European Water 25/26: 53-68, 2009.

The Impact of Geological Setting on the Groundwater Occurrences in some Wadis in Shalatein - Abu Ramad Area, South Eastern Desert, Egypt

A.F. Yousef, A.A. Salem, A.M. Baraka and O.Sh. Aglan
Geology Department, Desert Research Center, Egypt
1 Mathaf El Matariya, El Matariya, Cairo, Egypt Box No. 11753
ahmedfawzy63@yahoo.com

Abstract: This study focused on investigating the impact of geomorphological features and geological setting on the groundwater occurrences in arid area to the south of eastern Desert in Egypt. It aimed, in one hand, identification of geomorphological elements, some geological parameters and hydrogeologic situation. And from the other hand, to proposed different sites for future groundwater exploration that could be suitable to endue new environments for effective use of the groundwater by practicing some kinds of irrigated agriculture or rangeland enhancement, as an example. Remote sensing, meteorological, geomorphological, morphometrical, structural, permeability and hydrogeological studies as well as geographic information system were used for selection the proposed sites.

Six geomorphic units are recorded in the study area namely; high mountains, isolated hills, piedmont plain, alluvial fans and coastal plain as well as hydrographic basins. The morphometric parameters of the wadis indicate that they have reduced flooding ability and good chance for groundwater recharge. NE, NW, E-W and N-S are the main fault systems that well controlled the main wadis and their tributaries, and the highly deformated rocks are metavolcanics and metasediments. The dominant heavy minerals of the Quaternary sediments are amphiboles, biotite, epidotes, pyroxenes and garnet arranged in a decreasing order of abundance.

There are three main groundwater aquifers namely; Quaternary, Nubian sandstone and fractured basement. Quaternary aquifer is widely distributed especially in the eastern part. Three hand dug wells are recorded in the aquifer with salinities ranging from fresh (418 ppm) to brackish water (2444 ppm). Nubian sandstone aquifer is recorded at the upstreams of Sifeira and Shab wadis, but there is no water points due to lack of drilling. On the other hand, fractured basement aquifer occupies the western portion. All groundwater wells in the aquifer are dry due to the long period of drought facing the area for eight years without replenishment, except Meisah well in wadi Meisa that has salinity 2161.4 ppm (brackish water). The variation of the groundwater salinities are attributed to the difference of the size of watershed area, the closeness to recharge sources, lithology of the surrounding rocks, density of fractured systems, rate of leaching process, and the effect of direct evaporation of shallow groundwater.

Different sites for future groundwater exploration are proposed that are divided into four priority sites according to the thickness of groundwater saturation, size of the watershed area, rate of recharge and water quality. Different types of geophysical studies must be done in these sites for purification followed by test and production wells to determine the hydrological properties.

Key words: Egypt, Eastern Desert, groundwater aquifer, Quaternary, Nubian sandstone, fractured basemen

1. INTRODUCTION

Recently Shalatein - Abu Ramad area has got more attention as a promising region for different development activities such as tourism, fishery, animal husbandry, mining and as an eastern trading route between Egypt and Sudan. The growth of such activities requires a simultaneous strategy for using and developing of water resources. Where, the main sources of water are surface and groundwater. The study area is located at the far southeastern corner of Egypt and lies between longitudes 35° 15' - 36° 00'E and latitudes 22° 00' - 23° 00' N (Fig. 1). It is bounded by the Red Sea coast to the east, the Nile Valley hydrographic basins to the west and the Egyptian -Sudanese border to the south (lat. 22° 00' N). It has rugged topography in the western part and gently slope in the eastern part. It is accessible and traversed by a number of paved roads and tracks. Sifeira, Shab, Ibib and Meisa are the main wadis in the study area from north to south.

Shalatein - Abu Ramad area lies in semi-arid to arid belt where sporadic rain fall may occur from time to time and accompanied with flash floods. Sometimes an extremely rainless or shortage in rain fall may continue for six or eight years. The meteorological data of the area have been collected from Desert Research Center station at Shalatein of the period between January 1998 and June 2001. The area is hot in summer with maximum temperature of 33.6 °C in August and cold in winter with minimum temperature of 19.1 °C in January. The rain fall is scarce over most of the area where, rain fall precipitated only in March and May 1998 as well as in May 1999 with 1.27, 0.76, 1.27 and 2.54 mm, respectively. The relative humidity ranges from 44-71% and the evapotranspiration varied from about 8.1 mm in summer to 1.33 mm in winter months.

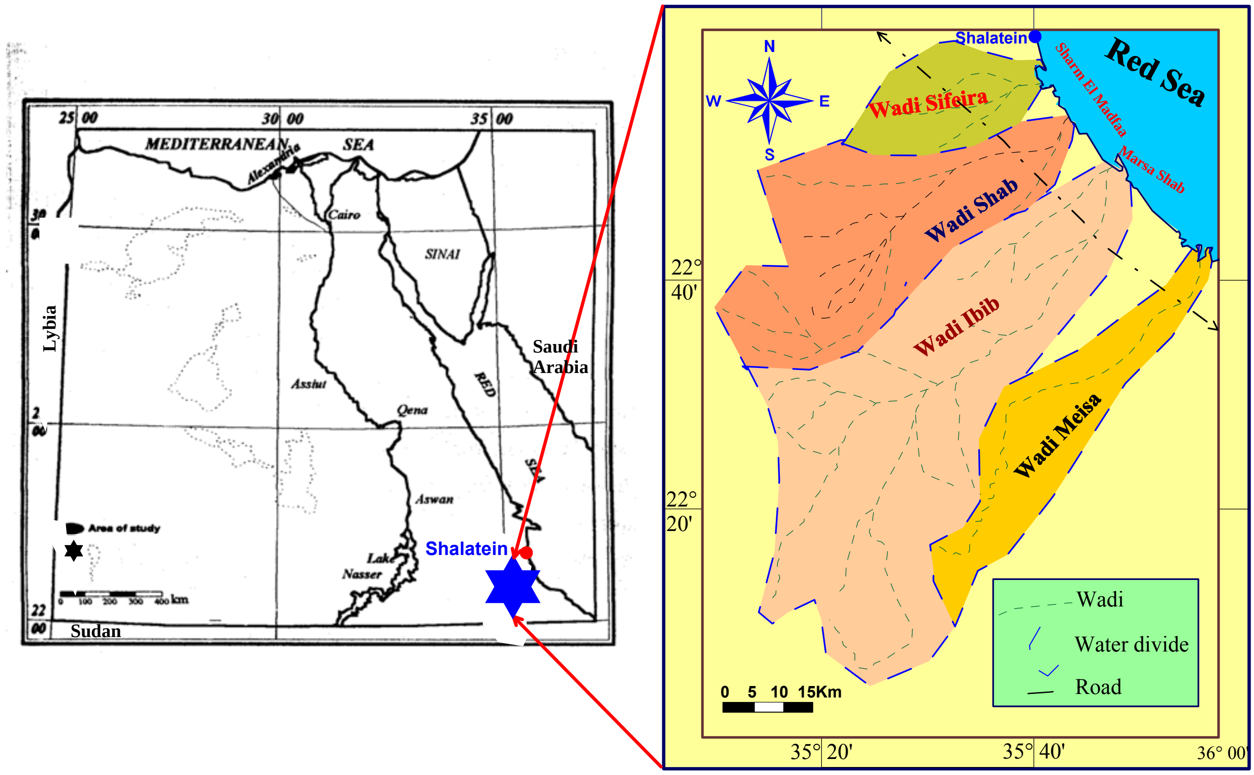

Figure 1. Location map of the study area.

The detailed previous works about the study area, especially those dealing with the geomorphology, morphometry and geology as well as hydrogeology are very scarce. However, Ramadan (1994), Zaghloul and Elewa (1999), Zaghloul et al. (1999), El Gammal (1999), Omar (2000) and Elewa (2000), Baraka (2003) and Yousef and Abdel Ghael (2004) studies are regional studies. Thereby, the present work aimed, in one hand, identification detail geomorphological elements, some geological parameters and hydrogeologic situation. And from the other hand, to proposed different sites for future groundwater exploration that could be suitable to endue new environments for effective use of the groundwater by practicing some kinds of irrigated agriculture or rangeland enhancement, as an example.

