GROUNDWATER IN THE EASTERN DESERT WITH REFERENCE TO APPLICATION OF REMOTE SENSING AND GIS

Hossam Hamdy Elewa*
National Authority for Remote Sensing & Space Sciences (NARSS), Engineering Applications and Water Division (EAWD), Cairo, Egypt

I. INTRODUCTION

1.1. Location

The Eastern Desert of Egypt comprises almost one-fourth of the land surface of Egypt and covers an area of about 222117 km^2. The northern tier is a limestone plateau, consisting of rolling hills, stretching from the Mediterranean coastal plain to a point roughly opposite Qena town on the River Nile. Near Qena, the plateau breaks up into cliffs about 487 m high and is deeply scored by wadis, which make the terrain very difficult to traverse. The outlets of some of the main wadis form deep bays, which contain small settlements of semi nomads. The second tier includes the sandstone plateau from Qena southward. The plateau is also deeply indented by ravines, but they are relatively free from obstacles, and some are usable as routes. The third tier consists of the Red Sea Hills and the Red Sea coastal plain. The hills run from near Suez town to the Sudanese border; they are not a continuous range but consist of a series of interlocking systems more or less in alignment (Figure 1). They are geologically complex, with ancient igneous and metamorphic rocks. These include granite that, in the neighborhood of Aswan area, extends across the Nile Valley to form the First Cataract—that is, the first set of rapids on the river. At the foot of the Red Sea Hills the narrow coastal plain widens southward, and parallel to the shore there are almost continuous coral reefs.

1.2. Climate

Throughout Egypt, days are commonly warm or hot, and nights are cool. Egypt has only two seasons: a mild winter from November to April and a hot summer from May to October. The only differences between the seasons are variations in daytime temperatures and changes in prevailing winds. In the coastal regions, temperatures range between an average minimum of 14° C in winter and an average maximum of 30° C in summer. The Eastern Desert occupies a portion of the arid zone belt of Egypt. The northern portion is affected by the sub-arid belt of the Mediterranean. Table (1) summarizes the climatological data (Egyptian Meteorological Authority, 2000)

Temperatures vary widely in the inland desert areas, especially in summer, when they may range from 7 °C at night to 43 °C during the day. During winter, temperatures in the desert fluctuate less dramatically, but they can be as low as 0 °C at night and as high as 18 °C during the day.

The average annual temperature increases moving southward from the Delta to the Sudanese border, where temperatures are similar to those of the open deserts to the east and west. Throughout the Delta and the northern Nile Valley, there are occasional winter cold spells accompanied by light frost and even snow. At Aswan area, in the south, June temperatures can be as low as 10 °C at night and as high as 41 °C during the day when the sky is clear. The Eastern Desert is characterized by hot summer with average temperature reaching 25 °C and by cool winter, with an average temperature of 5 °C.

* Prof. Dr. Hossam H. Elewa; Chair, EAWD in NARSS

Egypt receives fewer than eighty millimeters of precipitation annually in most areas. Most rain falls along the coast, but even the wettest area, around Alexandria town, receives only about 200 millimeters of precipitation per year. Moving southward, the amount of precipitation decreases suddenly. Most of the areas of Eastern Desert have scarce rainfall; many years may go without rain, and then experience sudden downpours that result in flash floods. The average rainfall rates are less than 25 mm/y, which increases northwards in the direction o the Mediterranean and southward in the direction of Gebel Elba.

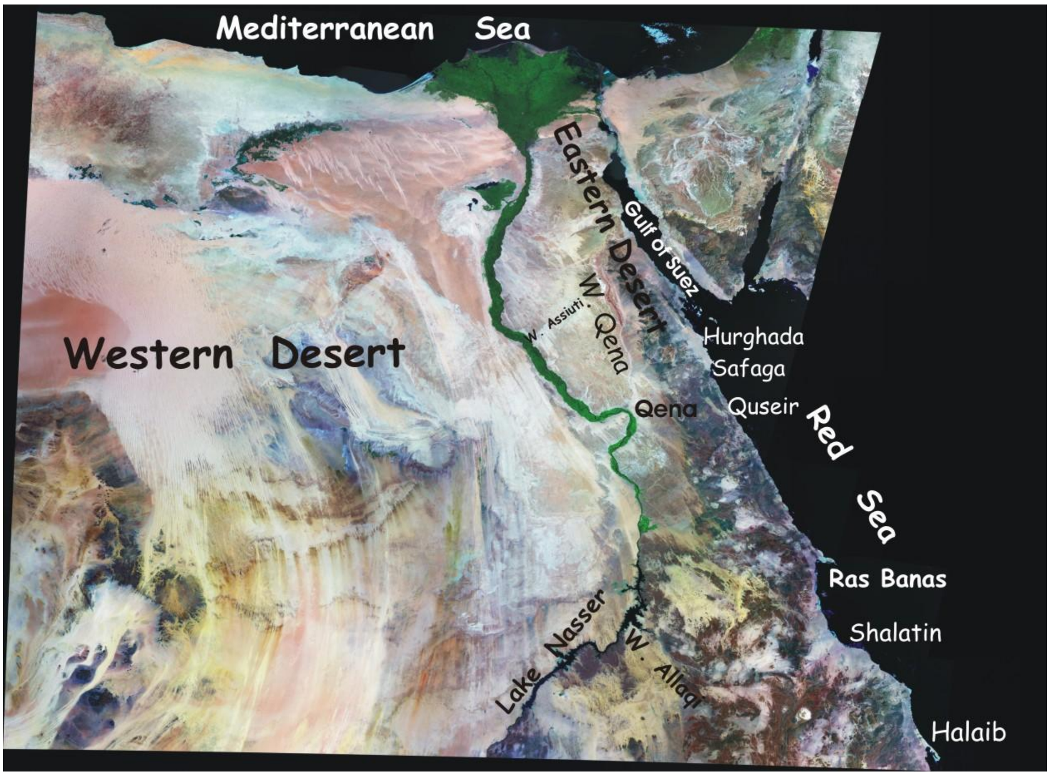


Figure (1): Landsat TM image for Egypt, showing the location of the Eastern Desert

Table (1): Climatological data of the Eastern Desert regions (Egyptian Meteorological Authority, 2000)

Location	Max. Temperature °C	Min. Temperature °C	Aver. Rainfall (mm/year)	Relative Humidity %	Evaporation mm/day
Giza	48.0	3.3	23.6	58	6.1
Malawi	46.2	3.0	2.7	58	5.0
Beni Suef	45.7	3.3	8.5	46	6.2
Minya	47.5	4.0	5.3	50	9.4
Assiut	47.7	4.0	0.1	3 8	15.0
Nag Hammadi	47.5	0.0	3.4	48	6.7
Qena	48.2	0.0	5.3	47	8.6
Kom Ombo	49.0	2.6	0.6	42	10.5
Aswan	50.6	1.7	1.4	22	15.4
Suez	45.6	0.0	23.6	51	11.5
Hurghada	43.8	3.4	4.0	49	9.4
Quseir	42.6	4.0	3.4	49	11.1
Ras Banas	32.4	19.1	7.6	43	16.8

1.3. Geomorphology

The landscape in Egypt can be broadly divided into the elevated structural plateau and the low plains (which include the fluviatile and coastal plains). The geomorphologic units play a significant role in determining the hydrogeological framework. The structural plateau constitutes the active and semi-active watershed areas. The low plains can contain productive aquifers and are also, in places, areas of groundwater discharge.

In the Eastern Desert, the following geomorphologic units are reported (Figure 2):

- The structural plateau and ridges underlain both by rugged crystalline rocks and by almost flat carbonate rocks. These occupy the major part of the area of the Eastern Desert.
- The structural plains, underlain by mainly sandstone and are particularly represented in the southeastern portion.
- The coastal plains, underlain mostly by beach sand and lagoonal mud in the north and by stony and reefal raised beaches in the south.
- The basement ridge, underlain by fractured hard igneous and metamorphic rocks and has an average elevation of about 1000 m above mean sea level. These are considered as the main watershed area, either in the direction of the Red Sea and / or the Nile trough.

Geographically, Egypt is divided into four regions with the following land area percentage of coverage: (i) the Nile Valley and Delta, including Cairo, El Fayoum depression, and Lake Nasser (3.6%); (ii) the Western Desert, including the Mediterranean littoral zone and the New Valley (68%); (iii) the Eastern Desert, including the Red Sea littoral zone and the high mountains (22%); and (iv) Sinai Peninsula, including the littoral zones of the Mediterranean, the Gulf of Suez and the Gulf of Aqaba (6.4%), (Shahatto, 2003).

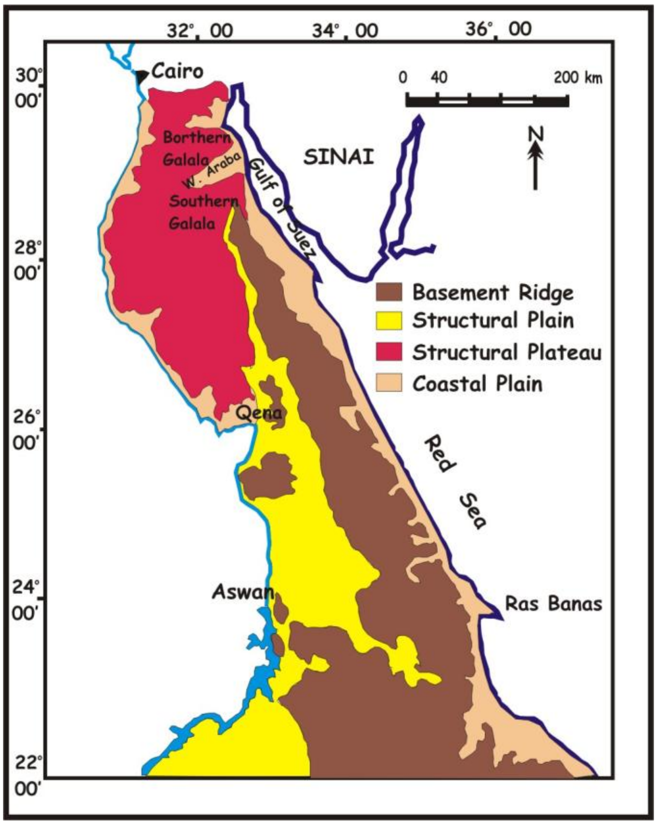


Figure (2): Generalized geomorphological map of the Eastern Desert. (Extracted from Landsat TM image)

1.4 Geologic Outline

The Eastern Desert is occupied by both sedimentary and crystalline basement rocks (EGSMA, 1981). The crystalline rocks are widely exposed forming the rugged mountainous terrain to the south of latitude 28^{o} 40' N. This terrain acts as the principal watershed, where two major drainage systems have been developed, i.e., the Red Sea-Gulf of Suez and the River Nile systems.

Locally, the Precambrian crystalline rocks constitute isolated northwest ranges, e.g., Esh El-Mallaha and Gebel El-Zeit between latitudes 27^{o} 30$'$ and 28^{o} N. These ranges have hydrogeologic significance, where they act as barriers separating various water bodies.

Lithologically, the Precambrian crystalline rock units are discriminated into eleven units. The physical properties of some of these units have led to their development into local aquifers of limited potentials.

The sedimentary succession overlying the Precambrian rocks is as follows from older to younger (Said, 1990):

- The Pre-Cenomanian clastics with minor carbonates (about 1759 m thick.).
- The Cenomanian – Eocene carbonates and shales with sandstone interbed (about 1900 m thick.).
- The Oligocene – Miocene clastics and evaporates (about 3950 m thick.).
- The Post Miocene varied sediments, almost clastics (about 240 m thick.).

Within the aforementioned succession, highly productive aquifers have been encountered. The most significant of these are Pre-Cenomanian sandstones (Nubia Sandstones), the Oligocene sandstones, the Miocene sands and sandstones.

Structural investigations in the Eastern Desert using modern techniques of structural analysis and Landsat imagery, beside the available information in previous publications and geological maps indicate the following (El-Shazly, 1977):

- Folds in the Gulf of Suez-Nile Valley are belonging to two main superimposed systems with the following main trends: ENE-WSW and NNW-SSE.
- The lineaments mapped in the Gulf of Suez-Nile Valley area are statistically analyzed according to trends taking their length proportion into consideration. The most predominant fracture sets are the N 35^{o} W-S 35^{o} E, N 45^{o} E and N 55^{o} W-S 55^{o} E.
- Three major fault trends are distinguished. These include the NW-SE, the NNE-SSW and the WNW-ESE trends. Faults of the first set are characterized by large vertical displacements, which have led to the formation of notable depressions. These includes Ish Mallaha (northwest Hurghada), and El-Nakheil Depression. Both depressions have considerable groundwater potentials.
- The intersection of faults of NW-SE and ENE-WSW to roughly E-W has remarkably increased the storage capacity of several basement rocks, e.g., the granites to the southwest of Hurghada and west Ras Gharib (Misak and Abdel Baki, 1991).

II GROUNDWATER AQUIFERS IN THE EASTERN DESERT

In the Eastern Desert two major categories of aquifer systems are present; the fractured Precambrian crystalline aquifers and the Phanerozoic aquifers. The Phanerozoic aquifers are of different lithologies and are exploited in numerous districts. Variable geologic and climatic conditions cause remarkable differences in the local hydrogeologic characteristics.

2.1 Major Groundwater Aquifer Systems and their Potential

Out of local structural complications, the main rock groups outcropping on the surface and occurring in the subsurface of the Eastern Desert could be distinguished in the following, arranged from base to top (RIGW, 1999):

1. Fractured Basement Complex. *(mainly of Precambrian age)*
2. Clastic group of sediments (Nubia Sandstones). *(Carboniferous-Upper Cretaceous)*
3. Fractured carbonate group. *(Upper Cretaceous-Paleogene)*
4. Neogene sediments (mainly on coastal belt). *(Neogene)*
5. Quaternary alluvial deposits. *(Pleistocene to Recent)*

2.1.1 Precambrian Fractured Basement Complex (Eastern Mountains and Southern Massif)

The Eastern Desert Mountains are drained by a multitude of wadis, with a typical catchment's area in the order of 500 km^2. Considering that the only regular water input is from the drainage of the adjacent rock massifs, their global regulated potential may be estimated as a few hundred thousands of m^3 per year per wadi. Since in the best of cases, only a fraction of this can be recovered, it can be said that the exploitation potential certainly does not exceed a few hundreds of m^3/day.

The basement complex forms a huge massif extending parallel to the Red Sea graben and consists mainly of schists, gneisses, granites and volcanics, all crystalline rocks which have no primary porosity of their own, and generally cannot therefore hold any large groundwater storage, unless they acquired secondary porosity by the effect of geological deformations (structures).

There is however, an abundance (several hundreds) of water points of all kinds. To understand the relative abundance of these water supplies, it is necessary to consider the elevated altitude, which probably induces comparatively high rainfall conditions (25 mm), and the youthful relief and denudation of the rock, which considerably limits the retention – so that may be 50 % or more of the rainfall is liable to directly runoff, or infiltrate into cracks, fractures and joints of the subsurface. Of this amount:

a) The major part is immediately or rapidly drained by the wadis. One fraction can escape directly as surface flow; the rest infiltrates into the sand beds. But because of the steep slopes, this storage is only transient, and it is drained downstream in a matter of weeks or months.

b) However, a fraction of the underflow may be retained in deeper alluvial pockets, or behind rocky shelves (dykes, faults, etc.). In the latter case, they may form diffuse emergences which evaporate at the ground surface. Such resources may be perennial, in as much as the leaks may be compensated by further water inputs from the embanking rock. This process is accompanied by a progressive degradation of the water quality

c) A lesser, but not insignificant (1-2 mm) fraction of the rainfall is stored and circulates only slowly in the finer cracks or fractures of the rock massif. This fraction represents the major part of the permanent water resources.

Many deep wells in the rock (Baramiya, Dungosh, Semna, Abu Marwat, Rabah, El-Seiyla, Tarfawi El Rayan, etc), seem to yield good supplies, reaching several tens m^3/day. Obviously, results are better along the planes of fracturation, and this type of prospection required detailed structural interpretations for the satellite images.

2.1.1.1 Red Sea-Gulf of Suez area
2.1.1.1.1 Halaib-Shalatin area

In Halaib-Shalatin area at the southeastern part of the Eastern Desert (Figure 3a), the occurrence of water points in the fractured basement rocks is highly controlled by the structural setting of the area (i.e. faults, dikes, joints, fractures, etc.) (Mina et al, 1996, Elewa, 2000, NARSS, 2000, Fathy and Elewa, 2002, and Fathy and Nagaty, 2003 and 2005.). The water body filling fractures is curiously skeletonized in shape and consisting of intersecting tabular members with tabular enlargements at the intersection. Determination of the sites of these intersections by remotely sensed data and satellite images interpretation is very important in groundwater exploration in fractured basement rocks. These sites are characterized by tubular enlargements filled with water and represent locations for groundwater drilling. Interconnection of fissures may extend over large areas, or the water body in a single fracture or group of fractures may be disconnected with the water body in adjacent opening as noticed in Wadi Serimtai. The process for locating a water body in fractured basement rocks are depending mainly on studying carefully the surrounding structural elements, especially orientation, size and density of the intrusive dykes, which act as a damming parameters of this percolated water, as in Bir Gahelia in Wadi Rahaba, which is strongly controlled by these dykes. The interaction between the role of both of the fractures (especially when intersected with each others) and the intrusive dykes, favor a high possibility environment for groundwater entrapment and these sites are recommended for groundwater drilling as noticed at Bir Aiqat 2 (Figure 3a).

