 m at Mahareka well (No. 10) to 326.5 m at Salalat Osar well (No. 13) due to topographic irregularities.

Moreover, the areal extension of the hydrogeological setting encountered in this region was illustrated through the cross section C – C’ (Fig. 5). The section revealed the extensions and characteristics of geological boundaries, barriers or structural faults that have a direct impact on the groundwater occurrence and its movement. It is clear, that the structural dykes act as barriers against the groundwater movement towards the north. So, the recent bore holes tests are dry.

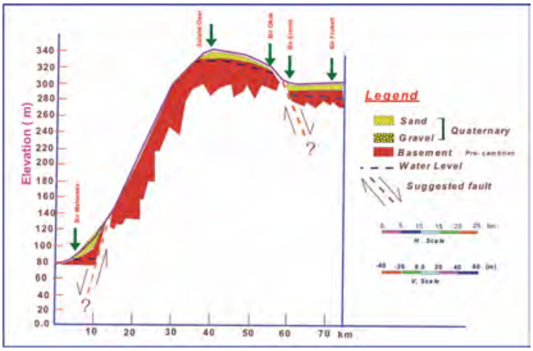

Fig. 4. Hydrogeologic cross section B-B’ from west to east (Halayeb region).

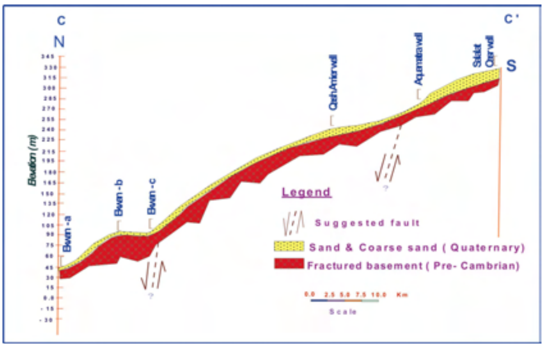

Fig. 5. Hydrogeological crossection (C–C’) from north to south (Abu Ramad – Halayeb district).

Hydraulic parameters

Seven pumping tests were carried out on selected seven dug wells using the following methods:

$T = Q / 4Л sw*F(Uw, B)$ $S = 4 Tt / (rw)^2 * (Uw)$ (Papadopolus and Cooper, 1967)

$T = (rc)^2 / t * 1$ $S = (rc)^2 / (rs)^2 * \alpha$ (Papadopolus et al., 1973)

Where,

T: is the transmissivity (m^2 /day)
Q: is the rate of discharge (m^3 / hour)
rw: is the well radius (m)
sw: is the well drawdown (m)
rs: is the radius of open hole (m)
rc: is the radius of casing in interval over which water level fluctuates (m)
F (μw, B): is the well function.

The obtained results (Figs. 6-12, inclusive Table 2), revealed a wide variation in transmissivity due to the strong impact of the structural and lithological setting on the groundwater occurrences. The fractured basement aquifer at Sararat area displays very low transmissivity due to less deformed younger granites. Poor groundwater potentiality is due to weak chance for surface runoff to replenish or feed the concerned aquifer (high velocity of surface runoff as a result of high channel gradient).

Table 2. The calculated hydraulic parameters of the basement aquifer.

Well No.	Water Point	T (Transmissivity) m^2/day	S (Storativity) dimensionless
1	EL Gahelia well	784	0.08
7	Meisah well	198	$7.06 X 10^{-3}$
10	Mahareka well	139	$5.95 X 10^{-3}$
17	Forkit–a well	19.23	$1.52 X 10^{-4}$
2	Eqat well	12	$2.22 X 10^{-5}$
11	Shoshab well	4.58	$1.13*10^{-6}$
12	Sararat well	2.75	$1.27* 10^{-6}$

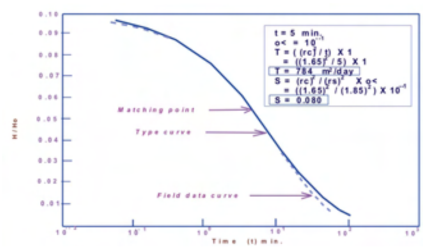

Fig. 6. Analysis of pumping test data of El Gahelia dug well using slug test (Papadopulos et al. 1997).