2. GEOMORPHOLOGICAL FEATURES

2.1 Landforms

Based on the geologic map, topographic maps, TM satellite image, filed observations and measurements as well as literature; the landform map of the study area is made (Fig. 2). The area is divided into six units namely; high mountains, isolated hills, piedmont plain, alluvial fans, coastal plain and hydrographic basins as follows:

High mountains represent 80% of the study area and constitute part of Arabian-Nubian Shield. They are characterized by the presence of Gabal (G.) Iss (+ 1740 m), G. El Dragaga (+ 1605 m), G. Abu Hodeid (+ 1485 m), G. Garf (+ 1420 m), G. Soaorib (+ 1385 m), G. Suruk (+ 1325 m) G. Madara (+ 1300 m), G Korbiai (+ 1090 m). They are dissected by a lot number of tributaries. Type of rocks, density of fractures and the amount of rain fall control the ground elevation and slopes of the mountainous area. The highly elevated mountains are composed mostly of ophiolitic rocks due to this are resistant to erosion, while granitic mountains have lesser elevation. Mountains that are composed of metavolcanic and metasediments rocks have ground elevation less than +900 m due to their dense fracture system and low resistant to erosion (Fig. 3).

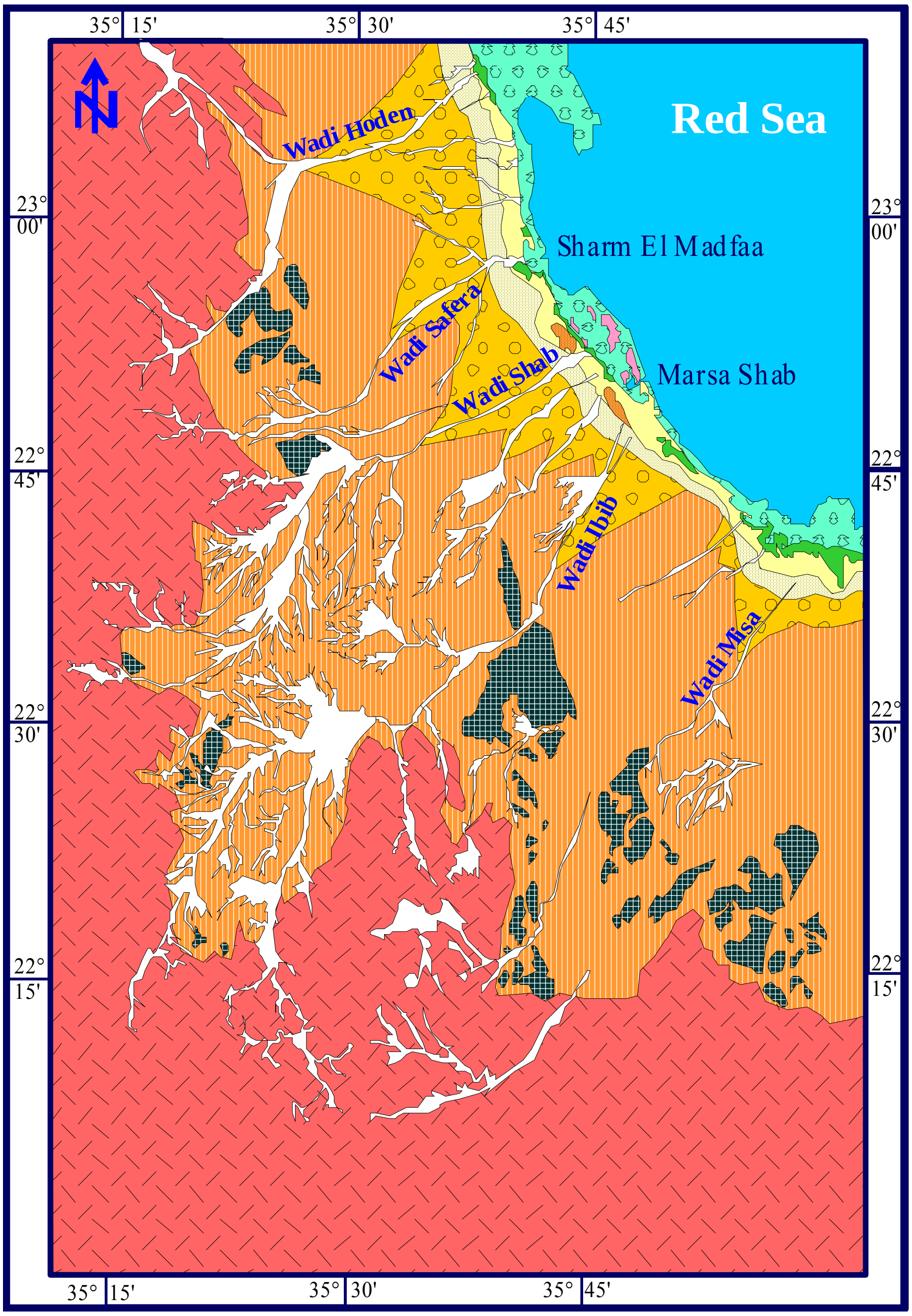

Figure 2. Landform map of the study area.

The isolated hills are located to the east of high mountains. They can be differentiated into three types according to their composition namely: basement, sedimentary and volcanic. The basement hills are composed of metavolcanics and metasediments rocks with ground elevation ranging from +600 to +800 m. The sedimentary hills are recorded only in wadi Sifeira and wadi Shab with ground elevations ranging from +400 to +500 m and are composed of high fractured Nubian sandstone rocks (Fig. 3). Tertiary volcanic hills are located to the east of both with semi-rounded peaks and are composed of basaltic rocks.

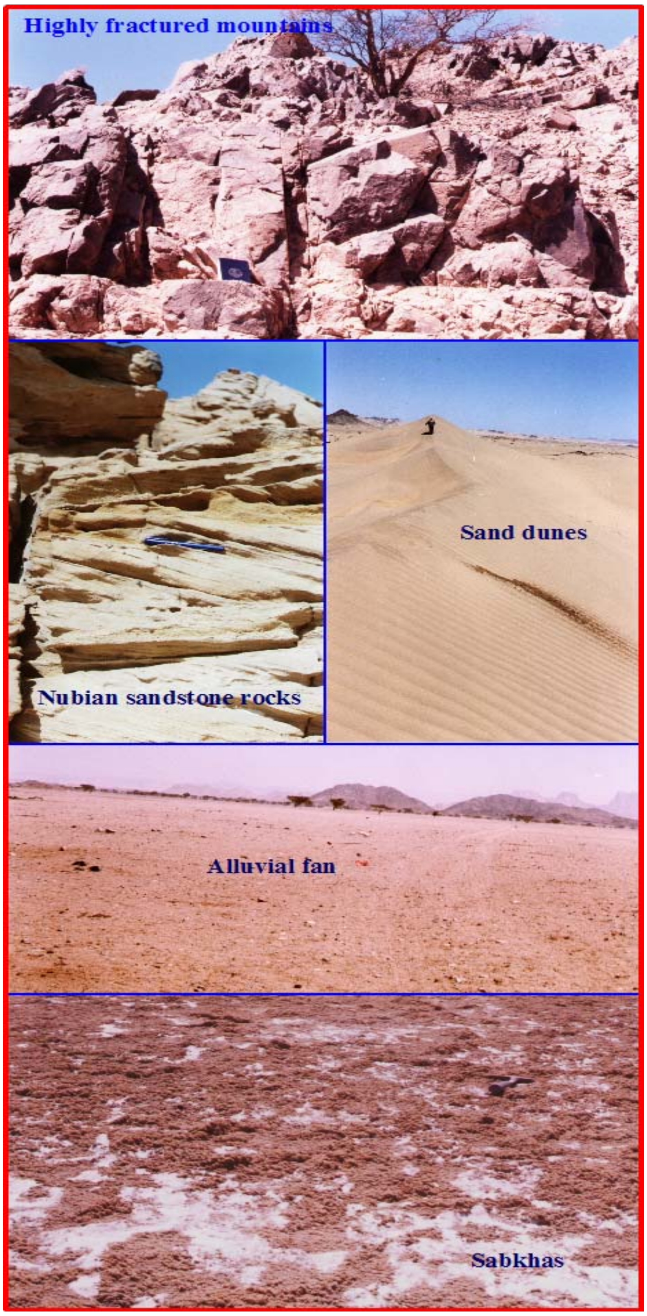

Figure 3. Field photos showing some features.

The piedmont plain occupies large portion to the east of the high mountains and isolated hills with ground elevation varying from +25 to +400 m. The plain is dissected by four main wadis and their tributaries that debouch their water into the sea. Pebbles, gravels and coarse sand constitute the main composition of the plain near mountains and changed eastward to finer sediments. It was formed as a result of the effect of rainy seasons during the Pleistocene and Recent times.