However using radar imaging technology in structural delineation in dry areas may be a sophisticated and efficient tool, especially in delineation of the buried channels that favor the occurrence of water bodies in structurally suitable basins or points (NARSS, 2001). The using of Landsat satellite TM images and radar remote sensing technologies has proved to be of prime importance in groundwater exploration, especially in an extensively deformed territory, like the basement complex unit of the Eastern Desert. These give a strong reflective true subsurface situation, if linked with other surface tools of recognition and interpretation. In NARSS, 2001 report, geomorphological mapping was used side-by-side with Landsat TM and radar images, in the identification of the groundwater capabilities and subsurface situation of Halaib-Shalatin area. The Landsat TM and radar images could remarkably recognize the intrusive dykes and obscured subsurface fractures. The fractures prevailing the basement complex were formed as an echo of the major faulting system (Figure 3a), and others are primary structures hence, they are numerous and intensified along the whole areas, with relatively shorter lengths than the main fault trends. These fractures are very important in groundwater studies (sometimes are called hydrogeological fractures) as they are responsible for the presence of many hand-dug wells and springs in basement complex territory of the Eastern Desert. The different basement rock units outcropped in the investigated area is injected by swarms of dykes of acidic, intermediate and basic composition. Generally, these dykes are arranged in parallel groups forming swarms of different trends. Also, these dykes are sometimes intersecting each others. As mentioned before, the rock types encountered in the basement complex territory are highly fractured and jointed. They are together with the dyke swarms play an important role in preserving water, where the former (fractures and joints) acts as passage ways and when they are intersecting with each others tubular water bodies are formed among them, while the latter (sealed dykes) preserve and block water, especially when they intersect each others or intersect with fractures or faults (Figure 3a).

The TM image provides a stochastic tool for the revelation of effective surface structural features used for groundwater exploration. To determine the best sites for groundwater drilling in the basement complex territories, the intimate investigation of the structural setting of the already existing water points and the application of all structural and geological factors controlling the water point's occurrences must be taken into consideration. When plotting the existing water points on the constructed structural lineaments map, it was concluded that most of these water points are structurally controlled as they are located at the intersection points between fractures and faults while some of them are controlled by dykes. The *imitation* of the structural setting of the existing water points led to the construction of a water potentiality map, which contains the proposed sites for groundwater drilling. These sites have high possibility to capture groundwater bodies as they have the most effective structural elements that provides a favorable environment to host groundwater bodies. The proposed sites for groundwater drilling which were determined by the areas of dykes intersections, as in the areas of Wadi Fiqo, Wadi Gimal and Wadi Ibib. Also, the intersection between these dykes and faults were suggested as sites for drilling, especially when occurred in wadi beds, i. e., the sites proposed in Wadi Ibib, Wadi Fiqo and Wadi Gimal. The intersection between fractures or between fractures and faults are other categories in determining the best locations for groundwater drilling. These factors led to propose many suitable sites for drilling, as in Wadi Rahaba, Wadi Amrit, Wadi Gimal, Wadi Fiqo, Wadi Shaab, Wadi Ibib, Wadi Kraf, Wadi Youder and Wadi Serimtai (Figure 3a).

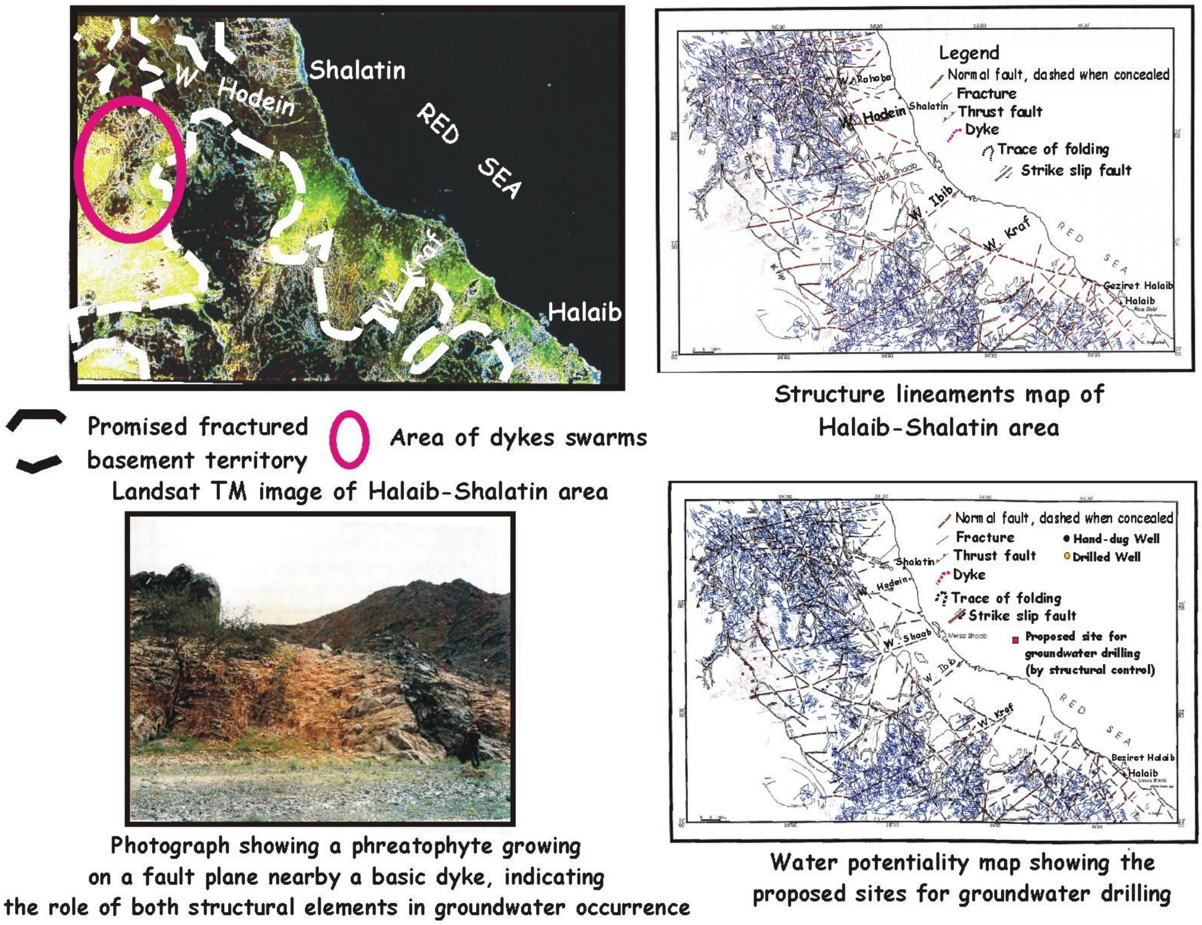


Figure (3a). The structure control factors responsible for groundwater entrapment in the fractured basement territory in Halaib-Shalatin area (after NARSS, 2000 and Elewa, 2000)

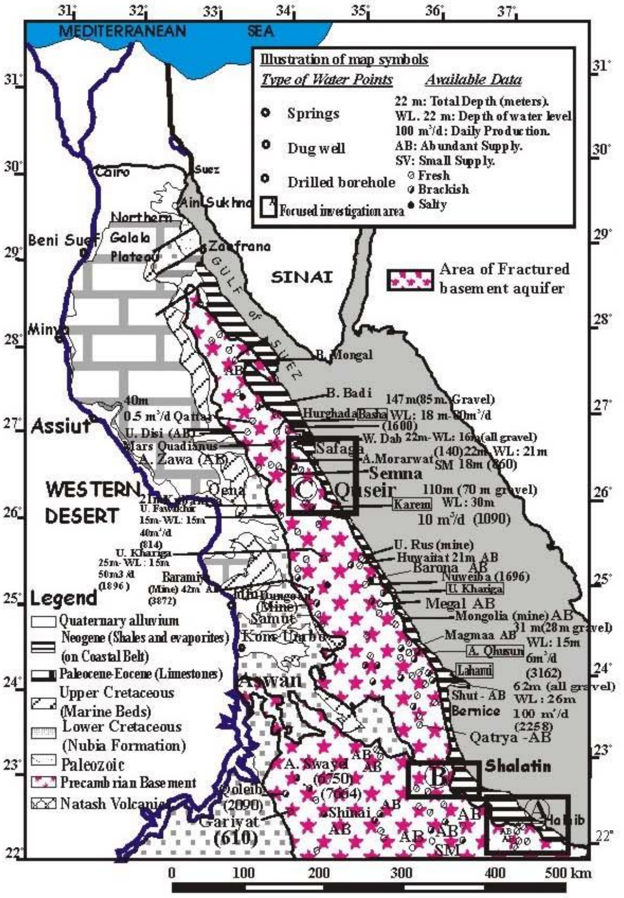
In most cases, water in fractured basement aquifers of the Eastern Desert (Figure 3b) is reported as good or acceptable (i.e. Bir Gahelia "472 ppm" in Wadi Rahaba of Shalatin area). About 34 water points are dugged in the fractured basement of Halaib-Shalatin area, where their salinities range from fresh (< 1000 ppm) to very saline (> 10,000 ppm) (Elewa, 2000). The water salinity in the deep-seated basement may be expected to be more constantly brackish than in the alluvial beds: 2,000 to 3,000 ppm (Pirard, 1981). Water indicted as brackish is noticeably bitter (high sulphate content). It corresponds to salinities 1,500 and 4,000 ppm. It is noted that the nomads and their flocks find such water quite acceptable. The latter limit of 3,000 ppm is only exceptionally exceeded, and this seems accidental (local evaporation). In fact, it would seem that most waters are in the range of 1,000 to 2,000 ppm.

The hand dug wells of Bitan, Gahelia 1, Urga and Aiqat are tapping the fractured basement aquifer and are of meteoric and deep meteoric (Fathy and Nagaty, 2005)

The available analytical and hydrogeological data are shown in Table (2). About 32 water points are found in the fractured basement rocks in the area extending from Shalatin to Halaib.

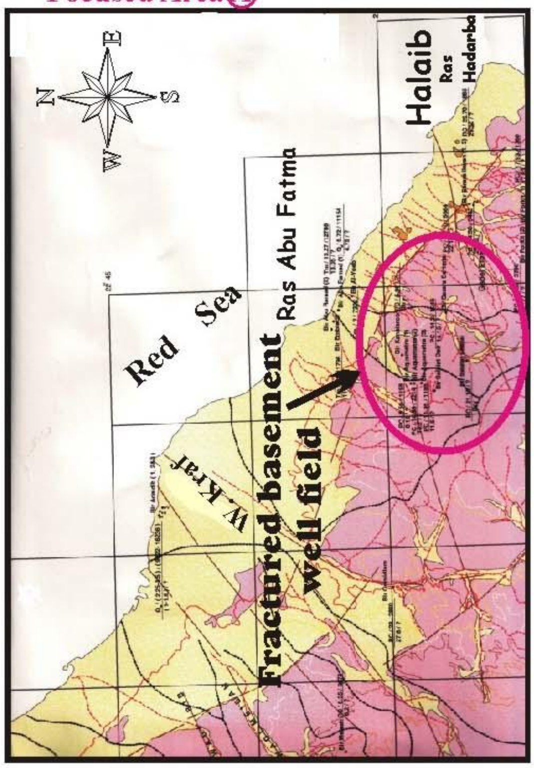
Table (2): Hydrogeological characteristics of the water points in fractured basement aquifers in Halaib-Shalatin area (Elewa, 2000)

Water point No.	Water Point name	Water Point type	Salinity ppm	Total depth (mbgs)	Depth to water (mbgs)	Aquifer type
1	Urga	Hand dug	1328	3.60	3.30	Free water table
2	Gahelia 1	Hand dug	480	11.45	8.39	Free water table
3	Al Bakhshabat	Hand dug	594	2.15	1.97	Free water table
4	Aiqat 1	Hand dug	1284	10.75	3.30	Free water table
5	Aiqat 2	Hand dug	2136	5.25	6.10	Free water table
6	Al-Bida 1	Hand dug	2118	3.50	3.2	Free water table
7	Abu Rayah	Hand dug	769	1.75	1.4	Free water table
8	Bitan	Hand dug	526	7.95	4.65	Free water table
9	Ababit	Hand dug	1082	5.30	4.95	Free water table
10	Baanit	Hand dug	3356	28.0	27.60	Free water table
11	Al Aissila 1	Hand dug	6900	13.0	12.97	Free water table
12	Madi	Hand dug	613	2.70	2.60	Free water table
13	Heba	Hand dug	1076	16.80	16.45	Free water table
14	Shinai	Hand dug	8.60	8.60	7.65	Free water table
15	Gomidlum	Fracture spring	2860	28.0	27.60	Free water table
16	Aquamatra 2	Fracture spring	2214	14.85	14.27	Free water table
17	Aquamatra 3	Fracture spring	1185	11.95	11.50	Free water table
18	Salalat Osir	Hand dug	1046	14.20	14.15	Free water table
19	Sararat Serimtai	Hand dug	5664	22.70	22.15	Free water table
20	Kansisrob	Fracture spring	---	5.90	Dry	Free water table
21	Gahelia Gedida	Hand dug	---	----	Dry	Free water table
22	Yebway	Hand dug	---	---	Dry	Free water table
23	Ain Moqur	Fracture spring	454	3.20	1.95	Free water table
24	Meisah	Hand dug	3674	6.35	6.2	Free water table
25	Ain Shinai	Fracture spring	826	8.60	7.65	Free water table
26	Sararat Ikwan 1	Hand dug	1865	29.70	29.30	Free water table
27	Sararat Ikwan 2	Hand dug	1850	30.70	29.60	Free water table
28	Forkit 1	Hand dug	1360	17.93	17.83	Free water table
29	Forkit 2	Hand dug	3798	27.33	27.27	Free water table
30	Shashoi	Hand dug	----	---	Dry	Free water table
31	Salalat Lasilai	Hand dug	-----	21.15	Dry	Free water table
32	Megih	Hand dug	826	2.14	2.12	Free water table



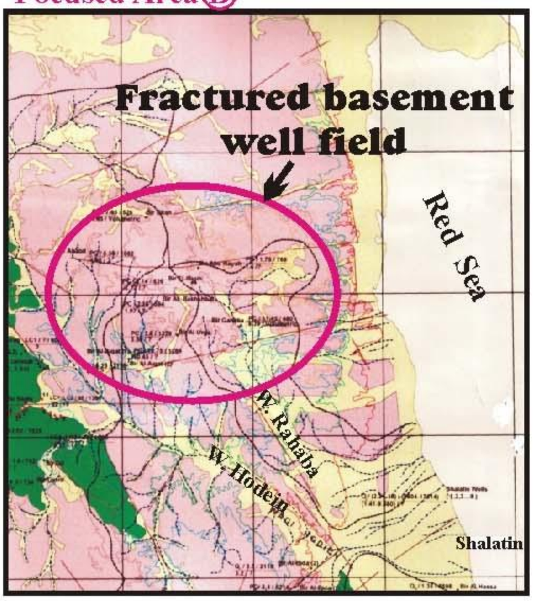
Fractured Precambrian basement aquifer system in the Eastern Desert
(Compiled from different Sources, as cited in text)

Focused Area A



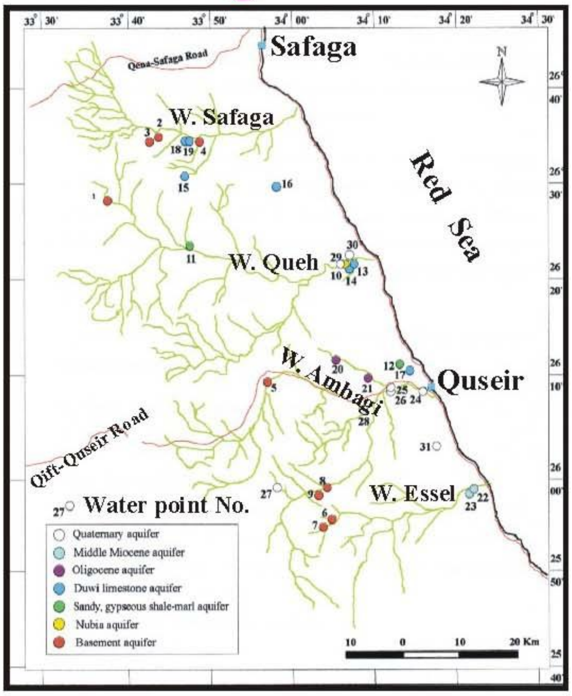
Part of hydrogeological map (Halaib area), prepared by NARSS, based on remote sensing and GIS techniques (NARSS, 2000)

Focused Area B



Part of hydrogeological map (Shalatin area), Prepared by NARSS, based on remote sensing and GIS techniques (NARSS, 2000)

Focused Area C



Fractured basement aquifer in Quseir-Safaga area (after Dabash, 2004)

Figure (3b): Fractured Precambrian basement aquifer system in the Eastern Desert. (Compiled from different sources) (Pirard, 1981, NARSS, 2000, Elewa, 2000 and Dabash, 2004)

2.1.1.1.2 Quseir-Safaga area

There is a little hydrogeologic information on the area under consideration. The works of El-Fakharany (1989), El-Ghazawi & Abdel Baki (1991), Misak and Abdel Baki (1991), Sallouma (1992), Gomaa (1992) and Dabash (2004) have contributed to the geology and hydrogeology of this area.