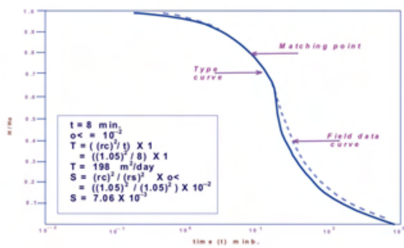

Fig. 7. Analysis of pumping test data of Bir Meisah dug well using slug test (Papadopulos et al. 1997).

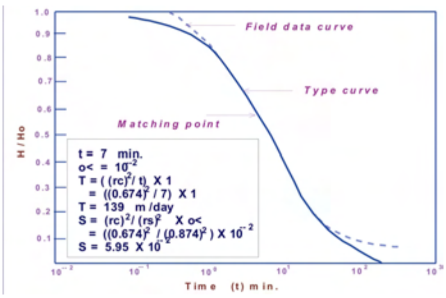

Fig. 8. Analysis of pumping test data of Bir Maharika dug well using slug test (Papadopulos et al. 1997).

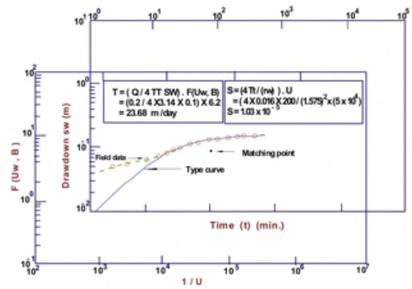

Fig. 9. Analysis of pumping test data of Frokeit well (Papadopulos' method).

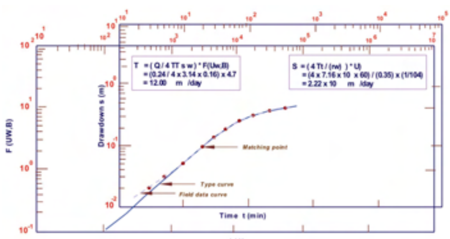

Fig. 10. Analysis of pumping test data of Eqat dug well (Papadopulos et al. 1997).

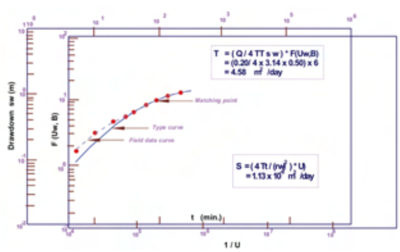

Fig. 11. Analysis of pumping test data of Shoshab dug well using Papadopulos method.

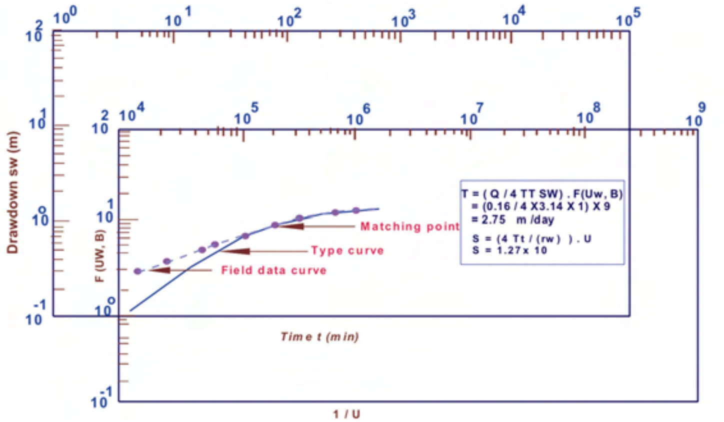

Fig. 12. Analysis of pumping test data of Sararat Sermatay by using Papadopulos method.

Hydrogeologic conditions of Nubia sandstone aquifer

Nubia sandstone aquifer has a tremendous importance in the area. It covers the northwestern part of the investigated area. Nubia sandstone rests directly on basement rocks. It is composed of fine to coarse sandstone intercalated with clay. The thickness ranges between 100 m up to 500 m (Aglan, 2001). It is detected as a water- bearing in Wadi Abraq, Abu Saafa and Wadi EL Dif. Five representative water points were selected in the study area. The groundwater occurs under confined conditions (Abraq spring) and semi- confined conditions (drilled wells). Rainfall and flash floods on the sandstone plateau and the surrounding fractured basement rocks are considered to be the main sources of groundwater replenishment. Depth to water varies from 8.17 m at (Abu Saafa-b well) to 21.75 m (El Dif well) from the ground surface. On the other hand, the water level ranges between + 248 m at Abu Saafa-a well and + 281 m at Abu Saafa–c well (Table 1).