Alluvial fans are located mostly at the outlet of main wadis taking triangle shape. They are connected with each other forming pajada. They have variable sizes which are affected by the size and lithology of watershed area, and the distance from the water divide. The low relief areas of the alluvial fans are occupied by sabkhas. They are composed of sandy gravel to coarse sand that is changed eastward to become fine to medium sand with silt (Fig. 3).

The coastal plain is located to the east of the alluvial fans and is divided into:

i. Sand sheets cover a wide area of coastal plain and composed of fine to medium sand. They are formed as a result of wind erosion of alluvial fans and piedmont plain.
ii. Two coastal sand dunes (4-5 km long) have been recorded around the outlet of Wadi Shab parallel to the present shoreline. The northern one is relatively wide (2 km) and has ground elevation about +6 m. The southern dune is narrow and has higher elevation (about +8m).
iii. Beach subunit extended parallel to the Red Sea with ground elevation varying from about +2m to less than 1 m. The beach is relatively wide against the alluvial fans and relatively narrows in between due to the effect of sediments supply. The low relief areas in the beach are occupied by salt marshes, sabkhas and water bodies.
iv. Sabkhas and salt marshes occupy the relatively low areas of the coastal plain. They are composed of fine sand with silts that covered by salt crust (Fig. 4). They are formed due to the flooding of the main streams and the tidal effect. However, there is a good relation between the watershed area of the main streams and the size of the recorded sabkhas. Where, the larger sabkhas are recorded in the coastal plain of wadi Ibib and wadi Shab (larger wadis).
v. Six islands are recorded in the sea opposite the downstream of wadi Shab. The larger one extends 9 km with 2 km width. They have irregular topography and the maximum ground elevation is +9 m.
vi. Submerged and consolidated coral reefs are grown parallel to the Red Sea Coast. They are characterized by narrow width opposite the alluvial fans and wide in-between may due to the effect of the sediment supply to the sea from the wadis. Mangrove plant community is recorded opposite the downstream of the main wadis in the sea and has a triangular shape. This means that there is a good relation between the occurrence of mangrove and the groundwater recharge from the wadis.

The study area is dissected mostly by four hydrographic basins namely Sifeira, Shab, Ibib and Meisa from north to south. Sifeira and Meisa are small basins (420.7 km^2 and 450.4 km^2) with length of 38 km and 64 km, respectively. On the other hand, Shab and Ibib are large basins (1090 km^2 and 1836 km^2) with large length reaches 67.5 and 92.0 km, respectively.

2.2 Morphometric Analyses

Topographic maps of scale 1:50000 were used for delineating and tracing the drainage network of the study area. The morphometric parameters of the drainage basins were measured (Table 1) according to Horton (1932 and 1945), Schumm (1954), Strahler (1952) and Melton (1957). Sifeira, Shab, Ibib and Meisa drainage basins are the main basins (Figs. 1, 4 and 5) and are characterized by the following:

i. Sifeira basin has pear shape, while the others have elongation that mean more travel time of surface water to the outlet.
ii. The estimated values of elongation ratio lie between 0.37 (Meisa basin) to 0.60 (Sifeira basin) and the circularity ratio range from 0.09 (Meisa basin) to 0.23 (Sifeira basin). These mean that the study basins are elongated rather than circular and have the ability of reducing flash flood.
iii. Channel slope (S 10-85) of Ibib, Meisa, Shab and Sifeira Basins are 6.7, 7.76, 8.1 and 8.4 m/km that mean more chances to feed the groundwater.
iv. The sinuosity ratios (Lc/LB) of the basins have less meandering channels that mean more effective for flooding than numerous meanders. Where, the sinuosity ratio values range between 1.17 (Sifeira) and 1.24 (Shab).

Table 1. Morphometric parameters of the study basins.

No.	Basin Name	Stream Order	Stream Number	Stream Length (Km)	Area (Km^2)	F (Km^{-2})	D (Km^{-1})	Rb	Sh. F.	Re	Rc	LB (Km)	Lc (Km)	Lc/LB	S10-85
1	Sifeira	5th	298	659	420.7	0.71	1.57	3.98	0.29	0.60	0.23	38.0	45	1.17	8.4
2	Shab	7th	3027	3485	1090	2.78	3.20	4.2	0.24	0.55	0.19	67.5	84	1.24	8.1
3	Ibib	7th	6985	5980	1836	3.80	3.26	4.2	0.22	0.53	0.17	92.0	105	1.14	6.7
4	Meisa	6th	1732	1385	450.4	3.85	3.08	4.3	0.11	0.37	0.09	64.0	78	1.22	7.76

Abbreviation:
A: Basin area *F: Stream frequency* *D: Drainage density* *Rb: Bifurcation ratio*
Sh.F: Shape factor *Re: Elongation ratio* *Rc: Circularity ratio* *LB: Basin length*
Lc: Main channel length *Lc/LB: Sinuosity ratio* *S-10-85: Man channel slope*

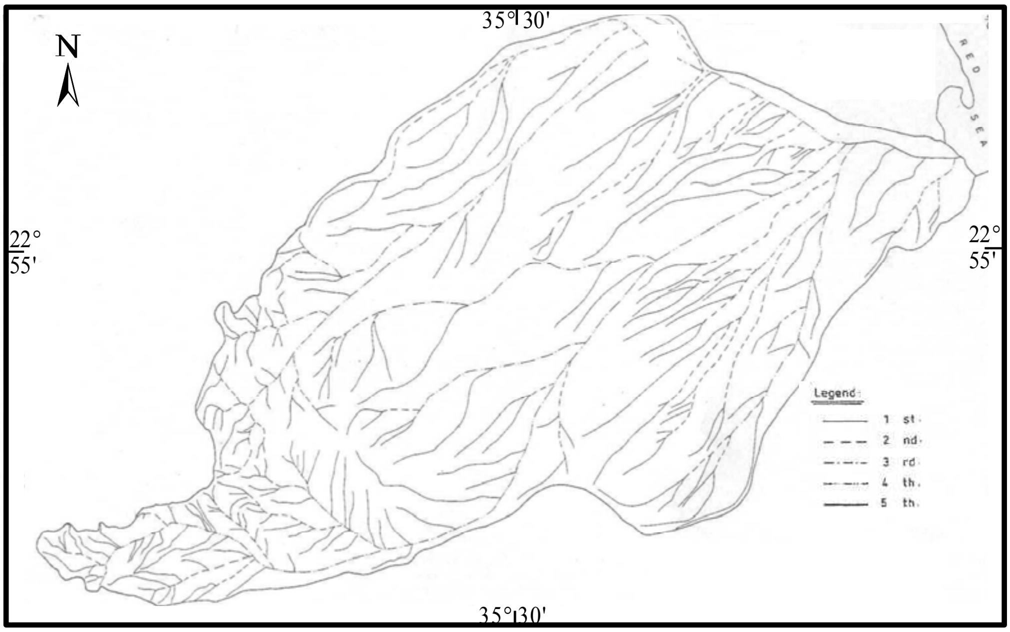

Figure 4. Drainage pattern of Sifeira Basin.

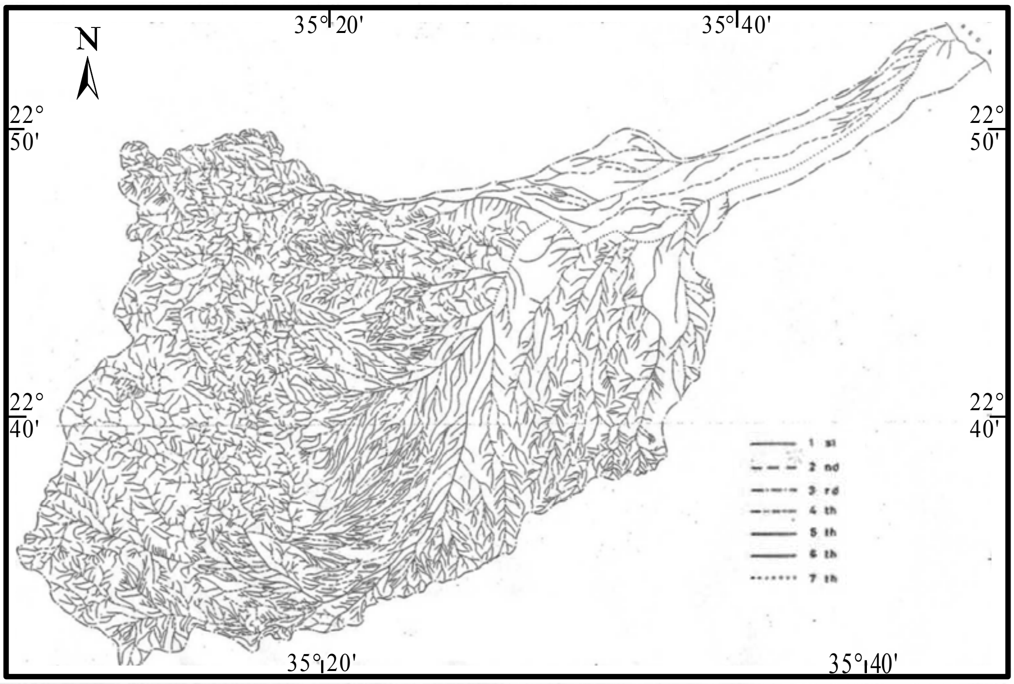

Figure 5. Drainage pattern of Shab Basin.