According to the lithological characteristics of rock types, the fractured Precambrian basement rocks in this area are distinguished into the fractured metamorphic rocks and the Hammamat rocks (Dabash, 2004).

The fractured metamorphic water bearing formations are classified into metasediments, the fractured metavolcanics, and serpentinites and related rocks.

In Semna area, the metasediments are detected as water bearing formations. The groundwater is extracted from Semna hand-dug Well (Water point no. 1, Table 3, Figure 3b). The depth to water is 13.10 m from the ground surface.

In Abu Marwat gold mine, Abu Marwat Wells I and II, (water points nos. 2 & 3), the fractured metavolcanics rocks constitute the water-bearing rocks. The depth to groundwater varies from 33.65 m (Abu Marwat I Well) to 34.75 m (Abu Marwat II Well) from the ground surface.

At Rabah area, the metavolcanics (andesite and rhyolite) are detected to be water bearing rocks and the groundwater is tapped from this formation at shallow depth (5.92 m from ground surface at Rabah hand-dug well, water point no. 4).

In El-Seiyala area, the fractured serpentinites rocks are considered to be water bearing rocks. The groundwater is discharged through El-Seiyala Well (Water point no. 5). The depth to water is 10.5 m from the ground surface (Figure 3b).

At Wadi El Tarfawi, the fractured Hammamat rocks are detected to be water bearing rock units. The groundwater is discharged from two wells (El-Tarfawi Riyan I and II, water points nos. 6 and 7). The water depth varies from 2.3 m at El Tarfawi Riyan I to 2.45 m at El Tarfawi Riyan II, from the ground surface. At Wadi Kareim the Hammamat rock types are the water host rock units. The groundwater is extracted from two wells (Kareim I and II, water points nos. 8 & 9). The quantity of stored water is very limited, which is due to the noticeable limited recharge. The depth to water varies from 15.35 m (Kareim II Well) to 17.42 m (Kareim I Well) from ground surface.

Table (3): Hydrogeological characteristics of the water points in fractured basement aquifers in Quseir-Safaga area (Dabash, 2004) (Figure 3b).

Water point No.	Water Point name	Water point Type	Water-Bearing Formation	Total depth (mbgs)	Depth to water (mbgs)	Aquifer type
1	Semna Well	Hand dug	Metasediments rocks	13.35	13.10	Free water table
2	Abu Marwat Well I	Drilled	Metavolcanic rocks	98.00	33.65	Free water table
3	Abu Marwat Well II	Drilled	Metavolcanic rocks	54.50	34.75	Free water table
4	Rabah Well	Hand dug	Metavolcanic rocks	5.40	5.92	Free water table
5	El Seiyala Well	Hand dug	Serpentine rocks	12.50	10.50	Free water table
6	Tarfawi El Riyan I	Hand dug	Hammamat rocks	18.92	17.42	Free water table
7	Tarfawi El Riyan II	Hand dug	Hammamat rocks	17.55	15.35	Free water table
8	Kareim Well I	Drilled	Hammamat rocks	5.95	2.30	Free water table
9	Kareim Well II	Drilled	Hammamat rocks	3.20	2.45	Free water table

2.1.1.1.3 Safaga-Ras Gharib area

According to REGWA, 1991, (Table 4), the fractured basement water bearing rocks are found in Wadi Gharib (hand dug well no. G33) and Wadi Kharm Ayun (hand dug well no. G34).

The water bearing rock is the fractured granite. In Wadi Abu Had, two drilled wells occur in the weathered granites (Wells nos. G07 and G08). However, it is pointed out by Nasr, 1990 that the Abu Had wells tap the weathered granites and the water table is available at a depth ranging between 46 and 76 m from the ground surface. The total salinity varies between 3186 and 3586 ppm. The recharge to Abu Had granites takes place through major NW-SE and NE-SW fractures dissecting the bounding granitic high lands.

The groundwater in Gebel Dara is represented by a spring, which issues near its summit (G30). It is developed in the young granitoids at the intersection of NW-SE and NE-SW fracture zones. The daily discharge of this spring is about 0.3 - 0.4 m^3. The water salinity attains 972 ppm. The water is used by the Bedouins for drinking. Furthermore, the groundwater in Ras Gharib area is locally detected in the fractured Precambrian rocks of Gebel Gharib (water points G33 and G34). The water is almost fresh (736 and 2000 ppm). The discharge is very small and exhibits seasonal variations. The water is used by Bedouins for drinking. The recharge takes place through the fracture systems which strike NW-SE and NE-SW.

In Hurghada area, the groundwater represents a secondary source of water supply. It is exploited by bedouins from shallow wells and springs. It is used for drinking and domestic purposes. In Wadi Bali, two hand dug wells are tapping the fractured metavolcanic rocks and weathered granite (Wells H 10 and H 11), whereas, one spring is issued from the fractured granite in Wadi Umm Dalfa (H 12). Wadi Bali (631.23 km^2) drains Gebels Abu Dokhan (+1626 m) and Qattar (+1713 m) which constitute portion of the Red Sea range. The groundwater in Wadi Bali is detected in two shallow dug wells. These are Bada Well (H10) and Umm Nefai Well (H11). Both wells are put down in narrow secondary channels in the upper reaches of Wadi Bali. In Bada and Umm Nefai wells, the groundwater is available at 2.58 m and 5 m, respectively. The water is fresh (552 ppm-1356 ppm). This is attributed to the closeness to the high mountains, which represent the main replenishment area (possible orographic precipitation) and the high altitude of the wells (500-600 m above sea level), where slight evaporation rates are prevailing.

Table (4): Hydrogeological characteristics of the water points in fractured basement aquifers in Safaga-Ras Gharib area, (REGWA, 1991)

Water point No.	Water Point name	Water point Type	Water-Bearing Formation	Depth to water (mbgs)	Water salinity (ppm)	Aquifer type
1	Wadi Abu Had 07	Drilled	Weathered granite	76.00	3188	Free water table
2	Wadi Abu Had 08	Drilled	Weathered granite	46.18	3586	Free water table
3	Wadi Gharib G33	Hand dug	Weathered granite	------	736	Free water table
4	Wadi Kharm Ayun G34	Hand dug	Weathered granite	4.00	2000	Free water table
5	Wadi Bali H10	Hand dug	Metavolcanics	2.58	1180	Free water table
6	Wadi Bali H11	Hand dug	Weathered granite	4.60	644	Free water table
7	Wadi Umm Dalfa	Spring	Weathered granite	Flowing	996	Flowing

2.1.1.2 Lake Nasser area

This type of aquifer is made up of fractured acidic granite and metamorphic rocks such as schists and gneiss. Bir Abu Swayel, Bir Um Gariyat, Haimur S and Qoleib represent this type of aquifer system. El-Shazly et al, 1985 carried out a research study about the groundwater conditions in Wadi Allaqi and adjacent areas, i.e. Abu Swayel Haimur South and others.

Bir Abu Swayel is the main source for water supply at Abu Swayel Mine; the depth is 68 m with dimensions of 3 x 3 m. The water bearing horizons are reached at depths of 24, 51.5, 55 and 61 m. It is thought that the groundwater is stored in the cracks and joints and between stratification planes in schist (metamorphic rocks) carrying copper and nickel. The water is salty, TDS is about 7664 ppm and it is of alkaline type. It could be used safely for animal husbandry.

In case of Bir Um Gariyat, the water is stored in fractures and joints of metamorphic schist rocks. The chemical composition of water samples taken from this well indicates that the water quality is the freshest water in Allaqi area, as the salinity is about 610 ppm, which is suitable for drinking and domestic uses.

2.1.2 Clastic group of sediments (Nubia Sandstones). *(Carboniferous-Upper Cretaceous?)*

The Nubia Sandstone forms a continuous belt of outcrops from the north of Eastern Desert to the Lake Nasser region. Directly overlying the basement, they plunge westwards underneath the impervious shaly strata of the Upper Cretaceous. They are the eastern continuation, across the Nile Valley, of the immense groundwater reservoir already well explored in the Western Desert (New Valley). Several zones can be distinguished (Figure 4).

2.1.2.1 Central Eastern Desert

The average thickness of the outcrops in the Central Eastern Desert could be about 400 m, although this seems variable.

2.1.2.1.1 Wadi Laquita

Wadi Laquita (El-Mathula basin), south of Qena, is located between Longitudes 33^{o} 10$^{'}$ and 33^{o} 30$^{'}$ E –Latitudes 25 ^{o} 55' and 26 ^{o} 01' N. It constitutes one of the hugest hydrographic basins (1200 km^{2}) in the River Nile drainage system (El-Shamy, 1985 and 1992). It is one of the most promising basins, where the main productive Nubian aquifer has been distinguished. About eight water wells (the total number of wells drilled by the private sector is not well-known) are drilled in the vicinities of Wadi Laquita and Wadi Zeidoun, and up to Umm El Fawakhir old mining area. They penetrated the Nubia Sandstone to depths range from 19.90 m (Um El-Fawakhir Well; touched the basement) to 592 m (Observation Well no. 1 in Wadi Laquita) (GARPAD, 1985). Only the lower 250 m are in permeable sandstones. The top section is mostly shaly. This upper section is succeeded by a unit of green, blue and red clay-shale and laminated siltstone (the "Variegated Shale Formation", which marks the passage to the massive formations of Upper Cretaceous age).

The Laquita boreholes demonstrate free-flowing artesian conditions, where the average discharges or productivity ranges from 168 m^{3}/day (Observation Well no. 1) to 1500 m^{3}/day (Production Well no. 2).

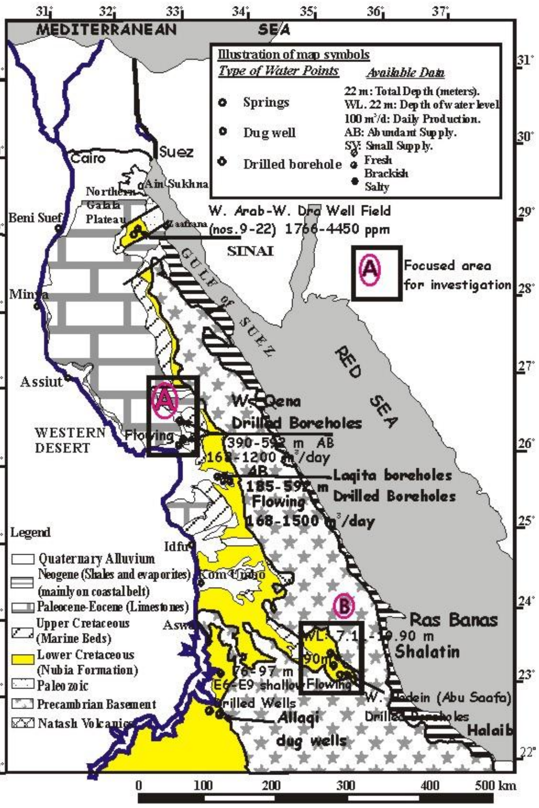
The total salinity ranges from 1876 ppm (Wadi Zeidoun Well) to 2520 ppm (Production Wells nos. 2 and 3). However, this type of water is being used safely for certain agricultural and domestic purposes, with certain precautions in surface drainage (Table 5).

The thickness of the Nubia Sandstone Formation generally increases towards the Nile Valley, although this seems irregular.

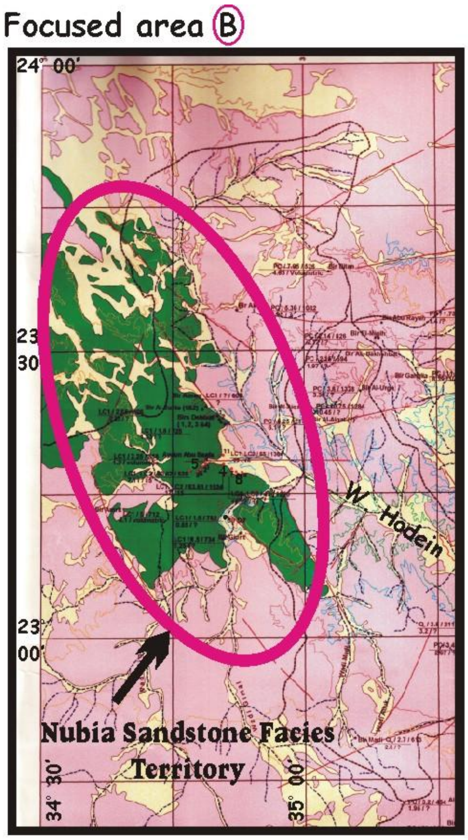
Table (5): Hydrogeological characteristics of the water points in Nubia Sandstone aquifer in Wadi Laquita area, (GARPAD, 1985).

Water point No.	Water Point name	Water point Type	Water-Bearing Formation	Total depth (mbgs)	Depth to water (mbgs)	Water salinity (ppm)	Total discharge (m^{3}/day)
1	Obs. Well 1	Drilled	Nubia Sandstone	592	Flowing	-----	168

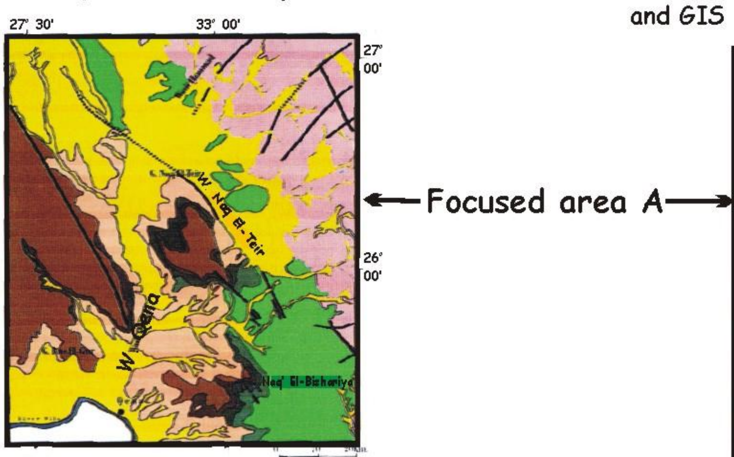
2	Prod. Well 2	Drilled	Nubia Sandstone	432	Flowing	2520	1500
3	Prod. Well 3	Drilled	Nubia Sandstone	461	Flowing	2520	1200
4	Prod. Well 4	Drilled	Nubia Sandstone	421	Flowing	-----	300
5	Prod. Well 5	Drilled	Nubia Sandstone	390	Flowing	-----	265
6	Obs. Well 6	Drilled	Nubia Sandstone	400	Flowing	-----	345
7	Obs.Well 7 (um Fawakhir)	Drilled	Nubia Sandstone	19.90	Dry	-----	-------
8	Obs. Well 7 (Zeidoun)	Drilled	Nubia Sandstone	185.66	87.0	1876	180



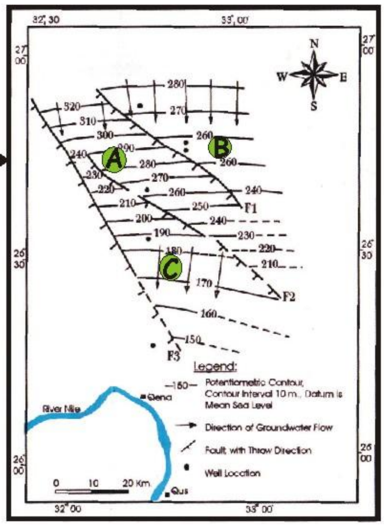
Nubia Sandstone aquifer system in the Eastern Desert (compiled from different sources, as cited in text)



Part of hydrogeological map (Shalatin area) prepared by, based on remote sensing and GIS techniques (NARSS, 2000)



Geological map constructed from TM image, showing the hydrogeological faults affecting the equipotentiometric characteristics of Nubia Sandstone aquifer (Elewa et al, 2000)



Hydrogeological faults extracted from TM image (Elewa et al, 2000)

Figure (4): Nubia Sandstone aquifer system in the Eastern Desert (Compiled from different sources, as cited in the text)

2.1.2.1.2 Wadi Qena

Wadi Qena (WQ) (18,000 km^2) is a unique geomorphic feature in the Eastern Desert. It extends in a nearly N-S direction (parallel to the River Nile) and joins the Nile Valley at Qena Town. It is located between Longitudes 32^o 45'- 32 ^{o} 55' E and Latitudes 26 ^{o} 15'-26 ^{o} 50' N. In Wadi Qena, six deep water wells are drilled in the Nubia Sandstone aquifer along the main course of the southern part of the wadi (GARPAD, 1985). Subsequently, the involvement of private sector in the developmental activities led to the drilling of many wells in the recent years (NARSS, 2006). In this area, the Nubia Formation is composed of fine to coarse-grained quartizitic sandstone of different colors, varying from white to dark brown, with shale intercalations. The sands are silicified with ferruginous and clayey matrix. Only two wells (1 and 2) drilled in the delta of the wadi (in the proper Nile Valley) are of artesian flowing type, whereas the other wells (wells nos. 3, 4, 6 and 8) drilled further north of the wadi, are not flowing, where groundwater level is encountered between 12 m and 43 m below ground level (Elewa et al 2000). The locations of main faults controlling the equipotentiometric levels of the Nubian aquifer in WQ were determined by the interpretation of TM satellite image (Elewa et al 2000) (Figure 4). The maximum discharge rates for the two flowing wells (1 and 2) are 3240 and 748 m^3/day, respectively. On the other hand, the other non-flowing Wells (4, 6 and 8) have discharge rates of 1200, 1080, 1920 and 345 m^3/day, respectively (Table 6). These discharge rates are reasonable if compared with the other yields given by the other aquifer systems of the Eastern Desert. The water of this aquifer is found to be acidic in reaction, with salinity ranging from 1162 ppm (Well no. 2) to 2359 ppm (Well no. 4) (Table 6). However, local structures of WQ and lateral lithological variations of the Nubia Sandstone Formation are the main factors controlling the salinity and equipotentiometric variations. The suitable alkaline $NaHCO_3$ water type covers most of the area of study of WQ. It has the best water quality for human drinking (e.g., in Wells 2 and 3) and for the cultivation of nearly all sorts of fruits and vegetables. The Na_2SO_4 water type is slightly hard water and occurs in Wells No. 4 and 8. Such water composition could be used for the cultivation of certain crops and animal husbandry, and for building purposes but with precautions.