Abu Saafa area

Abu Saafa area is considered one of the most important Wadis that run in the sandstone territory at the northwest of wadi Hodein. It runs almost E–W at its upstream, then merges to run S 30 o E to join Wadi EL Dif that lies south to it. To investigate the hydrogeological setting in this area, a hydrogeological cross section D–D' was constructed (Fig. 13). This section passes through Abu Saafa - b well, Abu Saafa-a well, Eqat–a well and EL Gahelia well. The section displays the succession of layers from to top to bottom as follows:

- The first layer extends through the whole section and represents Quaternary wadi fill deposits. Its thickness varies from 4 m at EL Gahelia well to 9 m at Abu Saafa-c well.
- The second layer extends through Abu Saafa's wells only. The thickness of this layer ranges between 15 m at Abu Saafa-a well and 20 m at Abu Saafa-c well. This layer reflects a part of Upper Cretaceous Umm Barmil Formation, which consists of fluviatile sandstone, and is considerable water- bearing formation.
- The third layer is composed of sequences of grained sandstone with thick shale intercalation of Upper Cretaceous Timsah Formation. The total thickness of this layer varies from 8 m at Abu Saafa well-b to 130 m at Abu Saafa-c well. Obviously, this layer is mainly affected by a predicated fault, which acts as a barrier for groundwater flow. So, Abu Saafa springs issues beside Abu Saafa well-b through such fault plain.
- The fourth layer represents the fractured basement rocks. The top surface of this layer is located at shallow depth (46 m from the ground surface at Abu Saafa–b well and deeper (210 m from the ground surface) at Abu Saafa-c well. ON the other hand, the top of this layer is not reached at Abu Saafa–a well.

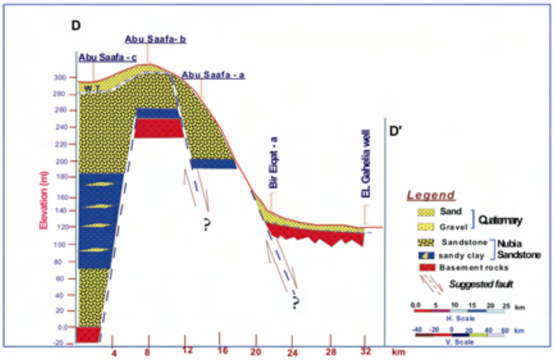

Fig. 13. Hydrogeological crossection (D–D') from southwest to northeast (Abu Saafa – El Gahelia area).

The hydraulic parameters of Nubian sandstone aquifer

Elewa (2000) mentioned that, the aquifer sediments reflect a wide range of transmissivity (from 2.72 m2/day to 72.4 m2/day)). This could be attributed to the lateral facies change as well as the impact of the structural setting. To confirm the obtained results, a trial was carried out by the author using raw data of pumping tests of EL Dif well (GARPAD, 1996), using Jacob straight line method (1963). The obtained value of the transmissivity is comparable to the previous data (Fig.14).

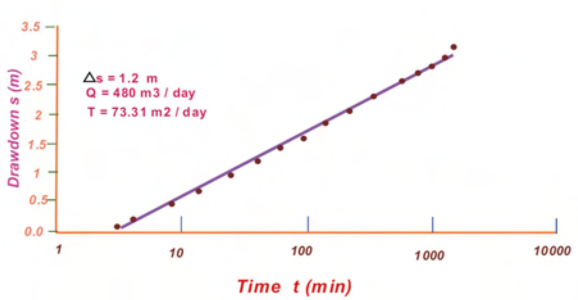

Fig. 14. Analysis of pumping test data of Bir El Dif.

Hydrogeochemical aspects

Hydrogeochemical aspects of parts of the concerned aquifers are discussed through the hydrochemical analyses of twenty three groundwater samples as well as two samples representing rainwater and Red Sea water (Table 3). They reflect the following results.

Groundwater salinity

The groundwater salinity ranges from 438 mg/l at Wadi Madi (No. 6) to 10409 mg/l at Wadi Shandodi (No. 15) indicating a wide variation in quality from fresh to saline in the fractured basement rock aquifer (Hem, 1989). On the other hand, the groundwater salinity varies from 459 mg/l at Abraq spring (No. 19) to 1292 mg/l at Abu Saafa wells (Nos. 20 and 21), reflecting fresh to brackish water in the Nubia Sandstone aquifer (as they are closer to the watershed area).