3. GEOLOGIC SETTING

3.1 Surface Geology

The surface geology of the study area is built up of Pre-Cambrian basement, Late Cretaceous and Tertiary volcanic rocks as well as Quaternary sediments (Fig. 7). Pre-Cambrian basement rocks are located in the western portion and form part of the Arabo-Nubian Shield. They are represented by gneiss and migmatitis, ophiolitic assemblages, metasediments, metavolcanics and old granite as well as young granite from older to younger. Gneiss and migmatitis rocks occupy most of the western part of Wadi Ibib, while the ophiolitic assemblages rocks (serpentinized, talc-carbonate and ophiolitic metagabbro) are located in the upstreams of wadi Shab, wadi Ibib and wadi Meisa. Metasediments (meta-greywackes and shist) and metavolcanics (meta-pyroclastics associated with meta-basalts, meta-andesite and meta- dacites) rocks occupy large portion of Wadi Meisa and small parts of the upstreams of the other wadis. Older granitic rocks (mainly plagioclase, hornblende, biotite and quartz) are located as isolated hills. Younger granitic rocks are recorded mainly in Wadi Shab and the upstreams of Meisa and Ibib wadis.

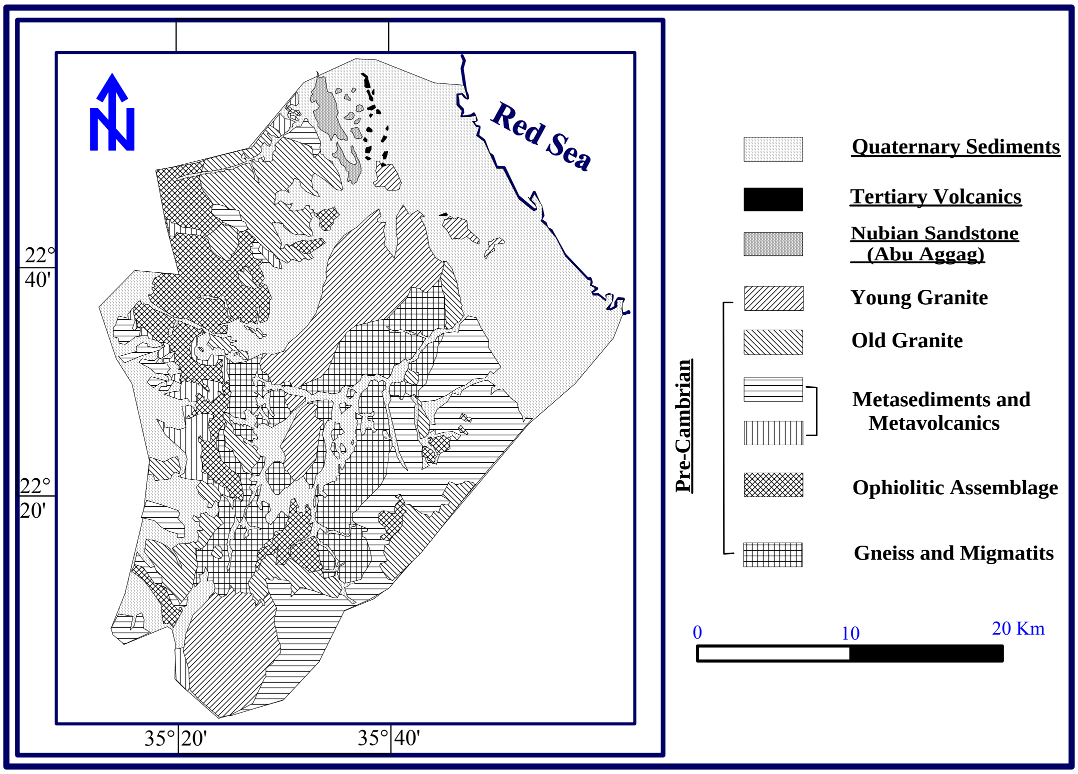

Figure 7. Geologic map of the study area (after Klitzsch et al., 1987).

Late Cretaceous is represented by Nubian sandstone rocks that are located as isolated hills in wadi Sifeira and wadi Shab. One surface section (15 samples) is collected from Nubian rocks (Abu Aggag formation). It has cross bedding and lamination medium to fine sandstone that deposited under continental condition (Fig. 8). Tertiary volcanics are extruded as a chain of isolated hills and composed mostly of basalt. Quaternary sediments occupy mostly the eastern portion of study area and the main channels. 42 shallow profiles (229 samples) have been selected (Fig. 8) to declare the depositional environments of the sediments. They are described in the field and in the laboratory using microscope and some of them have been selected for mechanical analyses. They are classified into continental and littoral sedimentological units. Alluvial (channels, fans, floods and fresh water ponds) and aeolian (inland dunes and sand sheets) are the main continental sub-units. The main littoral subunits are beach, coastal lagoons and coastal sand dunes. The mineralogical analyses of the selected fifty eight samples for heavy minerals studies show that the opaque minerals varying from 4.8% in wadi Meisa to 18.2% in wadi Sifeira. Non opaque minerals constitute the main percentage of heavy minerals that are represented mainly by amphiboles, biotite, epidotes, pyroxenes and garnet in decreasing order. Staurolite, zircon, tourmaline, apatite, monazite and rutile minerals are recorded as rare amounts (less than 1%).

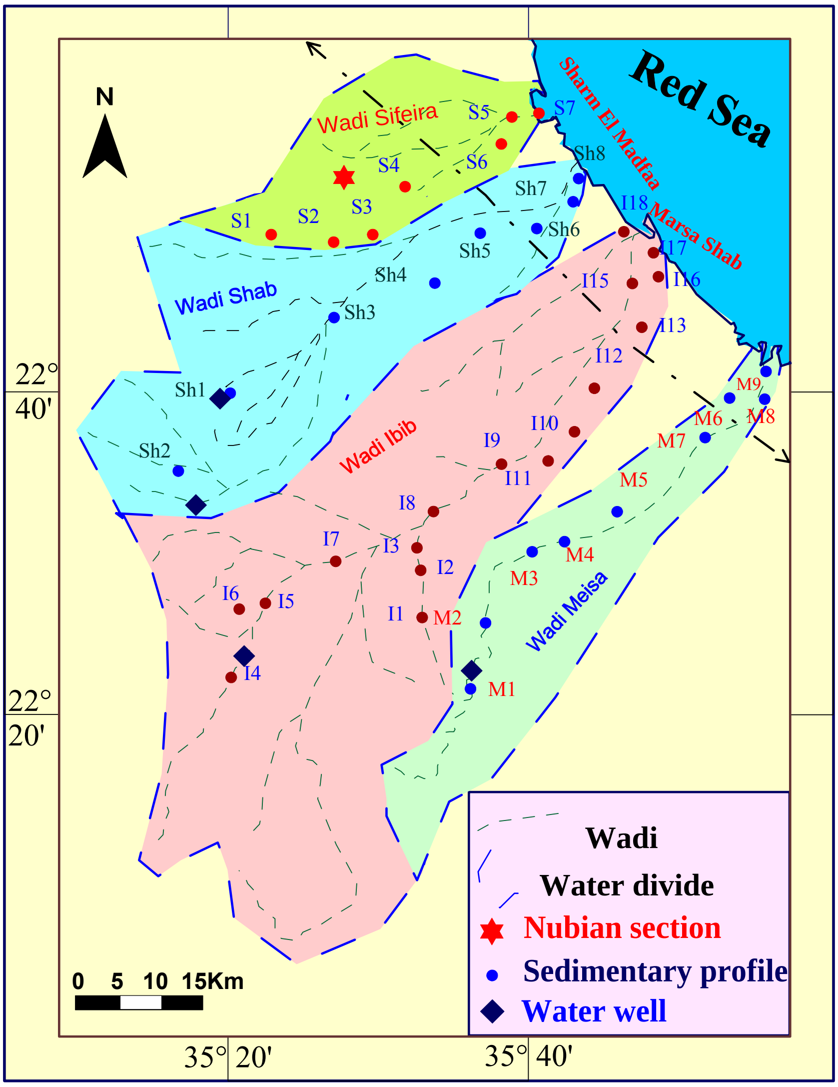

Figure 8. Location map of selected sedimentary profiles and recorded water points.