Table (6): Hydrogeological characteristics of the water points in Nubia Sandstone aquifer in Wadi Qena area.

Water point No.	Water Point name	Water point Type	Water-Bearing Formation	Total depth (mbgs)	Depth to water (mbgs)	Water salinity (ppm)	Total discharge (m^3/day)
1	Prod. Well 1	Drilled	Nubia Sandstone	592	Flowing	2080	3240
2	Prod. Well 2	Drilled	Nubia Sandstone	432	Flowing	1200	748
3	Prod. Well 3	Drilled	Nubia Sandstone	461	Free water table	1800	1200
4	Prod. Well 4	Drilled	Nubia Sandstone	421	Free water table	2360	1080
5	Prod. Well 6	Drilled	Nubia Sandstone	390	Free water table	1420	1920
6	Prod. Well 8	Drilled	Nubia Sandstone	400	Free water table	1470	345

Groundwater Potential in the Central Eastern Desert

It is certain that the Nubia Sandstones of the Central Eastern Desert have a very important exploitation potential, which is characterized by:

- A significant recharge, which is estimated at some 300 millions m^3/year (which is consistent with the proven flow of the Nubian aquifer opposite the Nile Valley: 3.5 millions m^3/day).
- An immense storage, allowing substantial exploration for prolonged periods.
- Low depth of the piezometric surface.
- Generally good water quality.

Given these characteristics, the Nubia Sandstone aquifer may be exploited for irrigation projects of a certain size (Pirard, 1981).

2.1.2.2 Nile Valley (Lake Nasser Area)

It is reported that the Nubia Sandstone Formation underlies the Nile Valley and Delta at a depth of 1,000 m from the surface west of Cairo and more than 3,000 m north of Cairo. It is exposed from Aswan district southwards with a thickness reaching to 600 m from the ground surface. It is thought that the highly mineralizes water of Helwan Springs (south of Cairo) is originated from the high pressure water of the Nubian Sandstone aquifer (level about 50 m above mean sea level) (Hefny et al, 1991).

East of Lake Nasser, the Nubia Formation remains uncovered, and exhibits horizontal attitude. Lithologically, it consists of four units beginning with a basal layer of Kaolinitic clays directly overlying the granitic basement, where the basal conglomerate is missing, and ended by permeable sandstones, dirty sandstones, and thin shales. In Wadi Allaqi, there is no doubt that beside the subjection to the occasional rainfall as the main water resource in this area, there is the effect of Lake Nasser. The fluctuation of the water level in the lake as a result of the input and output to and from the lake play an important role in the possible recharge and discharge of the groundwater potential in it. The aquifer is unconfined in the main areas of sandstone outcrops, when the water table is encountered at between 15 and 70 m below ground surface (Selim et al, 1991).

The groundwater flow is directed westwards, where the aquifer becomes confined by the upper shaly members of the Nubian formations. It is most likely that, the shallow aquifers which are regularly encountered saturating the alluvial fill of these wadis are fed by discharge of the Nubian aquifer, leaking through its shaly cover (Elewa and Fathy, 2005).

Conditions of aquifer recharge are certainly much poorer and probably non-existent in the areas east of the lake, because of very poor rainfall regime, and important retention by the sandy surface of the horizontal strata. Apart from the 60 km downstream section of Wadi Allaqi, there exists no external flow input. Originally, deep groundwater storage may have been maintained by the River Nile itself at an altitude of 100 m or so (i.e. at a depth of 100 to 300 m below ground surface). The initial aquifer was presumably brackish due to poor recharge conditions. Present leaks from the lake are bringing fresh water (Table 7) (Figure 5).

Geological investigations in Nubia (Said, 1981 and Issawi, 1983) indicate that the modern regime of the River Nile, with a stream flow largely dependent on rainfall over the Ethiopian highlands, may be a comparatively recent phenomenon, perhaps of Late Pleistocene age. Prior to that time, the Nile occupied its present Valley north of the second Cataract but appears to have been totally dependent upon non-Ethiopian source. This stream is called either the Egyptian Nile or the Pre-Nile to distinguish it from the modern river. Most probably that Wadi Allaqi was one of the Egyptian Nile streams.

Table (7): Nubia Sandstone groundwater points found in Allaqi area (NARSS, 1999).

Well no.	Well Name	Comments
6	El Nagal	Fresh water
7	Haimur	----
8	Bir Murra	Medium-Salty
9	Bir Abu Fas	----
10	Bir Ungat	Fresh water
11	Bir Tawit	----
12	No name	----
13	Bir Naba1	----
14	Bir Adrabit	----
15	Bir Naba2	----

16	Araft (Um Gerifat)	Fresh water
17	Muftah	Brackish
18	No. 6 Station	Pumped Well, brackish

However, several shallow wells were drilled to the Nubia Sandstone in the area of Garf Hussein near the mouth of Wadi Allaqi, located about 100 km south of the High Dam at the eastern side of Lake Nasser. These wells are (i.e., E8, E5, E6 and E7), with depths of 64.36, 76.40, 76.45 and 74.24 m, respectively. Additionally, Well E9 with total depth of 97.40 m touched the Precambrian basement at depth of 97.40 m from the ground surface.

The hydrogeological information obtained from these wells in the eastern region of the Nile Valley represents the hydrogeological conditions in the north and south of Wadi Allaqi.

Lithologically, the penetrated section is made up of sandstone with siltstone and clay intercalations. The section is directly overlying the basement rocks, mainly of pink granite of Precambrian to Paleozoic era. The total thickness is about 400 m, as reported in the region of Garf Hussein. The Nubia Sandstone aquifer can easily be differentiated into two water bearing zones (horizons) as reported by Tamer, 1974:

1- The Upper Zone: it is of unconfined aquifer type and fully saturated with the seepage from the River Nile water at the area of Garf Hussein through Lake Nasser.

2- The Lower Zone: It is of confined aquifer type and not affected by the water from the River Nile.

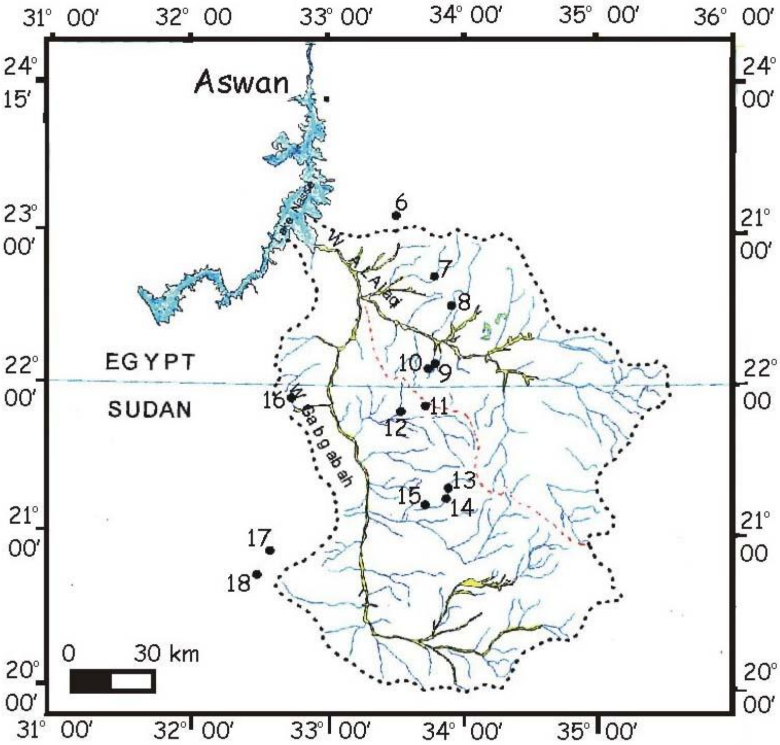


Figure (5): Nubia Sandstone hand dug wells of Wadi Allaqi regional area (NARSS, 1999).

2.1.2.3 Red Sea-Gulf of Suez Area

2.1.2.3.1 Halaib-Shalatin area, south eastern part of the Eastern Desert

The Nubia Sandstone *facies* rock units are formed of white color, fine to coarse grained, with clay and siltstone intercalations of Abu Aggag, Timsah and Umm Barmil Formations of the Upper Cretaceous. This rock unit covers about 916 km^2 and exposed at the northwestern part of Wadi Hodein, in Gebel Abraq and Abu Saafa areas (Figure 4). These rocks are block-faulted and slightly folded (CONOCO map, 1987 and NARSS, 1999), which are affected by the Red Sea rifting system. These rocks act as independent isolated aquifers, which are drained naturally in the minor springs (Abraq and Abu Saafa Springs) (Mina et al, 1996 and Elewa, 2000).

Recently, this rock unit was tapped by a number of deep drilled wells. These deep wells penetrate the Nubia Sandstone facies aquifer up to 90 m, with productivity up to 20 m^3/hour (Wells nos. 4, 5 & 8) (Elewa, 2000) (Table 8). The depth to water from the ground surface ranges from 7.11 m (Well no. 5) to 19.90 m (Well no. 8). The hydraulic parameters of Wells no. 4, 5 & 8 were deduced from pumping tests carried out in the field (Elewa, 2000).

Table (8): Hydraulic characteristics of the Nubia Sandstone *facies* aquifer units in Halaib-Shalatin area

Well No.	**Well depth (mbgs)**	**Static water level (mbgs)**	**Production zone thickness (m)**	**Transmissivity (m^2/day)**	**Hydraulic conductivity (m/day)**	**Salinity (ppm)**
4	83.63	17.00	35.41	72.40	2.04	1524
5	90.67	7.11	36.86	12.77	0.35	528
8	90	19.90	36	2.72	0.075	1760

The groundwater of Um Barmil Formation aquifer is of marine origin, while that of the Timsah Formation aquifer is of meteoric origin (Fathy and Nagaty, 2003). The groundwater of the wells of Dif, Abraq, El-Sunta, Abu Saafa Wells and Ain Abu Saafa are of meteoric and deep meteoric origin

2.1.2.3.2 Quseir-Safaga area

The Nubia Sandstone (Taref?) occupies the trough of the synclinal folds within the crystalline hill ranges to the west and south, and directly overlain by the sandy, gypseous shale-marl and Duwi Formation. It is exposed at Gebel Duwi, Gebel Anz, and Abu Shigeila areas. The thickness of the Nubia Sandstone is about 60 m. at Hamrawein area and about 230 m at the low hills along Quseir-Qena Road. This formation is detected as water bearing in Wadi Queh in a mining area (Queh 2H) (GEOMIN, 1971, and Dabash, 2004). The groundwater occurs under confined conditions and the piezometric surface is +32.5 m. This water bearing formation is considered as containing the main water reserve in the area (Table 9). The groundwater of Nubia Sandstone facies is discharged to the overlying aquifers as upward leakage along the fault planes.

Table (9): Hydraulic characteristics of the Nubia Sandstone *facies* aquifer units in Quseir-Safaga area, (Dabash, 2004).

Well No.	**Well depth (mbgs)**	**Static water level (mbgs)**	**Aquifer type**	**Water bearing formation**	**Water point type**	**Discharge Rate (m^3/day)**
Queh 2H)	156.00	26.00	Confined	Nubia Sandstone	Drilled	47.08

2.1.2.3.3 Gulf of Suez area

The Lower Cretaceous water bearing formation of Nubia Sandstone (90 m. thick) was tapped by a well in El-Sukhna locality at a depth of about 1230 m. The water bearing formations of

Lower Cretaceous age are consisting of Nubia Sandstone and clays are tapped by many wells in the Gulf of Suez region.

The Lower Cretaceous sandstone is recorded as water bearing formation in two main areas in the Gulf of Suez; Wadi Araba and Wadi Dara. In Wadi Araba (Wells nos. 9 to 14 and 22, Figure 6) (Aggour, 1990), the water occurs under confined conditions as springs and wells. The springs are represented at El-Bowirat area (no. 9a and 9e) and El Zaafrana (no. 22). The first location is affected by a local anticline (N80^o E - S80 ^{o} W), which is dissected by two sets of faults trending N80^o E - S80 ^{o} W and N10^o E – S10^o W.

On the other hand, the Zaafrana spring issues along N20^{o}E – S20^{o}W trending fault and its water bearing formation is affected by WNW-ESE fault trend.

The water salinity of the springs ranges from 1766 ppm to 4450 ppm reflecting the contribution of deep aquifers in El Zaafrana and rainfall in El-Bowirat.

The confined conditions are also encountered at El-Bowirat (no. 10, 11 and 12) and west Wadi Araba (no. 8). The piezometric level ranges between + 172.67 m and + 199.66 m. The variation is a matter of structure control. They have water salinity varies from 1036 to 2597 ppm.

In Dara area, the groundwater of the studied aquifer occurs under confined and unconfined conditions. The western high mountainous terrain and the exposed Nubia Sandstone to the west represent the watershed area. Dara Oasis is located on the downthrown side eastward of a fault trending NNW-SSE. The confining conditions are developed, where a succession of 160 m of evaporates, shale and limestone of Cenomanian age overlies the Lower Cretaceous sandstone. The aquifer attains a maximum thickness of 321 m. The groundwater is of artesian flowing type and the unconfined conditions are recorded west of the above mentioned fault (Nasr, 1990 and DRC, 2002). Due to the differences in local geologic conditions (structure and stratigraphic succession), the groundwater is encountered at variable depths (74-170 m). This depth increases southward due to the effect of a set of faults trending E-W and has its downthrown sides southward. Accordingly, the groundwater rises 1.42 and 2.75 m above the ground surface. The water salinities range between 2763.9 ppm and 3417.2 ppm revealing an increase eastward. The hydraulic parameters of the unconfined part (Dara Plain) indicate a transmissivity value reaching 293.97 m^2/day and storativity of 8.78 X 10^{-3} (Nasr, 1990). In the oasis, the hydraulic parameters were calculated to be T = 1600 m^2/day and S = 0.004 (Sweidan and Himida, 1991).

The Jurassic sandstone at Khashm El-Galala is recorded as water bearing formation in Wadi Nakhl Hamid, which drains the northeastern scarp of Northern Galala. The groundwater occurs under confined conditions, where groundwater is issued as spring along the intersection of two faults trending E-W and N-S. The recharge is mainly through upward leakage from old aquifers and scarcely from the surrounding exposures (Aggour and Sadek, 2001). The water level reaches + 12 m and the water salinity reaches 2772.75 ppm.

The Carboniferous sandstone is hydrogeologically explored as water bearing formation at Wadi Abu Darag and Wadi Araba Depression (nos. 1 and 23, Figure 6) (Aggour, 1990). The water of this aquifer occurs under unconfined conditions in the first well and confined conditions in the second well). At Abu Darag Well, the water lies at +5m and exists at a waterfall located at the intersection of two sets of open fractures (ENE-WSW and NNE-SSW). The salinity of the water attains 2316 ppm and the well produces 4 m^3/day. At Wadi Araba, several sand and sandstone interbeds are recorded as water bearing formations. They are intercalated with red shale within a carboniferous succession of 152.6 m. The upper 75 m are designated as a well (Misak and Abdel Baki, 1991). The groundwater occurs at confined conditions and the water level rises above the ground surface by 24 cm. This level stands now at this value reflecting recharge from the southern plateau through faults trending NNE-SSW. The groundwater of the aquifer has high salinity (8850.3 ppm) reflecting the low recharge and the intercalated shale. The hydraulic parameters reveal a transmissivity value of 13.1 m^2/day and storativity value of 0.033.