The presence of more than one peak or more than high frequency intervals for the investigated groundwater samples (Fig. 15) confirms the existence of different water types. This could be attributed to the presence of separate local parts of each aquifer and the great variation of facies.

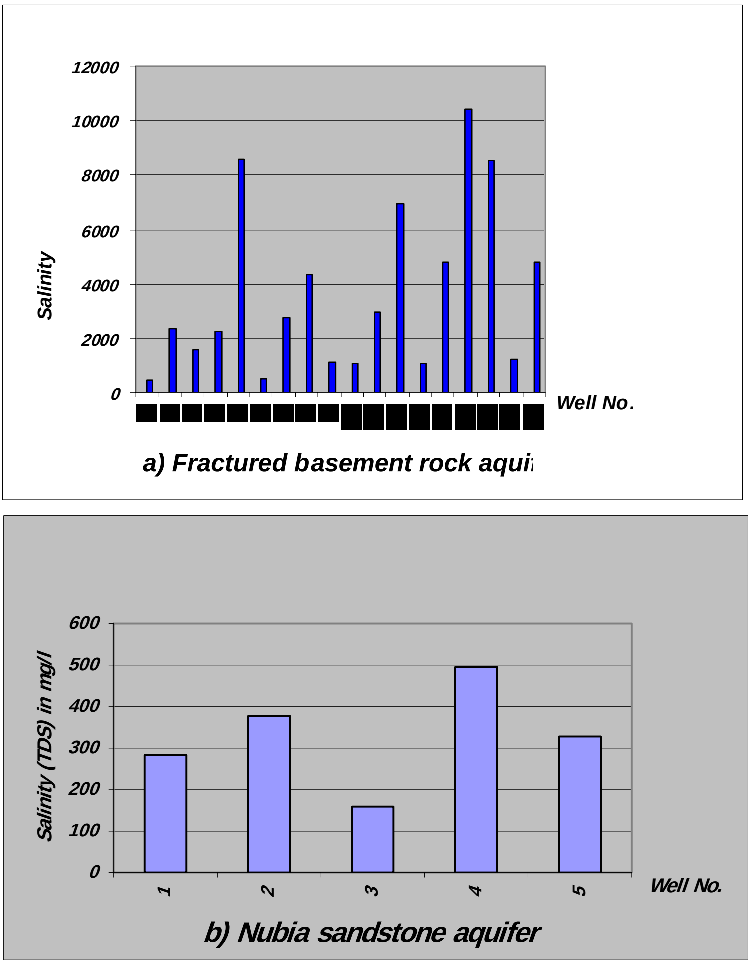

Fig. 15. Irrigular distribution of groundwater salinities.

Table 3. The hydrochemical analyses data (2004).

No	Water point	pH	TDS	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl
1	EL Gahelia well	8.10	438	9.80	45.24	95	12	7.62	312.5	15	98
2	Eqat–a well	8.35	2368	58.80	107.20	660	27	72.39	418.30	590	644
3	Eqat–b well	7.87	1600	47.04	111.90	385	21	22.90	511.30	370	386.40
4	EL Beida–a well	7.18	2244	135.20	69.54	600	10	Nil	230.12	200	1115
5	EL Beida–b well	7.13	8586	594.10	290.10	2100	13	Nil	275	1100	4352
6	Madi well	7.95	511	46.20	18.10	120	9	Nil	335	50	100.50
7	Meisah well	7.83	2750	219.50	19.05	680	19	11.43	352.5	600	1024.80
8	Gomidlum well	7.12	4330	712.10	160	550	15	Nil	49.70	950	1918
9	Aquamatra well	7.30	1111	58.20	40.10	290	15	Nil	296	180	380.11
10	Mahareka well	7.87	1080	113.68	38.10	220	10	3.81	143.30	135	448
11	Shoshab well	8.39	2980	58.80	71.44	1000	7	15.24	267.30	140	1554
12	Sararah well	7.85	6967	529.20	202.40	1700	23	15.24	286.60	1750	2604
13	Salalat Osar well	8.00	1096	54.9	38.10	310	12	19.05	367.90	100	378
14	Sararat well	8.00	4776	548.8	202.4	975	8	26.67	197.5	495	2422
15	Okak well	7.75	10409	901.6	476.30	2400	7	11.43	205.30	800	5712
16	Eremit well	7.85	8537	352.8	261.95	2500	6	15.24	344.70	100	5129.40
17	Frokeit–a well	7.30	1246	40.50	63.17	350	11	Nil	288.14	150	488.14
18	Frokeit–b well	7.12	4786	812.40	200	610	19	Nil	69.80	1100	2010
19	Ain Abraq	8.10	459	54.88	35.72	75	8	3.81	351.40	15	91.10
20	Abu Saafa– a	7.10	1223	44.10	65.12	310	12	Nil	310	100	537.10
21	Abu Saafa–b	7.30	1292	27.25	22.40	430	11	Nil	599.10	230	272.10
22	Abu Saafa–c	7.11	1219	88.15	67.14	250	14	Nil	265.10	230	438.10
23	EL Dif well	7.10	591	59.20	44.12	100	17	Nil	365	40	148.50
-	Rain water	7.86	155	10	9	21	2	Nil	63	14	31
-	Sea water	7.96	38120	439	1343	12000	380	18	137	2300	21568