3.2 Structure Geology

The study area is affected by four tectonic phases that were caused folding, faulting and fracturing. Folding is appear in the presence of higher structures in the western part and the presence of low structures in between, where the same phenomenon has been recorded by El Rakaiby and Kamel (1988) south to the Eastern Desert. The lineation map (Fig. 9) is prepared using geologic map and satellite images followed by intensive field works to determine the aerial extent of faults of each set. The predominant trends of fault systems are NE, NW, E-W and N-S in decreasing order. NE fault system controls the main courses of streams except Shab which is controlled by NW fault system. E-W controls some tributaries of wadi Shab, wadi Ibib and wadi Sifeira. N-S controls some tributaries of wadi Ibib. The area is cut by some E-W and NE dykes. The highly fractured rocks are metavolcanic and metasediments followed by granitic rocks.

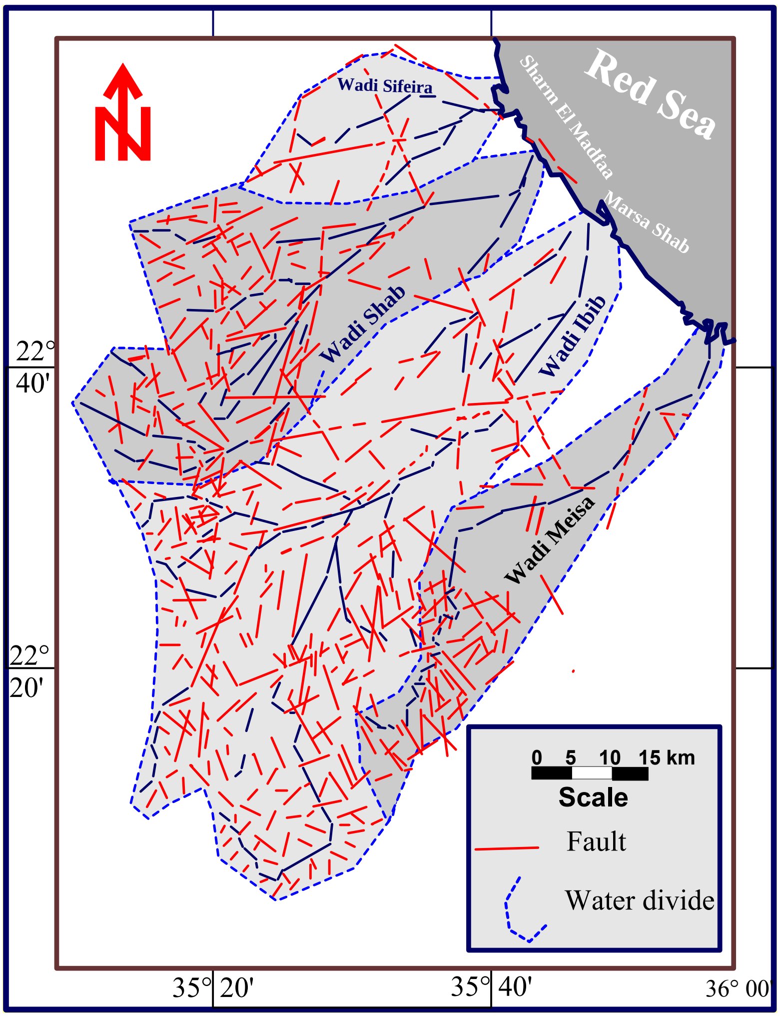

Figure 9. Lineation map of the study area.

4. HYDROGEOLOGIC CONDITIONS

Surface and groundwater are the main sources of water supplies for local Bedouins, agriculture and mining activities in the study area. The occurrences, distributions and salinities of groundwater aquifers controlled by different factors such as geomorphology, basin analysis, structure, type of rocks, lithofacies, mineralogy and climatology that are mentioned before. Based on these factors, chemical analyses of the recorded water samples according to ASTM (2004) (Fig. 8, and Tables 2 and 3) and hydrogeologic sketch (Fig. 10); there are three main groundwater aquifers as follows:

4.1 Quaternary Aquifer

Quaternary aquifer covers wadi channels, piedmont plain and coastal plain. It is composed of sandy gravel in the western part changed eastward to become clayey sand that overlain Nubian sandstone and/or fractured basement rocks. Three hand dug wells are recorded in the aquifer namely; Baaneit and Lasela wells in wadi Shab and Abu Hodied well in wadi Ibib with salinities 2444, 570 and 418, respectively. The aquifer recharged directly from rain fall and from the eastern watershed areas through faults. The variation of salinities are due to the effect of surrounding rocks and structures, where the high salinity of Baaneit well is due to the effect of highly fractured saline metasediments and metavolcanics rocks (Fig. 10), while the relatively low salinities of the others are due to the effect of low fractured non saline granitic and ophiolitic rocks. Also, the watershed area and the quantity of rain fall affect the rate of recharge and salinity of groundwater, where the area near Baaneit well is characterized by small watershed area, low density of fractures and low amount of rain fall, while the others (Lasela and Abu Hodied wells) are characterized by relatively high watershed and considerable amount of rain fall.

Table 2. Hydrogeological data of the recorded water points.

No.	Wadi	Name	Lat. N	Long. E	Aquifer Type	Total Depth (m)	Depth to Water (m)	Water column (m)	Salinity (ppm)
1	Shab	Baaneit	22 °40' 769	35 ° 22' 009	Quaternary	21.77	15.42	6.35	2444
2		Lasela	22 ° 34' 345	35 ° 16' 432		13.96	12.70	1.26	570
3	Ibib	Abu Hodeid	22 ° 22' 251	35 ° 19' 842		17.00	16.00	1.00	417.7
4	Meisa	Meisah	22° 21' 218	35 ° 35' 887	F. basement	7.75	7.50	0.25	2161.4

Table 3. Chemical analysis of the groundwater samples.

No.	Aquifer	Wadi	Well Name	TDS (ppm)	PH	Units	Cations (ppm)				Anions (ppm)		
							Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}
1	Quaternary	Shab	Baaneit	2444	8.12	mg/l	78.32	304.94	400.0	3.00	189.66	260.0	1302.2
						meq/l	3.91	25.08	17.39	0.08	3.11	5.41	36.72
						e%	8.41	53.98	37.44	0.17	6.87	11.96	81.16
2			Lasela	570	8.46	mg/l	10.68	60.55	65.00	3.00	194.8	14.0	167.1
						meq/l	0.53	4.98	2.83	0.08	3.19	0.29	4.71
						e%	6.33	59.17	33.58	0.91	38.95	3.56	57.49
3		Ibib	Abu Hodeid	417.7	7.50	mg/l	138.8	103.8	100.0	6.00	763.8	40.0	211.3
						meq/l	6.93	8.54	4.35	0.15	12.52	0.83	5.96
						E %	34.70	42.8	21.78	0.77	64.83	4.31	30.86
4	Fractured basement	Meisa	Meisah	2161.44	7.65	mg/l	234.96	47.6	500.0	10.0	251.2	290.0	953.3
						meq/l	11.72	3.91	21.74	0.26	4.12	6.04	26.88
						e%	31.15	10.4	57.77	0.68	11.11	16.30	72.58

The permeability of the 56 Quaternary profiles (Table 4) are calculated using Seelhiem equation (1980) to measure the ability to transmit a fluid under a hydro-potential gradient. The permeability values vary from area to other and from wadi to wadi, where along the main streams the permeability values decrease from 13.15 in the upstream (Wadi Ibib) to 3.34 in the downstream (Wadi Shab) due to the fining of sediments eastwards. However, in the piedmont and coastal plains the permeability values are relatively high and vary from 6.53 to 18.38 due to their coarser texture. This means that, the rate of groundwater recharge is higher in piedmont and coastal plains than in the main wadis. The same phenomenon has been recorded based on morphometric analyses.