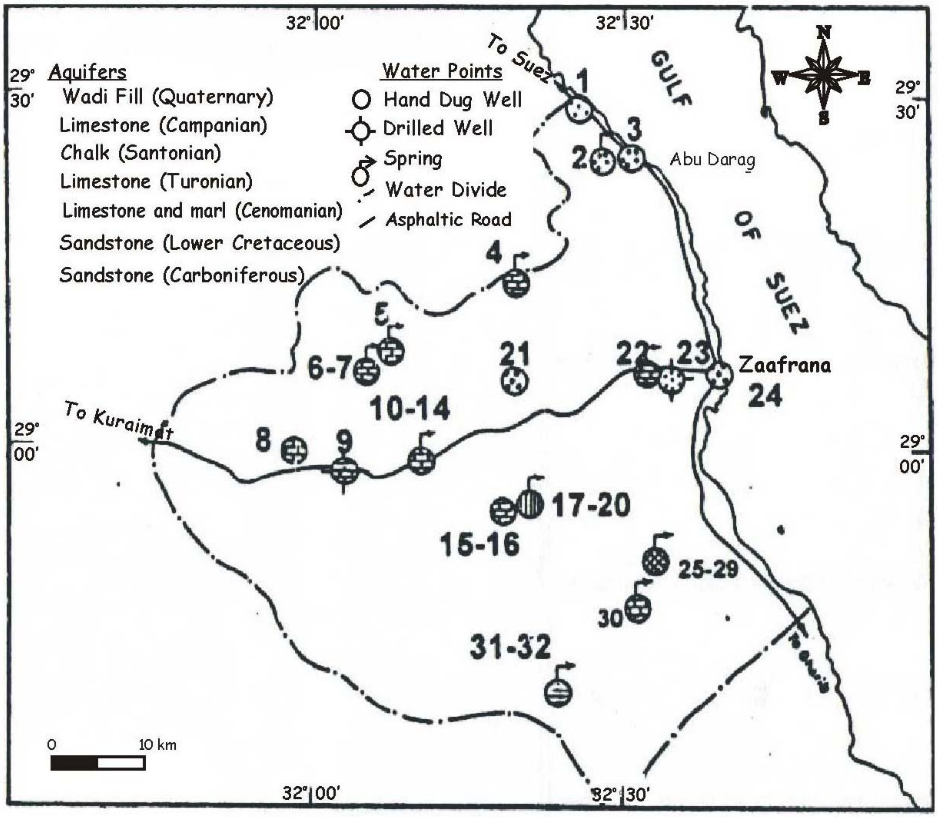


Figure (6): Detected aquifer systems in Wadi Araba-Wadi Dara area, (Aggour, 1990 and DRC, 2002).

2.1.2.4 Nile Valley area

It is reported that the Nubia Sandstone Formation underlies the Nile Valley and Delta at a depth of 1,000 m from the surface west of Cairo and more than 3,000 m north of Cairo (Hefny et al, 1991). It is exposed from Aswan district southwards with a thickness reaching 600 m from the ground surface. It is thought that the highly mineralized water of Helwan Springs (south of Cairo) is originated from the high pressure water of the Nubia Sandstone aquifer (level about 50 m amsl).

2.1.3 Fractured carbonate group. *(Cretaceous-Paleogene)*

Westwards, the Nubian Sandstone Formation is overlain by a thick series (± 500 m in the outcrop area) of shaly and marly sediments, with intercalations of sandstones and limestones of Upper Cretaceous age. They are capped, in turn, by the vast plateau of the Eocene limestone.

The thickness of the limestone varies from some 500 m in the cliffs to may be considerably more in the central zone of the Assiut Plateau: at EDX 1 Exploration borehole, it reaches 900 m, (Pirard, 1981). The hydrology of fissured and karstified carbonate aquifer complex is not well understood and needs different techniques to evaluate potential yields. It is the least explored and exploited of all rock types in Egypt.

2.1.3.1 Gulf of Suez area

2.1.3.1.1 Upper Cretaceous shally formations

These formations may be considered globally impervious. They form an aquiclude, which confines the underlying Nubian aquifer. The latter may be tapped by deep boreholes only (300 to 700 m), and the water level will be relatively deep, given the relatively high relief of the Upper Cretaceous outcrops compared to that of the Nubian. Small water resources, probably drained from the overlying limestones, can however be tapped at shallow depths.

3.1.3.1.2 Upper Cretaceous limestones and sandstones formations

The Cretaceous rocks comprise the high groundwater potentiality in the Gulf of Suez area. The groundwater is available from non-clastics (carbonates) as well as clastics (sandstone). The Campanian limestone was detected as water bearing along the eastern scarp of the Southern Galala from which it receives its recharge (El-Dakhel Springs, no. 31, and Figure 6). It yields from 3 to 5 m^3/day. The water occurs under unconfined conditions. The water salinity is 1430 ppm reflecting its high elevation (+840 m).

The Santonian chalky limestone aquifer is detected through gravity springs along the northern scarp of the Southern Galala (Saint Anthony Springs nos. 17 and 18, Figure 7). They are recharged from the rainfall through the connected open fractures (N60^{o}E-S60W and NNE-SSW (Aggour, 1990). They yield about 120 m^3/day, reflecting a wide watershed area (15000 km^2) and high fracture density.

The Turonian limestone is recorded as a water bearing formation along the scarps of El-Galala Plateau. The faults bounding Wadi Araba from its northern and southern sides control the hydrogeologic condition of the existing water points (nos. 4, 5, 6, 8, 19, 20 and 30, Figure 6). These faults brought the impervious strata against the fractured limestone. These strata prevent the groundwater flow to Wadi Araba (Aggour, 1990). They are recharged from the rainfall through open connected fractures. The water salinity ranges from 1124 to 2369 ppm. This variation is mainly attributed to the difference in location with regard to replenishment area, altitude, and size of recharging area and the nature of dissecting fractures (DRC, 2002).

The Cenomanian marl and limestone are recorded as water bearing formations in the area of St. Anthony Monastery along the eastern scarp of Southern Galala. They occur as gravity springs and free water table conditions (Aggour, 1990). The springs are of acceptable quality water (1600 ppm), yielding 100 m^3/day, and are surrounded by small oases.

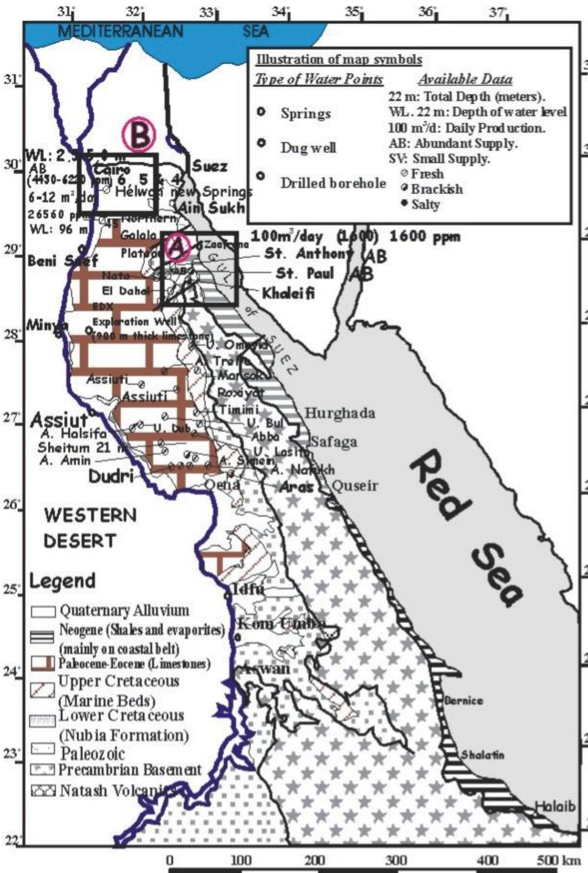
2.1.3.2 Western Eocene Limestone Plateau

The barren and karstic surface of the limestone seems favorable to the infiltration of a good part of the very rare rainfall. This infiltration would be in the order of 1 or 2 mm. It is sufficient to feed relatively numerous shallow water points, and perennial springs. In the areas south of latitude 27^o, the water quality is nearly always good or excellent. The northern part is entirely devoid of water points (Figure 7).

Conditions at depth are unknown. On the other hand, the limestone has been found fractured and permeable in the structures of the Gulf of Suez area. But it must be noted that in comparison with these structures, the western plateau has been relatively little affected by tectonic activity. Thus, it can be presumed that the water storage is mainly superficial, although the possibility of the occurrence of water in deeply fractured zones cannot be disregarded.

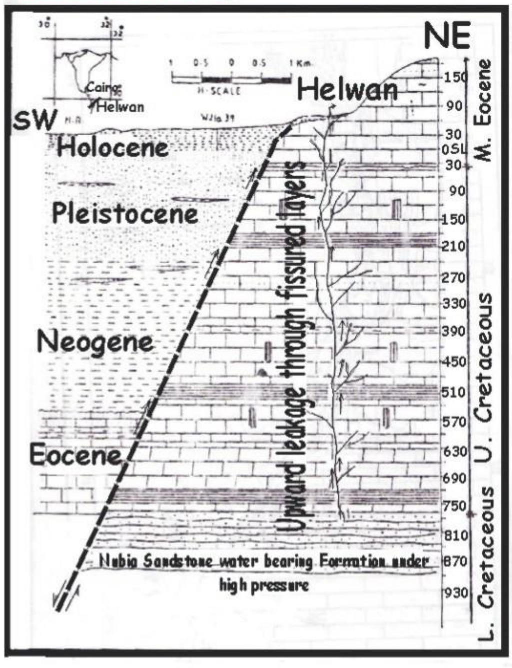
To the east of the Nile Valley (northern part of Upper Egypt), the Eocene aquifer is represented by a water bearing formation of low to high potentials (El-Gindy et al, 1999). To the north of El-Aiyat and up to El-Giza, the Eocene limestone is highly fractured and is probably subjected to a network of deep-lying faulting system (Abdel Daiem, 1971).

Therefore, the Eocene limestone in Helwan town and its vicinities is considered as a good groundwater reservoir. The groundwater of this aquifer occurs under the unconfined conditions. Worth mentioning, all the water points tapping the Eocene limestone aquifer eastern of El-Fashn town in south and El-Aiyat town in the north are of limited water potentials and have water of limited quantity and poor quality. This aquifer unit is made up of hard snow white highly fossiliferous limestone with shales and marl intercalations.



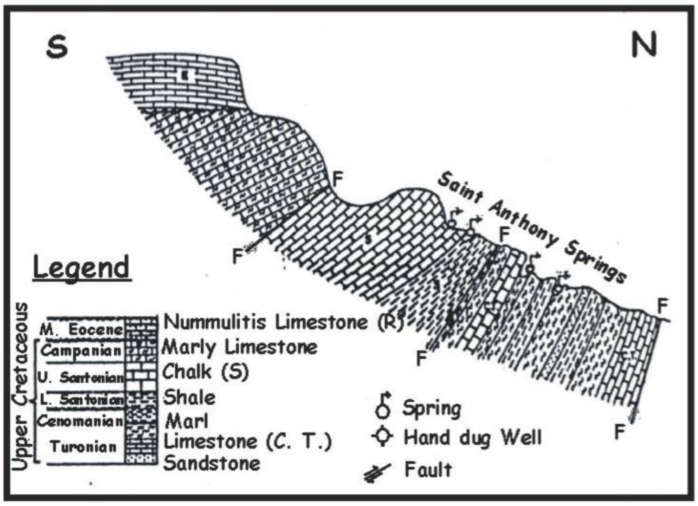
Fractured carbonate aquifer system (Cretaceous-Paleogene) in the Eastern Desert (Compiled from different sources, as cited in the text

Focused Area B



Hydrogeological cross section illustrating the hypothetical origin of water springs in Helwan (Abdel Daiem, 1971)

Focused Area A



N-S hydrogeological sketch, northern scarp, El-Galala El-Qibliya, Saint Anthony area (Aggour, 1990)

Figure (7): Fractured carbonate aquifer in the Eastern Desert (Compiled from different sources as cited in the text)

Tamer et al, 1975, mentioned that the limestone and marl series are detected in a thickness of about 500 m in two deep drilled wells at Beni Suef (Well no. U) and El Lahun (Well no. U). A considerable number of wells are tapping the Eocene limestone aquifer in the area extended from eastern Beni Suef in the south to Helwan in the north. In 1999, a number of new springs were naturally issued in Helwan district with a constant discharge of about 90 m^3/hour per each spring and temperature of 30 ^oC. The constant discharge and temperature of

Helwan new springs indicate a deep seated origin of water, which comes to the surface by upward leakage through a fracturing and faulting systems under high artesian pressure (El-Gindy et al, 1999). Consequently, the Eocene limestone aquifer is mainly recharged from the percolation of the atmospheric precipitation, the younger aquifers (e.g. Plio-Pleistocene and Prenile) as well as the upward leakage from the underlying Nubia Sandstone aquifer through the fractures and along the fault planes (Abdel Daeim, 1971). The salinity of the Eocene limestone aquifer at new Helwan springs ranges from 4550 ppm (Spring 6) to 6220 ppm (Spring 4). Thus, the salinity decreases considerably towards the River Nile, and vice versa (maximum recorded value is 26500 ppm, at Kuraimat) (Table 10).

Table (10): Hydraulic characteristics of the Eocene aquifer (El-Gindy et al, 1999)

Well No.	Static water level (mbgs)	Water bearing formation	Water point type	Discharge rate (m^3/hour)	Total salinity ppm (ppm)
4	5	Fractured Eocene	Spring	90	6220
5	3.5	Fractured Eocene	Spring	90	5850
6	2.5	Fractured Eocene	Spring	90	4550
45	96.0	Fractured Eocene	Spring	---	26560

In conclusion, the groundwater potential of the limestone plateau cannot really be appraised. As is often the case for carbonate formations, the permeability, which depends on the local conditions of fracturation, may be supposed to be very irregular. It is not impossible therefore that boreholes, carefully sited could achieved good yields. A structural interpretation of Landsat imagery could be of great assistance. These however, could not be multiplied, for the overall storage and recharge remain necessary limited (Low-productive aquifers).

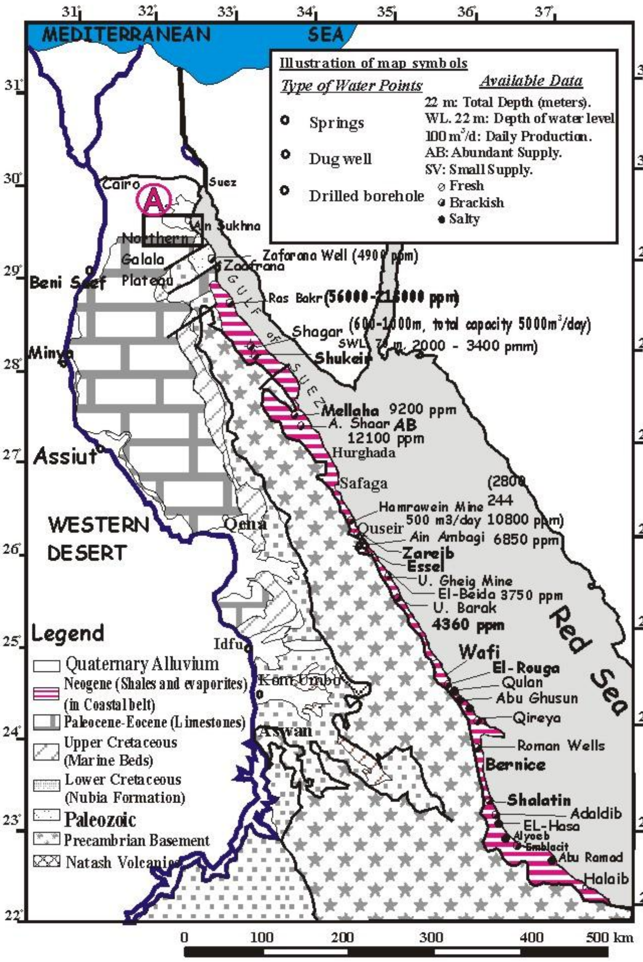
2.1.4 Neogene sediments (on coastal belt)

The Neogene sediments here are mainly represented by the Miocene succession on the Red Sea-Gulf of Suez coastal belt. They are variable in thickness. The evaporites facies predominate the upper part of the succession (South Gharib and Belayeim Formations) and clastic sediments predominate the lower portion (Kareem and Rudeis Formations). Therefore saline groundwater is expected in the upper formations and fresh to brackish groundwater in the lower formations. Generally, these aquifers are of limited productivity and poor water quality (Figure 8).

2.1.4.1 Red Sea-Gulf of Suez Coast

2.1.4.1.1 Halaib-Shalatin Area

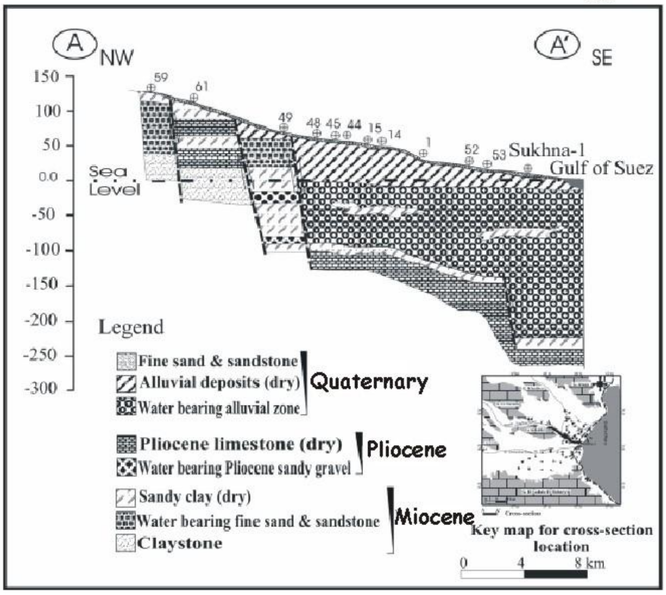
The Miocene sediments are found as isolated hills located to the west of Abu Ramad and Halaib areas in Wadi Serimtai, Wadi Aideib, Wadi Daaet, Wadi Kraf, Wadi Darera, and the region of Wadi Hubal. They are mainly consisting of alternating limestone and marl beds, and they are equivalent to the beds of Gebel El-Rusas Formation. The Miocene aquifer in these areas is of limited productivity and poor quality, which is attributed to the marine-origin sediments constituting its formations. Three hand dug wells namely; Abu Ramad 2, Al Yoeb and Emblacit were encountered in the Miocene deposits (NARSS, 1999, Elewa, 2000). The depth to water from the ground surface ranges between 11 m (Bir Emblacit) to 13 m (Bir Abu Ramad 2), while the groundwater salinity varies from 11302 ppm (Bir Al-Yoeb) to 12786 ppm (Bir Abu Ramad 2). Abu Ramad 2, Emblacit, Baanit, Aissila, Yoeb, Al-Bida are of marine and deep marine water origin (Fathy and Nagaty, 2005).