Note : TDS in mg/l; Ca, Mg, Na, K, CO_3, HCO_3, SO_4, Cl in ppm

Groundwater chemical types

The groundwater in the fractured basement aquifer is characterized by Na > Ca(Mg) > Mg(Ca) / Cl > SO4(HCO3) > HCO3(SO4) ionic proportion. So, the groundwater chemical type is mainly Cl–Na (Fig. 16), reflecting the final (mature) stage of groundwater evolution (except Nos. 1 and 6 are characterized by HCO3–Na water type, showing the initial phase of groundwater evolution as they are mainly closed to the watershed area). On the other hand, the ionic proportion; Na > Mg > Ca / HCO3 (Cl) > Cl (HCO3) > SO4 characterises the Nubia sandstone aquifer. Consequently, two chemical water types are recognized. The first type HCO3–Na is recorded at Abraq and Abu Saafa areas (Nos. 19 & 21), reflecting the first stage of groundwater evolution, while the second type Cl–Na is detected at Abu Saafa area (Nos. 20 and 22), indicating the final phase of groundwater metasomatism.

Groundwater hardness

The investigated groundwater is very hard (Table 4). In basement aquifer, it is mostly characterized by permanent hardness (except Nos. 1, 6, 13 have a perfect temporary hardness). This type of hardness can't be removed by boiling. On the other hand, in Nubia sandstone aquifer, the groundwater is mainly characterized by temporary hardness. Such type of hardness can be virtually removed by boiling water, where calcium and magnesium carbonates precipitate.

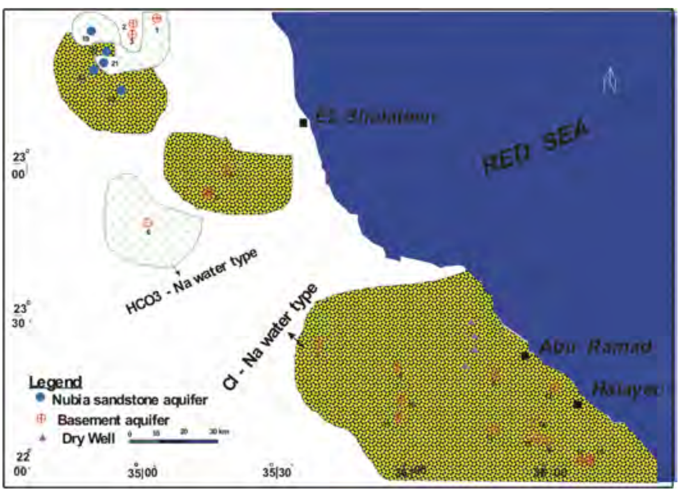

Fig. 16. Distributionof different chemical water types.

Salinity-major components relationships

The relation between salinity (TDS) and major components were statistically illustrated (Figs. 17 and 18). According to these diagrams, a positive correlation between salinity and concentration of ions is evident, since the increasing of major constituents leads to the increasing of total salinity. The more significant correlation coefficient, the more correlated with salinity. In the fractured basement aquifer, Cl, Na, Ca & Mg are significant, SO_4 is little significant, while HCO_3 is not significant with total salinity (Fig. 17). On the other hand, in Nubia sandstone aquifer, Na, SO_4 and Cl are significant, while Ca, Mg and HCO_3 are not significant (Fig. 18).