4.2 Nubian Sandstone Aquifer

Nubian sandstone rocks belonging to Upper Cretaceous time are outcropped in the upstream of wadi Sifeira and wadi Shab, and are composed mostly of ferruginous coarse to medium grained sandstone with shale interbeds (Abu Aggag formation). The aquifer recharged directly from the rain fall and indirect from the western basement rocks through fracture systems. No water points has been recorded in Nubian aquifer due to the lack of drilling, while there are a lot of water points tapping the aquifer in wadi Hodein to the north of the study area.

4.3 Fractured Basement Aquifer

Fractured basement aquifer occupies the western portion of the study area and composed mostly of granitic, ophiolitic, metasediments and metavolcanics rocks in decreasing order. The granitic and ophiolitic rocks have low density of fracture systems, while metasediments and metavolcanics rocks are characterized by high density of fracture systems. Rain fall is the main source of aquifer recharge. All hand dug wells in the study area are dry due to the long period of drought facing the area for eight years without replenishment, except Meisah well in Wadi Meisa that has salinity 2161.4 ppm. The accumulation of groundwater in Meisah site is due to the presence of dyke that acts as barrier preventing the groundwater movement down slopes, while the higher salinity is due to the effect of surrounding highly fractured metasediments rocks and the long period of drought without replenishment. The permeability of the aquifer is of secondary type that is formed due to the effect of regional and local structural events.

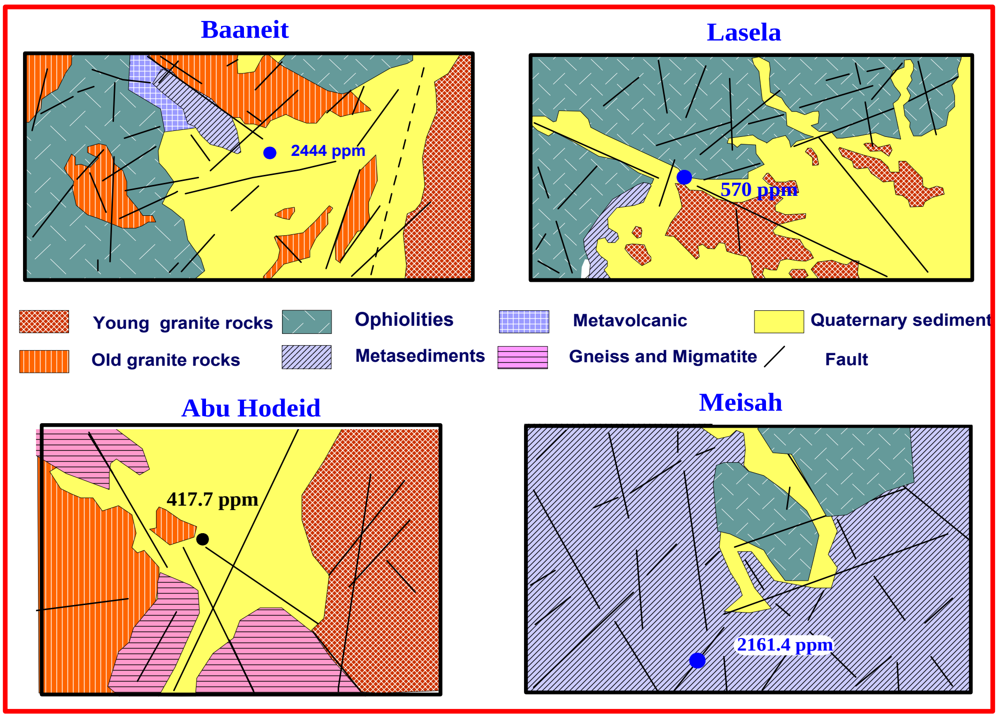

Figure 10. Hydrogeological sketch of the recorded water points.

Table 4. The average permeability of the Quaternary sediments in the study area.

Wadi	Main channels			Piedmont Plain	Coastal Plain
	Upstream	Midstream	Downstream		
Sifeira	8.34	2.73	3.82	6.53	11.66
Shab	9.99	6.16	3.34	18.39	7.65
Ibib	13.15	3.62	4.60	10.38	12.97
Meisa	3.44	8.71	3.70	11.67	6.92

5. HYDROGEOCHEMICAL CHARACTERISTICS AND WATER QUALITY

5.1 Hydrogeochemical Characteristics

The chemical analyses of the collected water samples (Table 3), ion dominance and the hypothetical salt (Table 5) show that the geochemical properties of water are well controlled by the type of aquifer characteristics, surrounding rock units and the source of recharge as follows:

i. The salinities of the aquifers vary greatly from one aquifer to another and even from one locality to another in the same aquifer. The variation is attributed to the difference of the size of watershed area, the closeness to recharge sources, lithology of the surrounding rock units, density of fractured systems, rate of leaching process, and the effect of direct evaporation of shallow groundwater. The salinities of Quaternary aquifer range from fresh water (417.70 ppm) in Abu Hodied well to brackish water (2443.7 ppm) in Baaneit well.

The lower salinity of Abu Hodied well is due to their location in the upstream and the surrounding rocks are granitic and ophiolitic rocks, while higher salinity of Baaneit well is due to the effect of surrounding highly fractured saline metasediments and metavolcanic rocks. On the other hand, the salinity of fractured basement aquifer is brackish (2161.44 ppm) in Meisah well due to the effect of surrounding highly fractured saline metasediments rocks.

ii. The pH values vary from 7.5 to 8.46 that indicate alkaline character.

iii. The dominated ions of the Quaternary Aquifer are arranged in three groups namely; Mg^{++} > Na^{+} > Ca^{++} / Cl^{-} > SO_4^{--} > HCO_3^{-} (Baaneit well), Mg^{++} > Na^{+} > Ca^{++} / Cl^{-} > HCO_3^{-} > SO_4^{--} - (Lasela well) and Mg^{++} > Ca^{++} > Na^{+} / HCO_3^{-} > Cl^{-} > SO_4^{-} - (Abou Hodeid well). The variations of dominant ions are due to the rate of recharge, surrounding rocks and leaching processes. The dominance of magnesium ion is due to the impact of the dissolution of rocks which rich in magnesium e.g. serpentine and other basic rocks. The dominated ions of fractured basement aquifer are Na^{+}> Ca^{++}> Mg^{++} / Cl^{-} > SO_4^{--} > HCO_3^{-}.

iv. The chemical water type of Quaternary aquifer is Magnesium - Chloride, while the chemical water type of fractured basement aquifer is Chloride - Sodium .

v. The main salt combinations of Quaternary aquifer are NaCl, $Ca(HCO_3)_2$ and $CaSO_4$ due to the leaching and dissolution processes of weathered basic rocks. NaCl, $Ca(HCO_3)_2$, $MgSO_4$ and $CaSO_4$ are the main salt combinations of fractured basement aquifer due to the dominance of altrabasic rocks (metasediments).

vi. Using Trilinear diagram (Piper 1944) for the classification of the groundwater samples geochmically, all samples are located in the upper triangle of the diamond shaped field of the diagram (Fig. 11). These reflect the secondary salinity properties, where (SO_4^{--}+Cl^{-}) exceeds (Na^{+}+K^{+}) and the characteristic water types are Ca^{++} and Mg^{++} Chlorides and Sulphates. Generally most of the groundwater samples of aquifers refer to infiltration (meteoric type) and the chemical compositions reflect the influence of the aquifer sediments.

Table 5. Ion dominance and hypothetical salts of the study groundwater samples.

No.	***Wadi***	***Aquifer***	***Ion Dominance***	***Hypothetical salts***
1	Shab	Quaternary	Mg^{++} > Na^{+} > Ca^{++} & Cl^{-} > SO4^{--} > HCO3^{--}	NaCl, $Ca(HCO_3)_2$, $MgSO_4$
2			Mg^{++} > Na^{+} > Ca^{++} & Cl^{-} > HCO3^{--} > SO4^{--}	NaCl, $Ca(HCO_3)_2$, $CaSO_4$
3	Ibib		Mg^{++} > Ca^{++} > Na^{+} & HCO3^{--} > Cl^{-} > SO4^{--}	NaCl, $Ca(HCO_3)_2$, $CaSO_4$
4	Meisa	Fractured Basement	Na^{+} > Ca^{++} > Mg^{++} & Cl^{-} > SO4^{--} > HCO3^{--}	NaCl, $Ca(HCO_3)_2$, $MgSO_4$, $CaSO_4$

5.2 Evaluation of Groundwater Quality

According to the international standards by the World Health Organization (WHO, 1971) for the evaluation of groundwater for drinking and domestic purposes, the water samples in the study area are classified as follows:

i. Excellent to good water (TDS < 500 mg/l) characterizes the sample of Abu Hodeid well (Quaternary aquifer).

ii. Permissible water (TDS 500 - 1500 mg/l) characterizes the sample of Lasela well (Quaternary aquifer).

iii. Unsuitable water (TDS > 1500 mg/l) characterizes the sample of Baaneit well (Quaternary aquifer) and the sample of Meisah (fractured basement aquifer).

iv. The U.S. Salinity Staff's Classification (1954) is used to evaluate the concerned water samples for irrigation purpose. This classification depends on the relationship between the sodium adsorption ratio (S.A.R.) and the electric conductivity (EC) of the water samples. The plotted water samples on the diagram (Fig. 12) show that the collected water samples are suitable for irrigation, where Abu Hodeid and Lasela samples of the Quaternary aquifer lie in the good water class, and sample of Baaneit (Quaternary) and sample of Meisah (fractured basement) lies in moderate water class.