Neogene sediments aquifer system (mainly on coastal belt) in the Eastern Desert

(Compiled from different sources, as cited in text)

Focused Area A



Hydrogeological cross section along NW-SE of Ain-Sukna area, showing the Miocene aquifer hydrogeological setting (NARSS, 2004).

Figure (8): The Neogene aquifer system in the Eastern Desert (mainly in coastal belt)

2.1.4.1.2 Quseir-Safaga Area

The rocks of this aquifer are widely distributed in the coastal plain south of Quseir City, where they are composed of sandstone water bearing formation overlained by shale and limestone (El Rusas Formation), followed by gypsum, shale and marl (Abu Dabab Formation). Furthermore, the basement rocks of metavolcanic type (Rhyolite and andesite) underlie this water bearing formation. These sediments are recognized to be a water bearing formation at the lower reaches of Wadi Essel in two water points nos. 22 and 23 (Essel wells I and II). These water points are located at about 6 km inland from the Red Sea coast. The groundwater in this aquifer exists mainly under semi-confined conditions due to the presence of the overlying impervious evaporates and shales (Dabash, 2004) (Table 11).

The field observations indicate that, faults and dykes have their impacts on the water flow in the aquifer in wadi Essel. As mentioned before, a granitic dyke crosses the main wadi channel in a NW-SE direction and is traced by a major fault, running in a NE-SW direction.

This allows the groundwater to discharge under the effect of both structural elements; the dykes and the faults (El Ghazawi, and Abdel Baki, 1991). The impervious evaporites and shales of Abu Dabbab Formation overly this sandstone aquifer. It must be mentioned that, the existence of this aquifer above the basement rocks with the prevailing faulting system allows the possible recharge from the underlying fractured basement rocks.

Table (11): Hydrogeological characteristics of the water points in the Miocene aquifer (Dabash, 2004)

Water point No.	Water point Name	Water point type	Water bearing formation	Total depth (m)	Depth to water (m)	Aquifer type
1	Essel well I	Driled	Middle Miocene Sandstone	78.00	12.00	Confined aquifer
2	Essel well II	Driled	Middle Miocene Sandstone	12.00	11.50	Confined aquifer

2.1.4.1.3 Gulf of Suez Area

The Middle Miocene limestone and Lower Miocene sandstone represent the Miocene water bearing rocks. One spring and three wells represent these aquifers (Gomaa and Aggour, 1999).

The Middle Miocene reefal limestone is recorded as water bearing formation at the southern part of the Gulf of Suez. It attains a thickness of 100 m (Abu Sha'ar Well, No. 31). This formation rests unconformably on the basement rocks. It is recharged laterally through the western nearby fractured basement rocks and also vertically along the fractures of the exposures of the water bearing limestone. The water occurs under confined conditions, where the shale and evaporites form the confining beds (Gomaa and Aggour, 1999). The water level is + 29 m and the water salinity reach 7123.95 ppm. The high salinity is attributed to the leaching of the intercalated shale and evaporites surrounding the water bearing rocks.

On the other hand, the Middle Miocene sandstone is detected as water bearing formation at the Northern Galala. The groundwater is issued from the undifferentiated Miocene sandstone along a NW-SE fault at the northeastern corner of the Northern Galala as spring (Ain Sukhna). The groundwater of this spring occurs under confined conditions and it has a high salinity (8173 ppm) (Abdel Samei and Elewa, 2005) and standard temperature (33 ^{o}C). This reflects that the source of this water is paleowater from deep aquifers (Aggour and Sadek, 2001, and Abdel Samei and Elewa, 2005).

The Lower Miocene white sandstone (Rudeis Formation) aquifer is considered as the main source of Ras Gharib and Ras Shukeir poultry water. It is composed of sand and sandstone, calcareous in some part. The thickness of the Rudeis Formation varies from 192 to 325 m in Shagar Field and from 36 m to 246.5 m in Shukeir Field. This aquifer has a maximum thickness of 185 m and the water occurs under confined conditions (Nasr, 1990). The water bearing formation is overlain by a thick section of impervious shale and evaporites (475 m thick). The recharge of this aquifer is mainly from the western main watershed area along the basement rocks (Gebel Gharib). The piezometric level varies from +17.5 to +55.7 m (Shagar Field) and from + 42.98 to +55.48 m (Ras Shukeir Field). The water salinity ranges between 1700 and 3400 ppm. The water salinity increases to the northwest in Shukeir Field and southeast directions in Shagar Field and the origin is meteoric.

2.1.5 Quaternary alluvial deposits. *(Pleistocene to Recent)*

These deposits are widely distributed in the area of study. They cover most of the wadis floors, alluvial fans, structural depressions, and rugged depressions. Alluvial deposits may be subdivided into two groups:

A. Wadi fillings: They are spreaded in the rugged depressions, in alluvial fans and in alluvial courses. They are extremely variable in thicknesses. They overlie both the sedimentary and crystalline rocks. In El-Sukhna area, they reach a thickness of 80 m and overlie the carbonate group of sediments (Eocene). They exhibit a greater thickness in the wadis debouching towards the Nile Valley and some major deltas of the Red Sea drainage basins.
B. Coral reefs and beach deposits: sometimes these reefs contain thin layers of perched fresh groundwater. This fresh groundwater lenses are expected to be formed on account of infiltration of surface water from coastal wadis debouching to the Red Sea direction.

2.1.5.1 Red Sea-Gulf of Suez Areas

The Quaternary aquifer is developed at the deltaic areas of the main wadis which cross the coastal plains. The water exists under phreatic conditions, nearly at sea level.

2.1.5.1.1 Halaib-Shalatin Area

At Halaib-Shalatin area, the wells are mostly shallow excavations in the alluvial Quaternary deposits of the wadi filling. They are tapping the runoff waters, which percolate underground seawards from the mountain ranges or in the surficial weathered fractured Precambrian basement rocks. They are naturally more frequent in the district near to the mountain ranges than the lower reaches of the wadis. The best wells are usually dugged at the junction points of small tributaries as they collect drainage water from these wadis. On the average, water is reached at a depth of one to thirty meters, in areas, where the wadi is crossed underground by damming dyke, which enables water be reached at very shallow depths. The total salinities range from 1952 to 17514 ppm (Elewa, 2000, Fathy and Elewa, 2002 and Elewa et al, 2003).

The depth to water in this aquifer varies from 1 m (Bir Adaldib to 9.85 m (Bir Shalatin 4). The salinity variation is from 2118 ppm (Bir Al-Bida 2) to 17514 ppm (Bir Shalatin 3) (Table 12).

In this area, the Quaternary aquifer consists of alluvial wadi deposits composed of pebbles, gravels and boulders, which are derived mainly from the basement rocks. About twelve hand dug wells are found in the alluvial fans of Wadis of Kraf, Shaab, Hodein, and in wadi basins such as Wadi Madi were reviewed (Elewa, 2000 and NARSS, 2000).

Table (12): Hydrogeological characteristics of the water points in Quaternary alluvial aquifer in Halaib-Shalatin area (NARSS, 2000 and Elewa, 2000)

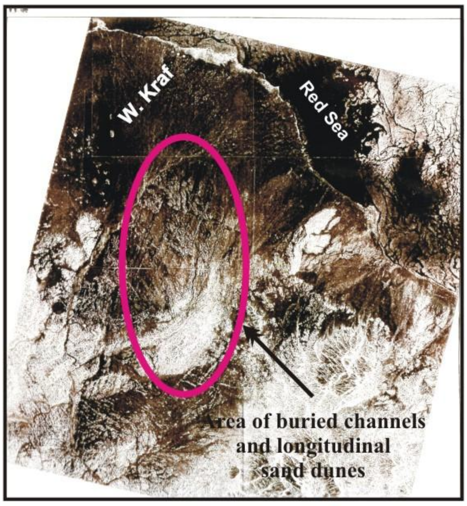
Water point No.	Water point Name	Water point type	Salinity (ppm)	Total depth (m)	Depth to water (m)	Aquifer type
1	Shalatin 1	Hand dug	8250	2.21	1.00	Free water table
2	Shalatin 2	Hand dug	6704	3.20	1.30	Free water table
3	Shalatin 3	Hand dug	10000	4.00	1.20	Free water table
4	Shalatin 4	Hand dug	8098	10.0	2.60	Free water table
5	Shalatin 5	Hand dug	5932	9.50	7.00	Free water table
6	Shalatin 6	Hand dug	9536	10.0	5.50	Free water table
7	Shalatin 9	Hand dug	17514	8.20	9.50	Free water table
8	Al-Hassa	Hand dug	5998	1.35	1.25	Free water table
9	Adaldib 1	Hand dug	10042	2.25	1.00	Free water table
10	Adaldib 3	Hand dug	9276	3.50	1.60	Free water table
11	Abu Ramad 1	Hand dug	16408	5.72	4.75	Free water table
12	Al-Bida 2	Hand dug	1952	3.50	3.20	Free water table

Radar application for paleodrainage and shallow groundwater exploration in Halaib-Shalatin area:

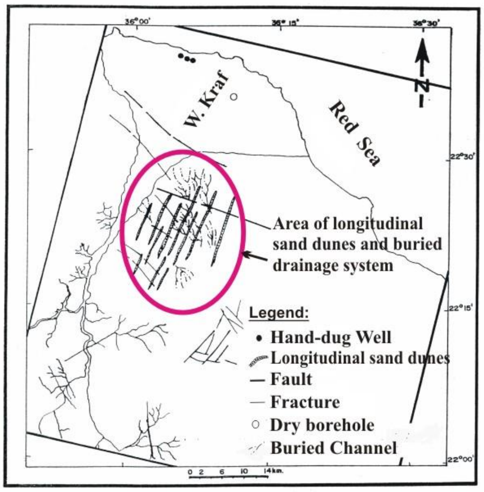
The RADARSAT image (Figure 9), was used as a strong reflective tool to reveal the infrastructural elements; as dykes and fractures that could not be sufficiently revealed by the Landsat TM image (NARSS, 2000 and 2001). The Radar image is also very useful tool to reveal the superficial buried drainage systems, especially those buried under dry linear or longitudinal sand dunes parallel to the south eastern flank of the Wadi Kraf basin. The buried drainage system under these dunes is not reflected by the normal Landsat images. Interpretation of Shuttle Radar image acquired in February 2001 (Figure 9) revealed the presence of buried paleodrainage system prior to the onset of Quaternary aridity. This system is now merely completely aggraded and obscured underneath the longitudinal stabilized sand dunes. These dunes seem to be controlled by structural elements, i. e. fractures. These fractures may create longitudinal troughs, which subsequently form basins for longitudinal sand accumulation. The radar image, with its relative penetrative capabilities, reflects the presence of buried paleodrainage regime underneath the dunes areas, which was strongly responsible for the stabilization of these dunes. Compared to the TM image of the regional Halaib-Shalatin area, the radar image could be used in the determination of proposed or promising sites for groundwater occurrences. The dual role of structural elements (fractures or dykes) and buried paleodrainage system found underneath the dunes area of Wadi Kraf could be very useful parameters for the entrapment of groundwater bodies, especially at the intersection points between the fractures and buried drainage lines as mentioned before.

2.1.5.1.2 Quseir-Safaga area

The alluvial deposits in Quseir-Safaga area are detrital alluvial sands, pebbles, boulders and rock fragments with variable thickness (from centimeters to twenty meters) acquiring wide area distribution. They occur as wadi fill or as terraces encountered in the course of the wadies and their tributaries. These deposits directly rest either on the fractured basement rocks in the upstream portions (inland deposits) or they cap the sedimentary rocks in downstream portions of all wadies (coastal deposits).



Radar image of part of delta W. Kraf, showing the buried channels and area of logitudinal sand dunes (NARSS, 2001)



Buried drainage system and longitudina sand dunes in W. Kraf (Halaib-Shalatin area), extracted from Radar image (NARSS, 2001)

Figure (9): Using radar image technology for the determination of efficient buried channels and surface geological features of promised water bearing longitudinal sand dunes in part of Halaib-Shalatin area

The hydrogeological review revealed that the Quaternary deposits are developed into aquifers in Wadi El Ambagi and Wadi Queh. In Wadi El Ambagi, the Quaternary groundwater occurs under free water table or spring conditions. The free water table conditions are detected in the shallow wells located in Quseir City (Dabash, 2004) (Table 13). The discharge of this well is very small (about 16 m^3/day). The main expected recharge is from west, besides the upward leakage from the deep Oligocene aquifer of El-Nakheil Formation through the faults and the fractures. The flowing springs are detected at E Ambagi Spring I and II, where the groundwater flows naturally and forming large swamp. The discharge rate of El Ambagi spring is about 120 m^3/day.

At the upstream portion of Wadi El-Ambagi, the wadi fills deposits are detected as water bearing rocks in Um El-Khurs hand dug Well at Wadi Karim tributary. The wadi fill deposits rest directly on the basement rocks. The total depth of the well is 18 m, while the depth to water is 17.6 m, producing low water quantity. The groundwater flows through the connected fractures and fissures dominate the basement rocks (Hammamat rocks).

In Wadi Queh, the alluvial deposits are detected as water bearing in the downstream portion of the Queh basin, where the floor is characterized by gentle slope giving the chance for the local rainfall and flash floods to infiltrate downward and feed the aquifer. The groundwater occurs under free water conditions and exists in thin sheets at depths varying from 1 m near the coast to about 19 m (Queh 6H and Queh coastal Well). The alluvial deposits rest either directly on the fractured basement rocks at the upstream portion or cap alternating beds of phosphate, shale, marlstone and oyster limestone of Duwi Formation at the middle stream portion.

Table (13): Hydrogeological characteristics of the water points in Quaternary alluvial aquifer in Quseir-Safaga area (Dabash, 2004)

Water point No.	Water point Name	Water point type	Salinity (ppm)	Total depth (mbgs)	Depth to water (mbgs)	Aquifer type
1	Quseir Well	Hand dug	---	4.50	3.50	Free water table
2	Ambagi Spring I	Spring	5336	---	---	Flowing
3	Ambagi Spring II	Spring	7711	---	---	Flowing
4	Um El Khurs Well	Hand dug	1484	19.50	17.5	Free water table
5	El Beida Well	Hand dug	19396	7.50	4.20	Free water table
6	Queh 6H	Hand dug	1649	36.0	17.0	Free water table
7	Queh coastal Well	Hand dug	11505	10.0	8.5	Free water table

2.1.5.1.3 Gulf of Suez Area

The Quaternary alluvial deposits are formed of sand, gravel and boulder filling the courses of the hydrographic basins. They have lateral and vertical variations in lithological composition according to the dominated rock exposures in the hydrographic basins. The alluvial deposits are detected as water bearing formation by three wells, two in Wadi Araba, and one in Abu Sunduq (Aggour, 1990). The recharge is mainly from direct infiltration and the underlying shales prevent its downward percolation. The wells have depth to water ranges between 0.5 and 3.21 m and the discharge ranges between 2 and 5 m^3/day. The water salinity of Wadi Araba wells is remarkably high (16210 to 30082 ppm) due to the stagnancy, evaporation, leaching processes and salt-water intrusion (Table 14).

Table (14): Hydrogeological characteristics of the water points in Quaternary alluvial aquifer in Gulf of Suez area, (DRC, 2002)

Water point No.	Water point Name	Water point type	Salinity (ppm)	Depth to water (mbgs)	Aquifer type
1	Quseib	Hand dug	3580	0.0	Flowing
2	Abu Sanduq	Spring	4750	0.5	Free water table
3	Mleiha	Spring	16210	1.15	Free water table
4	Zaafrana	Hand dug	30082	3.21	Free water table
5	Gharib East	Hand dug	11200	12.25	Free water table
6	Gharib West	Hand dug	9000	12.5	Free water table
7	Abu Nakhla	Hand dug	4710	0.9	Free water table
8	Mellaha up	Spring	25000	0.0	Flowing
9	Mellaha down	Spring	30000	0.0	Flowing
10	Abu Shar 1	Hand dug	6900	1.5	Free water table
11	Abu Shar 2	Hand dug	6600	1.2	Free water table

However, most deep hand-dug wells have had to be dug through between 15 and 25 m of sand before reaching the water table, which is very close to or within the bed rock and obtaining a regular supply of between 10 and 50 m^3 per day.

The Quaternary groundwater aquifer system in Ain Sukhna area occurs under different conditions reflecting the remarkable structural, lithologic and topographic variations. Generally, the water levels vary from west and northwest to east and southwest. The groundwater level decreases gradually from more than 100 m (towards the upstream of wadis) to few centimeters above the sea level near to the shoreline. This low level of the groundwater is due to the high permeability in the coastal plain and low relief in the delta of the drainage basins. The water level at the area of the Miocene aquifer in the northern parts of Ain Sukhna area is higher than that of the Quaternary aquifer areas. Due to that, the Miocene aquifer is the source of recharge to the Quaternary aquifer. At the southern part of the study area, the water level is higher than the water level in the middle parts, which is due to the higher ground level beside El Galala El Baharyia Plateau. The water level map constructed for the Quaternary aquifer during March 2004 reveals that the water levels in the Quaternary aquifer are regionally decreasing from the west and northwest to the east and southeast. But, there are minor directions from south to north and from north to south at Wadi Ghweibba and Wadi Badaa, respectively (Abdel Semei and Elewa, 2005).