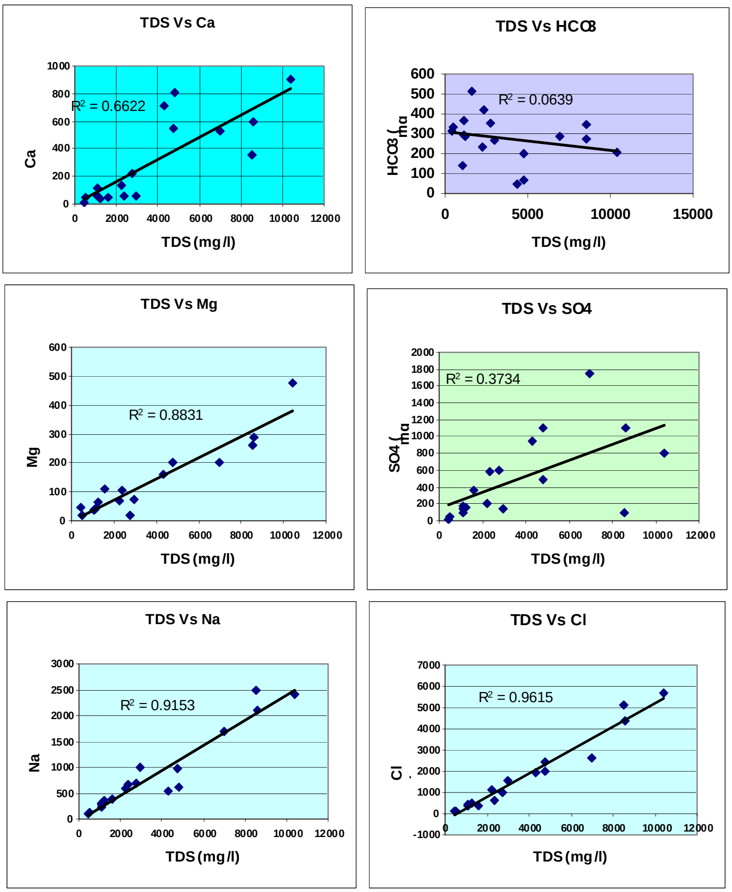

Fig. 17. Salinity–major components relationship in fractured basement groundwater.

Note: Ca, Mg, Na, Cl vs TDS are significant
SO_4 vs TDS is little significant
HCO_3 vs TDS is not significant

Groundwater classification

The investigated groundwater samples were plotted on semilogarithmic paper suggested by Schoeller (1962). They reflect a general resemblance and similarity among each other (Fig. 19). In the fractured basement aquifers, two ionic patterns are recognized, due to the presence of separate local parts of aquifers characterized by the great facies changes. The first is Ca > Mg < Na&K < Cl > SO_4 > HCO_3 (Nos 4, 5,6,7,8,10,12,14,15 and 18). The second is Ca < Mg < Na&K < Cl > SO_4 < HCO_3 (Nos 1,2,3,9,11,13,16 and 17). On the other hand, in Nubia sandstone aquifer, the groundwater samples follows the pattern; Ca < Mg < Na&K > Cl > SO_4 < HCO_3, exhibiting fresh water characters except the slightly increase of Mg over Ca due to the presence of sediments rich in Mg in Nubia sandstone aquifer.