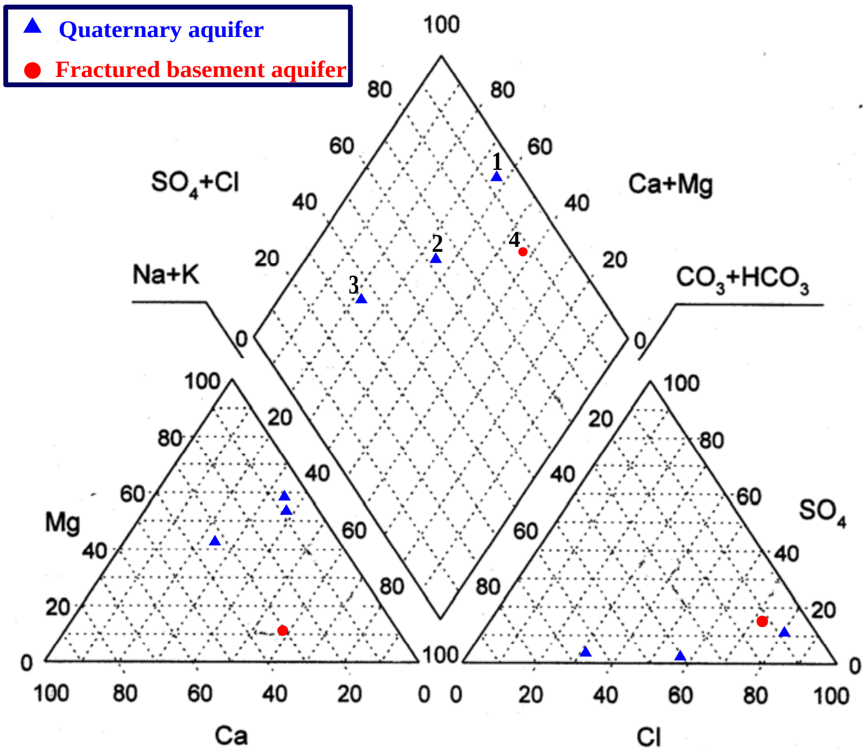

Figure 11. Genetic classification of water samples.

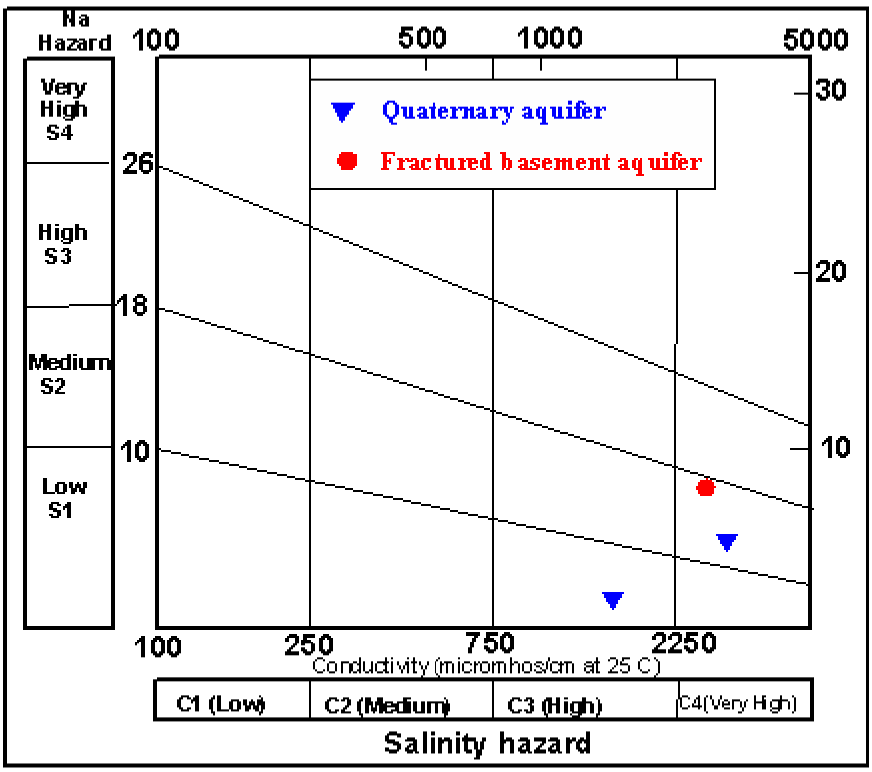

Figure 12. The plot of water samples on diagram for the classification for irrigation purposes (according to U.S. Salinity Staff, 1954).

6. SUMMARY AND CONCLUSIONS

This study focused on investigating the impact of geomorphological features and geological setting on the groundwater occurrences in arid area to the south of eastern Desert in Egypt. The main objectives of the present work are identification of the geomorphological characteristics (landforms and morphometry), some geological features (surface geology and structure geology), hydrogeological and hydrochemical conditions of Sifeira, Shab, Ibib and Meisa wadis south Shalatein. And from the other hand, to proposed different sites for future groundwater exploration that could be suitable to endue new environments for effective use of the groundwater by practicing some kinds of irrigated agriculture or rangeland enhancement, as an example. Based on the geologic map, topographic maps, TM satellite image, filed observations and measurements as well as literature, six geomorphic units are recorded in the study area namely; high mountains, isolated hills, piedmont plain, alluvial fans and coastal plain and hydrographic basins. The morphometric parameters of the wadis indicate that they have reduced flooding ability and good chance for groundwater recharge.

The surface geology of the study area is built mostly of Pre-Cambrian basement, Late Cretaceous Nubian sandstone and Tertiary Volcanic Rocks as well as Quaternary sediments. One surface section (15 samples) is collected from Nubian rocks (Abu Aggag formation). It has cross bedding and laminated medium to fine sandstone that deposited under continental condition. 42 shallow profiles (229 samples) have been selected to declare the depositional environments of Quaternary sediments. They are classified into continental and littoral sedimentological units. Alluvial (channel, fan, flood and fresh water pond) and aeolian (inland dunes and sand sheets) are the main continental sub-units. The main littoral subunits are beach, coastal lagoon and coastal sand dune. The mineralogical analyses of the selected fifty eight samples for heavy minerals studies show that the opaque minerals varying from 4.8% in wadi Meisa to 18.2% in wadi Sifeira. Non opaque minerals constitute the main percentage of heavy minerals that are represented mainly by amphiboles, biotite, epidotes, pyroxenes and garnet in decreasing order. The predominant fault systems trends are NE, NW, E-W and N-S. NE system controls the main courses of streams except of wadi Shab which is controlled by NW system. E-W controls some tributaries of Shab, Ibib and Sifeira wadis. N-S controls some tributaries of Wadi Ibib. The study area is cut by some acidic and basic dykes trending mostly E-W and NE. The highly fractured rocks are metavolcanics and metasediments followed by granitic rocks.

There are three main groundwater aquifers namely; Quaternary, Nubian sandstone and fractured basement. Quaternary aquifer is widely distributed especially in the eastern part. Three hand dug wells are recorded in the aquifer with salinities ranging from fresh (418 ppm) to brackish water (2444 ppm). Nubian sandstone aquifer is recorded at the upstreams of Sifeira and Shab wadis, but there is no water points due to lack of drilling. On the other hand, fractured basement aquifer occupies the western portion. All groundwater wells in the aquifer are dry due to the long period of drought facing the area for eight years without replenishment, except Meisah well in wadi Meisa that has salinity 2161.4 ppm (brackish water). The variations of the groundwater salinities are attributed to the difference of the size of watershed area, the closeness to recharge sources, lithology of the surrounding rocks, density of fractured systems, rate of leaching process, and the effect of direct evaporation of shallow groundwater. The main salt combinations of Quaternary aquifer are NaCl, Ca $(HCO_3)_2$ and $CaSO_4$ due to the leaching processes of weathered basic rocks. NaCl, Ca $(HCO_3)_2$, $MgSO_4$ and $CaSO_4$ are the main salt combinations of fractured basement aquifer due to the dominance of altrabasic rocks (metasediments). Abu Hodeid water sample is excellent for drinking and domestic purposes and Lasela water is permissible (Quaternary aquifer), but the others are unsuitable. Abu Hodeid and Lasela samples are suitable for irrigation purposes, while Baaneit water sample (Quaternary aquifer) and Meisah water sample (fractured basement) are moderate.