Water harvesting is a very important and urgent need for the major wadis of the Gulf of Suez to develop the groundwater reserves in the Quaternary aquifer system. Remote sensing is an efficient tool for surface mapping of the drainage basins and subbasins. GIS is another tool, which when used integrally with remote sensing gives realistic and optimum efficient locations for surface water retardation dams (NARSS, 2004 and Elewa, 2005a). Five hydrographic basins are found in Ain Sukhna area. These basins are W. Ghweibba, W.Badaa, W.Hagul, W. Hammtih and W.South Hagul. The construction of retardation dams in some selected locations will enhance the groundwater recharging, or at least minimize the flood damage with the concomitant increase in seepage/runoff ratio. The sites selection of these dams was determined according to several criteria, e.g. soil characteristics, soil infiltration capacity, slope factors, morphometric characteristics and flood mitigation measurements, remote sensing and GIS (NARSS, 2004 and Elewa, 2005a).

The water seepage rate in Wadi South Hagul is 0.08 x 10^6 m^3/h, which gives good chance for a large part of flood water to percolate through the surface soil to the under ground. The trunk channel of W. Hammtih basin is characterized by high runoff rate, when it is compared with the seepage rate (0.17 x 10^6 m^3/h). Wadi Hagul basin is characterized by low seepage rate, where the high flooding episode of 3.24 x$10^6$$m^3$ occurred in 1990 with runoff rate of 2.26 x 10^6 m^3/h and seepage rate of 0.71 x 10^6 m^3/h. For Wadi Badaa basin, the seepage/ runoff relationship indicates that W. Badaa is moderate in the accumulation of floods water, where, the high flood rate of 5.06 x 10^6 m^3/h. happened in 1990 with seepage rate of 2.93 x 10^6 m^3/h. Finally, W. Ghweibba basin has high runoff rate of 22.8 x 10^6 m^3/h. in 1990 with seepage rate of 9.70 x 10^6 m^3/h (Elewa, 2005a).

2.1.5.2 Nile Valley Area

This aquifer is formed by the alluvial sediments (Quaternary) of the Nile Valley and Late Tertiary sands and gravels intercalated with clay lenses. Water bearing formation is located between an impermeable bed at the bottom and the sides of the Nile Valley and a thin semi impermeable clay layer at the top. The thickness of the aquifer decreases from 300 m at Suhag and Assiut to a few meters in the north near Cairo and south near Aswan (Figure 10).

The thickness of the upper clay layer varies between 5 and 20 m with an average thickness of 12 m. Water-bearing formations extend east forming horizontal gravel and sandy plains, i. e. through Wadi El-Assiuti drainage basin..

The previous studies about Wadi El-Assiuti proved the existence of prolific aquifer system in the Quaternary sediments. During the past thirty years, the groundwater occurrence and the aquifer lithology of Wadi El-Assiuti area were described by many authors, among them; Mousa et al. 1993, Abu El Ella 1999, Yan et al 2004, NARSS, 2005, Elewa, 2005b, and Elewa, 2006 and others.

Nine wells were drilled by Assiut Governorate during the period from 1992 to 1996, having depths ranging between 171 m and 235 m. They partially penetrated the Pleistocene aquifer successions. Pumping tests were performed for all these wells by the GARPAD (1995). The Pleistocene aquifer is characterized by relatively good hydraulic characteristics (Table 15). Later on, the number of drilled water wells increased to become about 85 water wells, especially with the involvement of the private sector into the development activities (Figures 11 and 12).

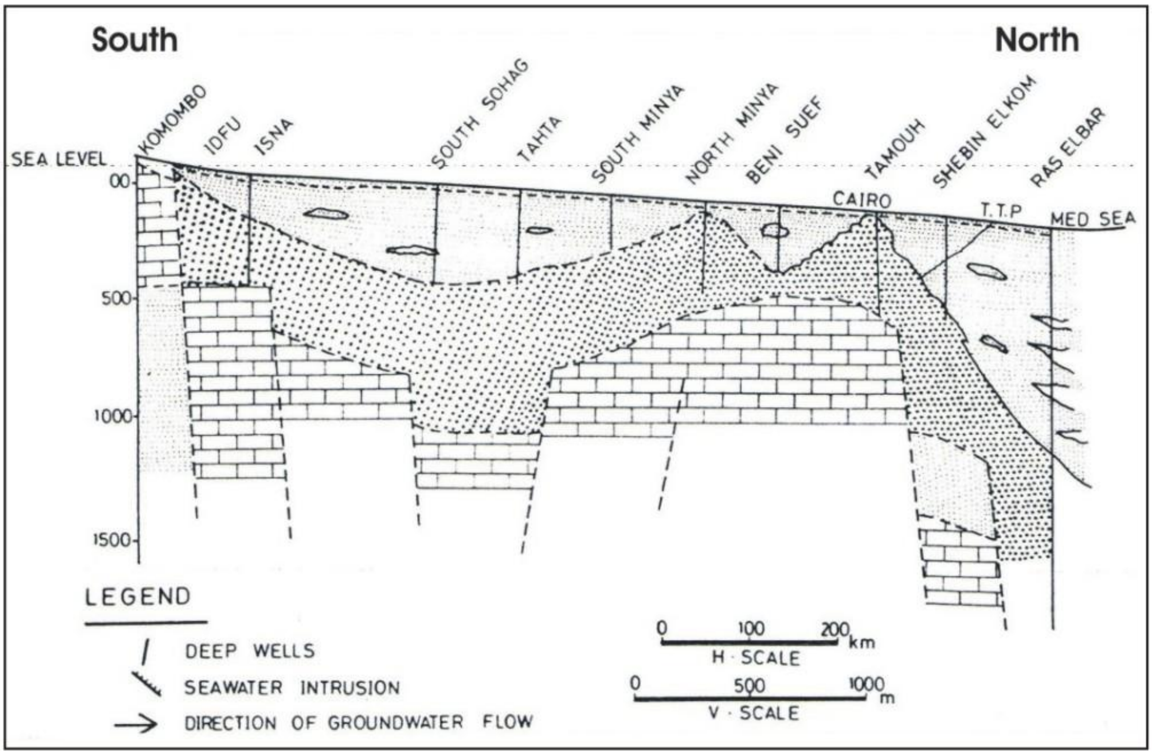
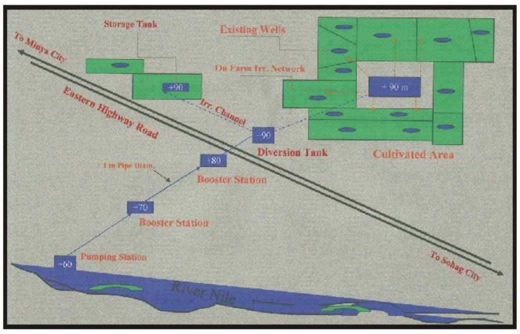


Figure (10): Hydrogeological profile through the Nile Valley and Delta basins (Hefny et al., 1991)

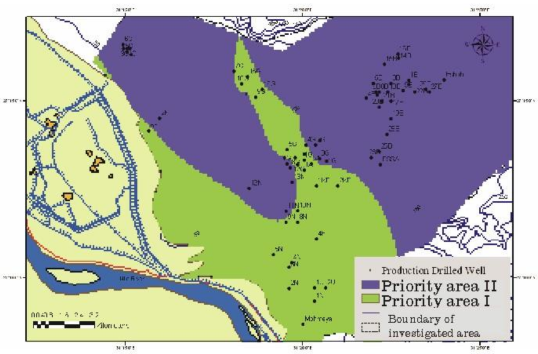
Table (15): Average results of pumping tests in Wadi El Assiuti, Assiut area, Eastern Desert, Egypt, (NARSS, 2005 and Elewa, 2005b)

Well No.	Aquifer Parameters			Formation Loss Coefficient (B) (day/m^{-2})	Well loss coefficient (C) (day^2/m^{-5})	Optimum Yield (m^3/day)	Well efficiency (%) at (70 m^3/hr)
	Transmissivity (m^2/ day)	Hydraulic Conductivity (m/day)	Storativity				
9G	293	5.43	2.3 x 10^{-3}	0.63 x 10^{-3}	2.8x 10^{-7}	1920	53.96
12G	204.3	2.55	1.3 x 10^{-3}	1.9 x 10^{-3}	4.56 x 10^{-7}	2160	68.46
1A	219.6	3.66	1.6 x 10^{-3}	7.9 x 10^{-3}	1.17 x 10^{-7}	2400	96.03
15G	510.7	6.90	2.6 x 10^{-3}	0.92 x 10^{-3}	2.66 x 10^{-7}	2160	64.3
14G	220	5.79	2.4 x 10^{-3}	3.16 x 10^{-3}	0.91x 10^{-7}	2880	94.76
2A	439	10.71	3.78 x 10^{-3}	2.92 x 10^{-3}	3.87 x 10^{-7}	2640	79.72
15B	420	7.50	2.45 x 10^{-3}	2.07 x 10^{-3}	9.70 x 10^{-7}	1920	52.64
16G	300	4.29	2.85 x 10^{-3}	1.03 x 10^{-3}	6.30 x 10^{-7}	1920	45.99
17G	340	6.94	3.84 x 10^{-3}	2.20 x 10^{-3}	1.1 x 10^{-6}	1920	50.79

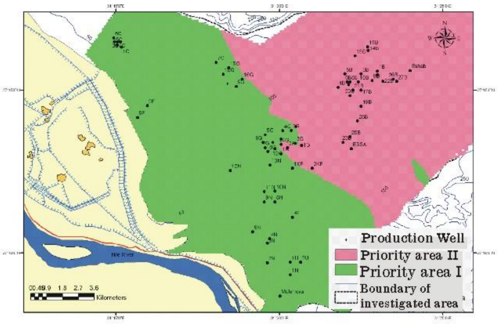
The Pleistocene sediments of Wadi El-Assiuti, the main groundwater aquifer, are mostly influenced by the River Nile recharge and to a less extent by the surface runoff water from the Eastern Desert valleys. Farthest inside the eastern tributaries of Wadi El-Assiuti, the influence of the Nile River diminishes, and the main recharging sources are those coming from the upward leakage from older formations or from the rainfalls of the Red Sea mountain range, outcropping to the east. The regional water flow is from east northeast towards west southwest directions, with some adverse minor directions at the north-central part of the study area (NARSS, 2005). The depth to water (from ground surface) is topographically controlled. The groundwater is available at depths ranging between 27.5 m (Well 5F) and 44.2 m (Well Abna'a Eshaab) below ground surface.



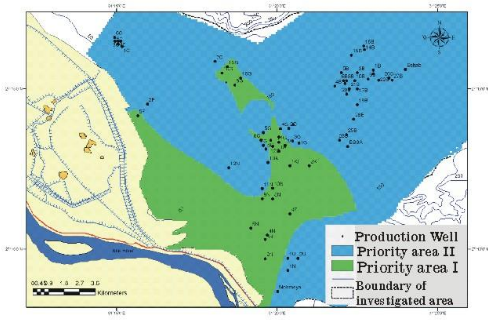
Generalized (Proposed) layout for conveyance the surface Nile water to irrigate and augment the groundwater in Wadi El-Assiuti watershed area



Determining priority area I for development by GIS technique, according to values of depth to water < 40 m and groundwater salinity < 1500 ppm



Determining priority area I for development by GIS technique, according to values of depth to water < 40 m with aquifer useful thickness > 50 m



Determining priority area I for development by GIS technique, according to values of depth to water < 40 m, groundwater salinity < 1500 ppm and SAR < 10

Figure (11): Determination of water/land use developmental priority regions and planning for conjunctive water use of surface and ground waters in W. El-Assiuti (NARSS, 2005 and Elewa, 2006)

The National Authority for Remote Sensing and Space Sciences (NARSS 2005) conducted a project about the water and land resources assessment for the eastern fringes of Assiut district and its adjacent areas. One of the main objectives of this project was the integration of remote sensing and geographical information system "GIS" as useful tools for constructing data base that could be useful in proper decision making and successful investigation of groundwater resources. The hydrogeological investigations for determining the Pleistocene aquifer characteristics; its geometry, thickness, water depths and levels, hydraulic parameters and Geographic Positioning System (GPS) for determining wells locations were stored in digital maps or overlays in GIS format to predict the future water levels drawdown scenarios of the Pleistocene aquifer system of Wadi El-Assiuti area**.** Consequently, recommendations about the sustainable use and future management items of the aquifer system were presented. Furthermore, evaluation of water resources is carried out through using the well known empirical and analytical relationships (Figures 11 and 12).

(NARSS, 2005 and Elewa, 2006), used the remote sensing change detection and image processing techniques, where developmental activities in Wadi El-Assiuti were monitored from 1984 to 2000. The remotely-sensed data and Geographic Information Systems (GIS) technology could determine the water/land use developmental priority regions and discuss the conjunctive water use (River Nile water/groundwater), which is an alternative need for the enhancement of the present hydrogeological and hydrological conditions (Figure 11). Landsat TM data was used for monitoring and quantifying the growth of cultivated lands in Wadi El Assiuti, which is surely accompanied by growth in water use and demands. Based on the results reached from the hydrochemical and hydrogeological analysis, the promising areas for future development plan were identified. These results are analyzed through a GIS system using ARC Info\ARC GIS Software and model. This model provided several maps determining the priority areas for future development in Wadi El-Assiuti Valley. These areas were determined according to certain parameters; i. e. shallow depth to water, satisfactory low total dissolved solids (TDS), low sodium adsorption ratio (SAR), high hydraulic conductivity (K) and big tested aquifer useful thickness. These techniques designated the south western part of the study are as a priority areas suitable for the developmental activities (Figure 11).

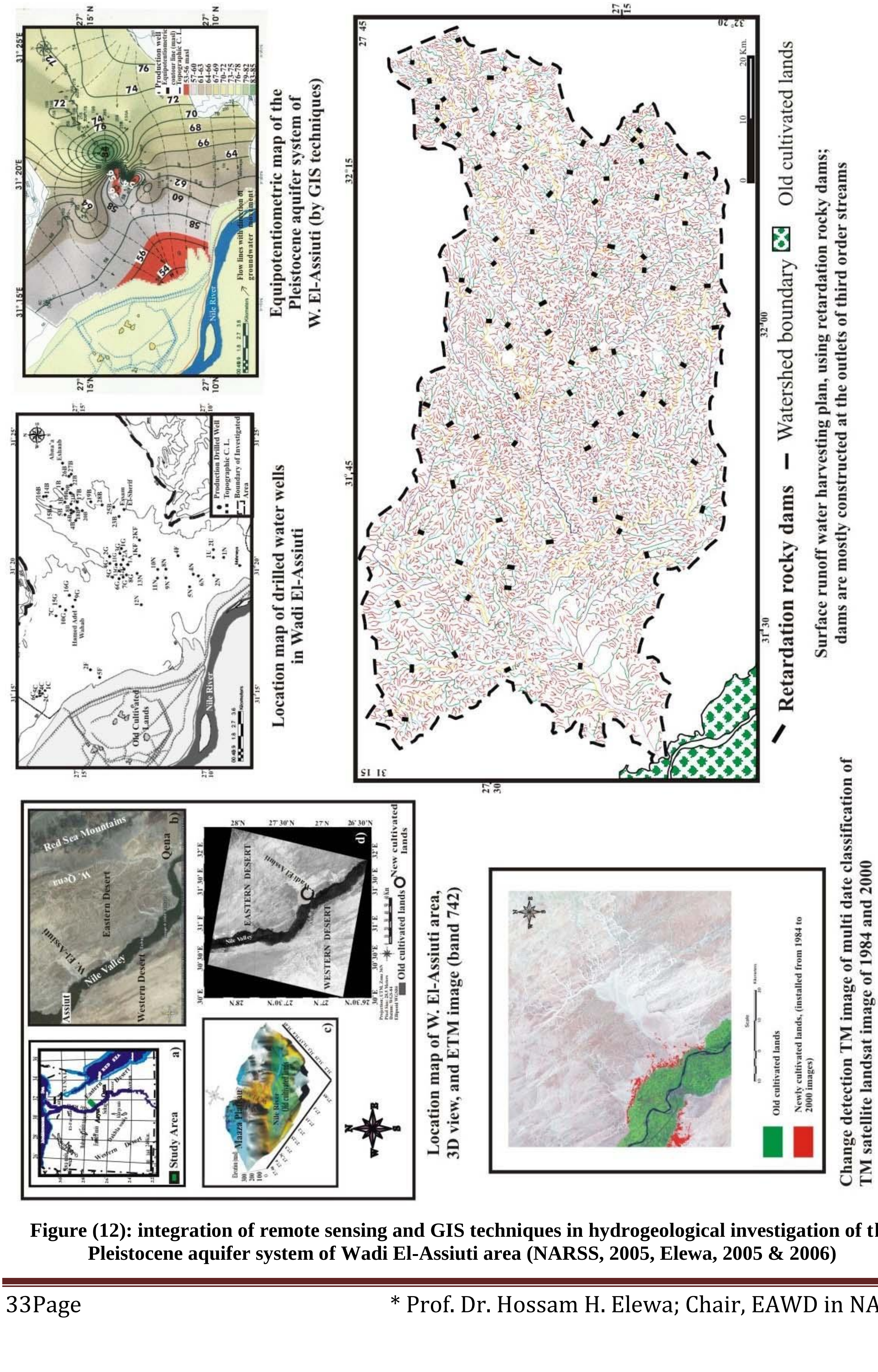


Figure (12): integration of remote sensing and GIS techniques in hydrogeological investigation of the Pleistocene aquifer system of Wadi El-Assiuti area (NARSS, 2005, Elewa, 2005 & 2006)

The remote sensing could be used as an evaluation technique for water harvesting planning. The established stream ordering map constructed for Wadi El Assiuti drainage basin (Figure 12) is highly valuable for determining the best locations for the construction of rocky retardation dams. These dams are of two fold uses; firstly, they are used for flash hazards alleviation as they hamper, but not fully stopping the rushing runoff water, thus decreasing the damages of these floods. Secondly, they are used as successful tool for harvesting the surface runoff water, for the sake of groundwater aquifers (especially the shallow ones) development and recharging. These dams are mostly located at the outlets of small sub-watersheds, mostly the third ordered drainage streams (NARSS, 2005 and Elewa, 2006).