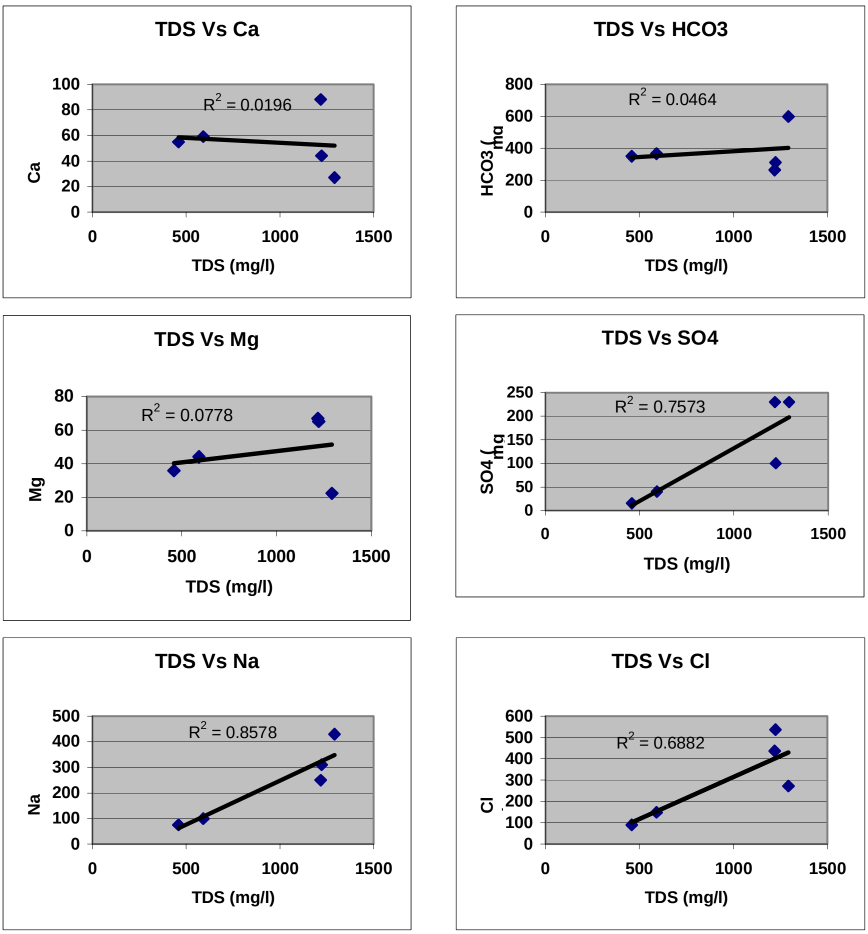

Fig. 18. Salinity–major components relationship in Nubian sandstone groundwater.

Note: Na, SO_4, Cl vs TDS are significant
Ca, Mg, HCO_3 vs TDS are not significant

Table 4. Some hydrochemical parameters (2004).

Well No.	Total Hardness*	Alkalinity*	Temporary hardness*	Permanent hardness*	Specific Electrical Conductivity**	Sodium Adsorption Ratio
1	210	275	275	-65	684	2.77
2	560	463	463	97	3700	12.15
3	577	457	457	120	2500	6.97
4	623	188	188	434	3506	10.47
5	2677	225	225	2451	13415	17.65
6	189	274	274	-85	798	3.80
7	981	307	307	673	4296	9.45
8	2436	40	40	2396	6765	4.84
9	341	292	292	48	1735	6.84
10	438	123	123	315	1687	4.57
11	440	244	244	196	4656	20.80
12	2154	259	259	1894	10885	15.87
13	293	333	333	-40	1712	7.87
14	2203	206	206	1997	7462	9.04
15	4211	187	187	4024	16264	16.10
16	1958	307	307	1651	13339	24.59
17	360	236	236	124	1946	8.04
18	2850	57	57	2793	7478	4.97
19	283	294	294	-11	717	1.94
20	377	254	254	123	1910	6.94
21	159	490	490	331	2018	14.83
22	495	217	217	278	1904	4.89
23	328	299-	299-	29	923	2.39

* mg/l as $CaCO_3$ **micromhos/cm

Table 5. Drinking water standards (WHO, 1984).

Items	Acceptable (mg/l)	Permissible (mg/l)
PH	7-8.5	6.5-9.5
TDS	500	1500
Ca	75	200
Mg	50	150
SO_4	200	400
Cl	200	600

Suitability of groundwater quality for uses

Comparing the results of the hydrochemical analyses (see Table 3) with World Health Organization standards (WHO,1984), (Table 5), it is clear that, the groundwater quality of fractured basement aquifer is suitable for drinking at El-Gahlia and Madi areas, where the salinity lies within the range 438 to 511 mg/l (Nos. 1 and 6). In Nubia sandstone aquifer, the groundwater quality is suitable for drinking at Abraq and El-Dif areas, where the groundwater salinity lies within the range 459 to 591 mg/l (Nos. 19 and 23). On the other hand, the proposed approach by the United States Salinity Laboratory staff of agriculture (USSLs, 1954) is applied for determining the suitability of groundwater for irrigation. In this method a nomogram based on specific electrical conductivity as a function of salinity