Based on meteorological, geomorphological, morphometrical, geological, structural, permeability, hydrogeological and hydrochemical studies as well as geographic information system (GIS) and literature; different sites are proposed for future groundwater exploration and site need deep geophysical studies. These sites could be suitable to endue new environments for effective use of the groundwater by practicing some kinds of irrigated agriculture or range land enhancement, as an example. The proposed sites can be classified into four priority according to the thickness of groundwater saturation, watershed area, rate of recharge and water quality (Fig. 13). There are four sites of first priority that are located at the interacting between basement and sedimentary in Shab and Ibib Wadis, near the downstream of Wadi Sifeira and in the midstream of Wadi Meisa. They have low drainage pattern, high watershed, low topography, relatively coarse texture, high infiltration rates and intersecting between fault systems as well as dense natural vegetation. Five sites have been selected for second priority; three of them are in Um Rasain, Husum and Abu Ragem main tributaries of wadi Ibib, while the others are located in wadi Shab and wadi Meisa. They are characterized by relatively low drainage pattern, relatively high watershed, undulating topography, medium texture, relatively high infiltration rates and intersecting between fault systems as well as relatively dense natural vegetation. Third and fourth priority sites are located in wadi Meisa. They have relatively low drainage pattern, moderate watershed, low topography, moderate to low infiltration rates and natural vegetation. Different types of geophysical studies must be done in these sites for purification followed by test and production wells to determine the hydrological properties.

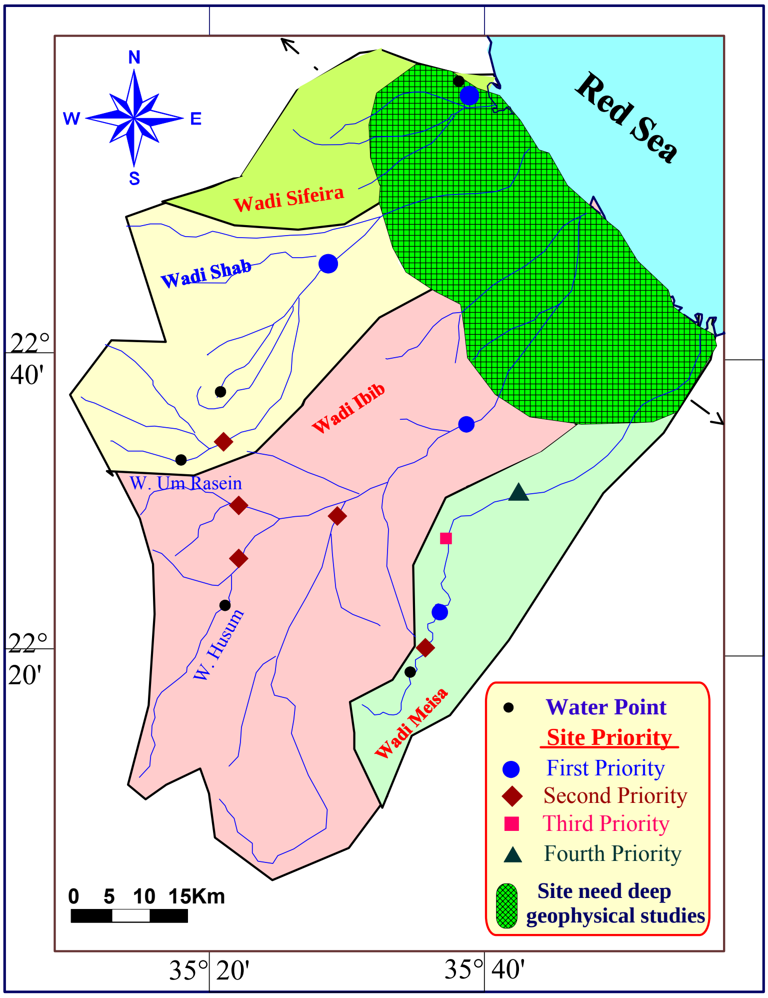

Figure 13. Proposed sites for future groundwater exploration.

The occurrence of Nubian sandstone aquifer north the study area and Miocene aquifer to the south as well as the presence of outcropped Nubian sandstone in the upstreams of wadi Sifiera and wadi Shab, encourage the authors to proposed the presence of the same aquifers in the eastern portion of the study area. For purification, deep geophysical explorations and different test and production wells must be done.

REFERENCES

American Society for Testing and Materials (ASTM) 2002. "Water and Environmental Technology". Annual book of ASTM standards, Soc. 11, Vol. 11, West Conshohocken, U.S.A.

Baraka, A. M., 2003. Geologic studies on the Neogene and Quaternary sediments and their bearing on water resources in Shalatein – Halaib area, Egypt. Ph. D. Fac. of Sci., El-Azhar University, 175p.

Elewa, H. H., 2000. Hydrogeology and hydrological studies in Halaib - Shalatin area, Egypt, using remote sensing technology and other techniques. Ph. D. Thesis, Fac. of Sci., Ain Sham University.

El Gammal, E. A., 1999. Impact of geomorpholohical features on sustainable development of the south Eastern Desert, Egypt, using landsat images. Egypt, J. Remote Sensing and Space Sci., 2: 57 - 68.

El Rakaiby, M. L. and Kamel, A. F., 1988. Factors controlling the distribution of radioactivity in south Eastern Desert, Egypt. 4th Conf. Nuc. Sc. and Appl., 1: 186 - 192.

Horton, R. E., 1932. Drainage basin characteristics. Trans. Am. Geophys. Union, 13: 350 - 361.

Horton, R. E., 1945. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56: 275 - 370.

Klitzsch, E., List, F. K. and Pohlmann, G., 1987. Geological Map of Egypt, Baranice sheet. Scale 1:500,000, in Corporation/CONOCO, T.E.G.P., ed.: Baranice, Egypt.

Melton, M. A., 1957. Geometric properties of mature drainage systems and their representation in an E4 phase space. J. Geol., 66: 35 - 54.

Omar, H. H., 2000. Hydrogeology and Hydrological studies in Halaib – Shalatein area, Egypt, using remote sensing technology and other techniques. Ph. D., Fac., Ain Shams Univ., 282p.

Piper, A. M., 1944. A graphic procedure in the geochemical interpretation of water analysis. Transactions, American Geophysical Union, 25: 914 - 923.

Ramadan, T. M., 1994. Geological and Geochemical studies on some basement roks at Wadi Hodein area south Eastern Desert, Egypt. Ph. D. Thesis, Fac. Sci., Al-Azhar univ., Egypt, 192p.

Schumm, S., 1954. The relation of drainage basin relief to sediment loss, Int. Union Geodesy Geophys., 10th Gen. Assembly (Rome). Int. Assoc. Sci., Hydrol. Publ. 36, 1: 216 - 219.

Strahler, A. N., 1952. Hypsometric (area attitude) analysis of erosional topography. Geol. Soc. Am. Bull., 63: 1117 - 1142.

U.S. Salinity Laboratory, 1954. Diagnosis and Improvement of Saline and Alkaline Soil. S.S. Dept. of Agriculture, Hand Book, No. 60, 160 p.

World Health Organization "WHO" 1971. International standards for drinking water. Geneva, World Health Organization, 70 p.

Yousef, A. F. and Abel Galel, K., 2004. The impact of geological and structural setting on the groundwater occurrences and their quality in the area between Abu Ramad and Ras Hederbah, south Eastern Desert, Egypt. Geological Society of Egypt, 47: 459 - 474.

Zaghloul, E. A. and Elewa, H. H., 1999. Reports on studying Halaib-Shalatin area water resources. Unpublished report in National Authority for Remote Sensing and Space Sciences (NARSS).

Zaghloul, E. A.; Abdel Samie, S. G. and Elewa, H. H., 1999. Determination of origins and genesis of the groundwater in Halaib and Shalatin area (southeast Egypt) using environmental isotopes. Bull. of Isotope and Radiation Research, 12pp.