The groundwater salinity values vary generally from 580 to 2445 mg/l indicating fresh to brackish water. The variation in water genesis could reflect the diversity of the recharge sources for the Early Pleistocene aquifer (Elewa and Fathy, 2005).

The environmental isotopic investigation (O^{18} & D) of the Pleistocene aquifer system of Wadi El-Assiuti addresses the old origin of the main bulk of groundwater, where the groundwater carries the depleted isotopic signature of the paleo-water characterizing the Eastern Desert of Egypt. The replenishment source of this water for the wadi proper could be from the local rainfalls on the upstream reaches of Wadi E-Assiuti, in addition to the underlying Nubia aquifer through a direct contact along deep seated faults. Towards the western reaches, at the entrance of the wadi (Nile Valley), the aquifer is almost recharged by the River Nile. The ^{14}C age determination indicated that the Pleistocene water of Wadi El-Assiuti is mostly paleo-water with a significant portion of relatively recent water recharging the aquifer from the rainfalls of the Red Sea mountainous area, in addition to the local ones (Elewa and Fathy, 2005).

Generally speaking, the Quaternary aquifer system of the Nile Valley area contains a large resource of water amounting to about 200 x 10^3 million m^3 a year (Hefny et al 1991). The fringes are recharged by the infiltration water from valleys during torrent periods or from upward movement of groundwater from the Nubian aquifer south of the Nile Valley. The Nile receives a total amount of 1.6 x 10^3 million m^3/year as drainage from the aquifer, meanwhile 1 x 10^3 million m^3/year of groundwater is extracted through productive wells. The groundwater is of good quality and suitable for irrigation and domestic uses with an average total dissolved solids (TDS) less than 1000 ppm. Approaching the east extremities of the aquifer, the groundwater salinity increases to TDS range between 500 - 3,000 ppm.

To the North, east of the Nile Delta, the Quaternary deposits constitute the principal aquifer in the area, attaining a thickness of about 500 m in average (Abdel Mogheeth and Sallouma, 1988). Generally, the thickness of the Quaternary sediments increases seaward. The old deltaic deposits belonging to the Quaternary are of hydrogeological importance. These deltaic sediments decrease markedly towards the east. Such sediments may rest on the impervious pyretic clays and gypseous marls (200 m thick), especially in the localities adjacent to Damietta Branch. However, in the most eastern parts, the basal portion of the deltaic deposits rests unconformably on the Miocene sandstone and sandy limestone (200 m thick).

The Quaternary aquifer occupies the area between Damietta Branch and Ismailia Canal. The aquifer is lithologically composed of graded sands and gravels. The thickness of this aquifer increases seaward attaining 900 m thick, close to sea. The southward thinning (100 m thick) is attributed mainly to E-W faults (Shata and El-Fayoumy, 1970).

The aquifer is mainly recharged by subsurface flow from Damietta Branch, Ismailia Canal and the net of irrigation canals and drains as well as the infiltration of the occasional rainfall. The discharge takes place by pumping wells for the irrigation and domestic uses and by seaward seepage into the El-Manzala Lake and the Mediterranean Sea.

Literatures Cited

Abdel Daiem A.A., 1971: Hydrogeological studies of springs in area east of Cairo, M.Sc. Thesis, Fac. Sci., Ain shams Univ.

Abdel Mogheeth, S.M. and Sallouma, M.K., 1988: Some hydrological and hydrochemical criteria for land reclamation east of the Nile Delta, Egypt. Mans. Sci. Bull. Vol. 15 (2). pp. 227-244.

Abdel Samie, S.G. and Elewa, H.H., 2005. Hydrogeochemical and Environmental isotopic evaluation of groundwater of the area located to the northwest of the Gulf of Suez coast, Egypt. Jour. of Geol., V. 49, p. 109-131.

Abu El- Ella E. 1999: Hydrogeochemical evolution of groundwater aquifers in the area east of Assiut Nile basin, Egypt, Bull. Fac. Sci., Assiut Univ., Vol. 28 (1-F), pp 1-16.

Abu El-Ella, E.M., Farrag. A.A., Bakheit, A.A., Ibrahim, H.A. and El-Hussaini, A.H., 1994: New treatment of groundwater aquifers in Wadi El-Mathula area, Eastern Desert, Egypt, using geophysical and hydrogeological methods. 2nd Int. Conf. Geology of the Arab World, Cairo University.

Aggour, T.A. and Sadek, M.A., 2001: The recharge mechanism of some cases of the different groundwater aquifers, Eastern Desert, Egypt. Mans. Sci. Bull. (C Nat. Sci. and Phys. Sci.), Vol. 28 (1).

Aggour, T.A., 1990: Response of geomorphological and geological features on groundwater in Wadi Araba, Eastern Desert, Egypt. M. Sc. Thesis, Fac. Sci. Ain Shams Univ. 179 p.

Aggour, T.A., 1997: Impact of geomorphological and geological setting on groundwater in Qena-Safaga district, Central Eastern Desert, Egypt. Ph. D. Thesis. Fac. Sci., Ain Shams. Univ. 355 p.

CONOCO, Corp., 1987: The geological map of Egypt. Scale 1:500.000, Bernice Quadrangle, General Petrol. Corp., Cairo, Egypt.

Dabash, M.H.A., 2004: Evaluation of water resources in the area between Quseir-Safaga, northern Red Sea coast, Egypt. M. Sc. Thesis submitted to Fac. Sci. Assiut Univ., 176 p.

Desert Research Center (DRC), 2002: Mineral, petroleum and groundwater assessment program. DRC, Cairo, Egypt. Aid Project 2633-0105, Groundwater investigation in the Eastern Desert: Volume II: Groundwater supplies in selected mining and petroleum districts, A: Wadi Araba (143 p), B: Ras Gharib-Ras Gemsa (194 p) and C: Quseir-Mersa Himeira (256 p).

Egyptian Geological Survey and Mining Authority (EGSMA), 1981: Geologic map of Egypt 1 : 2,000,000.

Egyptian Geological survey, 1981: Geologic map of Egypt, Scale 1: 2,000,000.

Egyptian Meteorological Authority, 2000: Meteorological Department. 1980-2000: Climatic Normals of Egypt: Int. Reports.

El Fakharany, M.A., 1989: Hydrogeology of Quseir area and its vicinities. M.Sc. Thesis, Fac. Sci., Cairo univ., 150p.

El Ghazawi, M.M., and Abdel Baki, A.A. 1999: Groundwater in Wadi Essel basin, Eastern Desert, Egypt. Bull. Fac. Sci. Menofiya Univ. Egypt, Vol. V pp. 25-44.

Elewa, H.H. and Fathy, R.G., 2005: Recent recharges possibilities determination of the Pleistocene aquifer system of Wadi El-Assiuti basin, Egypt, using Hydrogeochemical and environmental isotopic criteria, Egypt. J. Appl. Geophysics, Vol. 4, No. 2, September 2005, pp. 251-267.

Elewa, H.H., 2000: Hydrogeology and hydrological studies in Halaib-Shalatin area, Egypt, using remote sensing technology and other techniques. Ph. D. Thesis submitted to Fac. Sci. Ain. Shams Univ., 282 p.

Elewa, H.H., 2005a: A strategy for optimizing groundwater recharging by flood water in the northwestern coastal zone of the Gulf of Suez, Egypt. 5th International Symposium on Management of Aquifer Recharge (ISMAR 5), 10-16 June, Berlin, Germany.

Elewa, H.H., 2005b: Prediction of future water levels of the Pleistocene aquifer system of Wadi El-Assiuti area, Eastern Desert, Egypt. J. of Geol., V. 49, pp. 159-175.

Elewa, H.H., 2006: Determining priority areas for the sustainable development of Wadi El Assiuti Valley, Eastern Desert, Egypt, using hydrogeological, remote sensing and GIS criteria. Egypt. J. of Remote Sensing & Space Sci., V. IX, pp. 79-92.

Elewa, H.H., Fathy, R. G. and Zaghloul, E. A., 2000: Groundwater potential of the southern part of Wadi Qena basin, Eastern Desert of Egypt using remote sensing techniques. Egypt. J. of Remote Sensing & Space Sci, V. 3, pp. 135-152.

Elewa, H.H., Fathy, R. G. and Zaghloul, E. A., 2003: Potentiality of water resources of Halaib-Shalatin area, south Eastern Desert, Egypt., 2nd Int. Symposium on Integrated Water Resources Management: Int. Assoc. of Hydrol. Sciences, ISHS, South Africa.

El-Gindy, A., El-Shemi, A. and El-Sayed E., 1999: Geology of the groundwater resources in the northern part of Upper Egypt and its impact on the aquifer potentials. The first Int. Conf. on the Geology of Africa. Vol. (1), pp. 481-498, Assiut, Egypt.

El-Shamy, I.Z., 1985: Quantitative geomorphology and surface water conservation in Wadi Matula-Wadi Abbadi area, Central Eastern Desert. Annals of the Geol. Surv., Egypt, Vol. XV, pp. 349-358.

El-Shamy, I.Z., 1992: Recent recharge and flash flooding opportunities in the Eastern Desert, Ann. Geol. Surv., Egypt, pp. 323-334.

El-Shazly, E.M., 1977: The geology of the Egyptian regions. In A. E. Nairm W. H. Kones & F. G. Stehli (eds), the ocean basins and margins. Plenum Press. 4 (A). pp. 379-444.

El-Shazly, E.M., 1985: Groundwater studies in Wadi Al-Allaqi environs. Remote Sensing Center, Cairo.

Fathy, R.G. and Elewa, H. H., 2002: Hydrogeoelectrical investigations conducted at Wadi Hodein, Wadi Ibib and Wadi Serimtai located at the southeastern part of Egypt, Al-Azhar Bull. Sci. Vol. 13, No. 2 (Dec.): pp. 15-38.

Fathy, R.G. and Nagaty, M. A., 2003: Contribution to the hydrogeological and hydrochemical characteristics of the Nubia Sandstone aquifer, Wadi Abu Saafa, Shalatein area, south eastern Desert, Egypt. Ain Shams Sci. Bull., Vol. 41, pp. 77-97.

Fathy, R.G. and Nagaty, M. A., 2005: Contribution to hydrogeochemical characteristics of the groundwater aquifer, in Shalatein-Abu Ramad area, south eastern Desert, Egypt. J. Appl. Geophys., Vol. 4, No. 2, September, 2005, pp. 143-153.

GARPAD, 1985: (General Authority for Rehabilitation Projects and Agricultural Development). Internal report on Wadi Qena, groundwater studies, First Phase, Cairo, 95 p. (in Arabic).

GARPAD, 1995: (General Authority for Rehabilitation Projects and Agricultural Development). Technical Unpublished Report About Wadi El Assiuti Groundwater.

GEOMIN, 1971: Mining Geology of States Bucharest-Romania. Preliminary report on hydrogeological investigations performed in Hamrawein area., 50 p.

Gomaa, M. A., 1992: Hydrogeological studies between Quseir-Safaga area, Eastern Desert, Egypt. M. Sc. Thesis submitted to Fac. Sci. Ain Shams Univ., 150 p.

Gomaa, M.A., and Aggour, T. A., 1999: Hydrogeological and hydrogeochemical conditions of carbonate aquifers in the Gulf of Suez region, Egypt. Assiut Sci. Bull., Vol. 28, No. 2, Fac. Sci., Assiut Univ., Egypt. pp. 191-214.

Hefny, K., Farid, S. and Hussein, M., 1991: Groundwater assessment in Egypt. Round Table Meeting (RTM-91) "Planning for groundwater development in arid and semi arid regions. pp. 93-103.

Issawi, B., 1983: Ancient rivers of the Eastern Egyptian Desert. Episodes, Vol. No. 2.

Mina, M., Shatya, F., Mansour, S. and Hassan, A., 1996: Exploration for groundwater at the area between Halayieb and Shalaten, Eastern Desert, Egypt. Proc. Geol. Surv. Egypt Cenn. Conf., pp. 581-598.

Misak, R.F. and Abdel Baki, A.A., 1991: Classification of Phanerozoic aquifers in the Eastern Desert with emphasis on the newly explored ones. Bull. Fac. Sci. Assiut Univ. 20 (2-F). pp. 19-38.

Mousa S.E., Attia F.A., and Abu El Fotouh, 1993: Geoelectric investigation for groundwater at Wadi El-Asyuti, Egypt, Ain Shams Science Bulletin, Vol. 31 pp 425-439.

NARSS 2005: (National Authority for Remote Sensing and Space Sciences). Water and land resources assessment for the Eastern fringes of Assiut district and its adjacent areas, Egypt, using geoinformation technologies. Internal unpublished final report, 253 p.

NARSS, 1997: (National Authority for Remote Sensing and Space Sciences). Hazard assessment and mitigative measures of flash flooding on the Red Sea towns, Egypt. Scientific Report presented to the Red Sea Governorate, 294 p.

NARSS, 1999: (National Authority for Remote Sensing and Space Sciences). Water resources in south east Aswan and Wadi Allaqi areas. Internal un-published report, 25 p.

NARSS, 2000: (National Authority for Remote Sensing and Space Sciences). Using remote sensing applications in studying the natural resources in Halaib-Shalatin area. Project submitted to the Academy of Scientific Research and Technology, 300 p.

NARSS, 2001: (National Authority for Remote Sensing and Space Sciences). Intrusive dykes and its relation to the groundwater occurrence in the southeastern part of Egypt. Internal unpublished report. 30 pp.

NARSS, 2004: (National Authority for Remote Sensing and Space Sciences). Water resources assessment and future land use planning of the area located to the northwestern coast of the Gulf of Suez, Egypt, Internal unpublished final report of a research Project, 247 p.

NARSS, 2006: (National Authority for Remote Sensing and Space Sciences). Assessment of water and land resources in Wadi Qena basin for sustainable development. Unpublished internal report, 120 p.

Nasr, I.M., 1990: Geological and geophysical studies on the groundwater potentialities in the area between Ras Gharib and Ras Gemsa, A.R.E. M. Sc. Thesis, Faculty of Science, Al-Azhar Univ. 218 p.

Pirard, F. 1981: Red Sea Governorate Regional Plan, Final Report, Assessment of the water resources, Interim report (BRGM) (Bureau de Recherches Geologiques Et, Minieres). Vol. II, 205 p.

REGWA, 1991: Water resources for the area between Gharib and Quseir; Red Sea Development Organization. Submitted report to the Ministry of Housing, Development and New Communities. 271 p.

RIGW, 1999: (Research Institute for Groundwater). Hydrogeological Map of Egypt, 2nd Edition Scale 1:2,000,000. Ministry of Public Works and Water Resources, Cairo, Egypt.

Said, R., 1981: The geological evolution of the River Nile, Springer Verlag, Berlin, 151 p.

Said, R., 1990: The Geology of Egypt. A. A. Bulkema/Rotterdam. Brookfield, 734 p.

Sallouma, M.K., 1992: Groundwater studies on Queh-Sakia Basin in Quseir Area, Eastern desert, Egypt. Bull. Fac. Sci. Assuite Univ., 23 (2-F), pp. 181 - 198.

Selim, S.A., Bakheit, A.A., and Ibrahim, H.A., 1991: Geoelectrical measurements in Wadi Allaqi area, Eastern Desert of Egypt, and their groundwater significance. Bull. Fac. Sci., Assiut Univ. 20 (1-F), PP. 159-169.

Shahatto, S., 2003: Environmental impact of development in coastal areas: Desalination, internal report, Cent. of App. Geosc. (ZAG), U. of Tubingen, 45 p.

Shatta, A., and El-Fayoumy, I.F., 1970: Remarks on the hydrology of the Nile Delta. Proceedings of Hydrology of Delta Symposium, UNESCO, Vol. 2.

Sweidan, A.S. and Himida, I.H., 1991: Evaluation of hydraulic parameters for Dara area (Gulf of Suez), Egypt. Qatar Univ. Sci. J., 11: 307-330.

Tamer, M.A., 1974: Hydrogeology of A. R. E. and some changes occurring as a result of the construction of hydrotechnologic projects. ph. D. Thesis, Kieve University (in Russian).

Yan E., Wagdy A., Sultan M. and Becker R. 2004: Assessment of renewable groundwater resources in the Assiuty Hydrologic system of the Eastern Desert, Egypt, Second Regional Conference on Arab Water 2004, Action Plans for Integrated Development. pp 1-9.