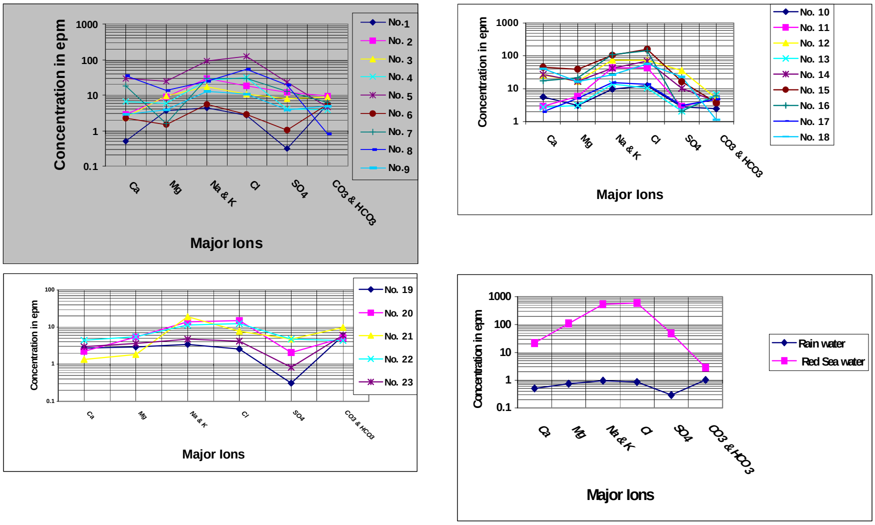

Fig. 19. Logarithmic representation of the investigated groundwater (Following Schoeller diagram, 1962)

against sodium adsorption ration as a function of sodium hazard is used. Distribution of the groundwater samples within the nomogram (Table 4 and Fig. 20), revealed that, groundwater of El-Gahlia, Madi, Abraq and El-Dif is suitable for irrigation. On the other hand, groundwater quality of El-Beida-b, Gomidlum, Sararah, Sararat, Okak, Eremit and Frokeit-b is not suitable for irrigation due to high salinity as well as high sodium hazard (only can be used to irrigate tolerant crops as palm trees). The rest of groundwater samples are of intermediate scale and suitable to irrigate certain kinds of crops as alfalfa, tomato, lettuce and cucumber.

Conclusions and Recommendations

The aquifers of fractured basement and Nubia sandstone rocks represent the available groundwater resources in the investigated area. The main sources of recharge are the local rainfall and sometimes flash floods after occasional showers. Groundwater occurrence and movement in basement aquifer are mainly controlled by the structural features, where the interaction between fractures and intrusive dykes reflect a good environment for groundwater entrapment. The hydraulic parameters of the fractured basement aquifer revealed wide variation in the transmissivity due to the strong impact of the structural and lithological setting on the groundwater occurrences. The poor groundwater potentiality of the fractured basement aquifer is attributed to the weak chance of infiltration of water during surface runoff to replenish the concerned aquifer.

On the other hand, Nubia sandstone aquifer is detected as a water-bearing formation in Wadi Abraq, Abu Saafa and Wadi EL Dif. It rests unconformably directly above the fractured basement rocks. The groundwater occurs under confined conditions (Abraq spring) and semi–confined conditions (drilled wells). It is worth to mention that, the aquifer reflects a wide range of transmissivity (2.72 m^2/day to 72.4 m^2/day). It can be attributed to the lateral facies changes of the water–bearing rocks as well as the impact of the structural setting.

From the hydrochemical point of view, the groundwater quality of the fractured basement aquifer varies from fresh to saline, while in Nubia sandstone aquifer, it varies from fresh to brackish. In basement aquifer, the type Cl–Na is dominant, while in Nubia sandstone aquifer,

HCO_3-Na and Cl-Na water types are recognized. In basement aquifer, the groundwater is mostly characterized by permanent hardness (except Nos. 1, 6 & 13 have a perfect temporary hardness). In Nubia sandstone aquifer, the groundwater is mainly characterized by temporary hardness. In basement groundwater, Cl is the most significant correlated anion with salinity (R^2 = 0.9615), and Na is the most significant correlated cation with salinity (R^2=0.9153). In Nubia sandstone groundwater, SO_4 is the most significant correlated anion with salinity (R^2 = 0.7573) and Na is the most significant correlated cation with salinity (R^2 = 0.8578).

In view of the present conclusions, aiming to the safety use and development of groundwater resources, the following are recommended:

- A detailed study of the structural setting should be done to find out the relation betwwen Nubia sandstone aquifer and the underlying fractured basement one.
- More attention should be focused on flood insurance through the construction of earth and concrete dykes on the upstream portions, specially of Red Sea wadis, which have high gradients to prevent the risk of flash floods and also to increase groundwater recharge.
- Large diameter wells are recommended to be drilled in the fractured basement rocks.
- Advanced irrigation system must be applied (drip and sprinkle irrigation).
- Chemical analyses should be carried out periodically for groundwater samples to ensure that water is valid for different uses (as a long term monitoring program).

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