Egyptian Geophysical Society
EGS Journal, Vol. 9, No. 1, 61-74 (2011)

HYDROGEOLOGICAL EVALUATION OF WADI QENA BY USING GEOELECTRICAL AND AERIAL PHOTOGRAPHIC TECHNIQUES

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تقييم هيدروجيولوجي لوادى قنا باستخدام التقنيات الكهربية و الصور الجوية

الخلاصة: يقع وادى قنا بالجزء الأوسط من الصحراء الشرقية لمصر حيث يجرى من الشمال الشرقى الى الجنوب الغربى بامتداد حوالى ٢٧٠كم فهو وادى معكوس الاتجاه حيث يصب في وادى النيل عند مدينة قنا. وتبلغ مساحة حوض وادى قنا ١٨٠٠٠كم^{٢} تقريبا. تهدف هذه الدراسة إلى تقييم الوضع الهيدروجيولوجى لحوض وادى قنا باستخدام كل من التقنيات الجيوكهربية والصور الجوية. فقد تم عمل دراسة مورفومترية تفصيلية باستخدام الخرائط الطبوغرافية بمقياس رسم ١: ١٠٠,٠٠٠ لمنطقة حوض قنا. تم رسم بيانات الوادى من موزايك يتكون من ٧٤٠ صورة جوية تغطى معظم حوض وادى قنا. كما تم أجراء ٤٣ جسة كهربية رأسية عبر المجرى الرئيسى لوادى قنا بطول ١٢٠كم وكذلك الفرعين الرئيسيين لوادى جردى ووادى فطيرة.
أوضحت التحاليل المورفومترية بأن الحوض الهيدروجرافى لوادى قنا له قيمة تكرارية منخفضة للمجارى المائية (٨٦٧ و ٠ كم$^{-١}$) وهذا يعنى ان الحوض فرصته ضعيفة لتجميع مياه الجريان السطحى مما يعطى فرصة أكبر للتخلل داخل طبقات الحوض خاصة وأن الحوض يميل الى الطول وحيث أن حوض وادى قنا يستقبل كميات كبيرة جدا من المطر سنويا لذلك فانه يعتبر واحدا من أكثر أحواض الصحراء الشرقية خطورة من ناحية شدة السيول الفجائية. ويتميز الجزءان الشرقى والأوسط لحوض وادى قنا بوجود صدوع رئيسية تأخذ أتجاه العقبة حيث تلعب دورا رئيسيا فى تغذية الخزان الرملى النوبى.
يتميز الجزء الشمالى للحوض بوجود اتجاهين للتشققات هما أتجاها خليجى السويس والعقبة مما يعطى فرصة أكبر لتغذية المياه الجوفية فى هذا الجزء. يعتبر الحجر الرملى النوبى هو الخزان الجوفى الرئيسى وهو خزان مقيد حيث أنه مغطى بطبقات غير منفذة. ويصل منسوب الماء البيزومترى ٣٠٠م فوق سطح البحر. تم تسجيل وجود مستودعين للمياه الجوفية عبر القطاع الرئيسى بوادى قنا الأول الخزان الضحل (خزان حشو الوديان) والآخر خزان عميق (خزان الحجر الرملى النوبى). كما توجد ثلاثة صدوع رئيسية عبر وادى قنا تؤثر على مستوى الماء الجوفى وسمكه.

ABSTRACT: *Wadi Qena Basin lies in the Central part of the Eastern Desert of Egypt. It runs from north-east to south-west for about 270 km long (obsequent wadi). It debouches into the Nile River at Qena City. Its watershed area reaches about 18000 km^2. The main task of this work is studying the hydrogeological setting of Wadi Qena basin by using both the morphometric, aerial photographic and geoelectric techniques.*
Detailed morphometric analysis was made using topographic maps (scale 1:100,000) for the whole Qena basin. A mosaic from 740 aerial photographic sheets was made covering most of the study basin. 43 vertical electric sounding (VES) stations were conducted along the main stream of wadi Qena (covering about 120 km) and two main tributaries (wadis Qerdy and Fateira sub-basins). The detailed morphometric analysis clarifies that Wadi Qena hydrographic basin has low stream frequency value (0.867 km^{-1}). This means that this basin has less possibility to collect surface water runoff. Accordingly, this situation gives more chance to the downward infiltration. The basin tends to be elongated. It has a relatively high bifurcation ratio (3.8). The basin has a vast area and receives annually too much water quantities to infiltrate all downward. Accordingly, this hydrographic basin is considered as one of the dangerous basins among the Eastern Desert in its flash flood phenomenon. The eastern and middle parts of Qena basin has the main trend of El Aqaba (NE-SW) that plays a principal role in recharging the Nubia Sandstone aquifer. The northern part of Qena basin has both Suez and Aqaba Gulf trends (NW-SE and NE-SW respectively) that may give a more chance for groundwater recharge in this zone. The main water bearing formation (Nubia Sandstone aquifer) is confining by the capping impermeable layers. The peizometeric water level is recorded to be about 300 m.a.s.l.
The drilled wells at the southern portion of that profile are detected to be flowing (artesian); while at the northern portion the well is of free table type. Two aquifers along the main profile of Wadi Qena were detected. The first is the shallow aquifer (at the wad fill which detected at the delta of the wadi, especially at Aras hand dug well), and the second is the deep and the main aquifer (Nubia Sandstone) which detected along the profile.
Three faults were detected along Wadi Qena (between sites of VES No. 1 to VES No. 24), which affect the ground water level and thickness of the water bearing formation.
Keywords: *Wadi Qena, morphometric analysis, aerial photography, geoelectric, hydrogeology, wadis Qerdy and Fateira.*

INTRODUCTION

Wadi Qena hydrographic basin lies in the Egyptian Central Eastern Desert (Fig. 1). It extends from north to south for about 270 km long. It locates between Lat. 26°05' and 28°05'N and Long. 32°10' and 33°35' E. It debouches into the Nile River at Qena City. Its watershed area reaches about 18000 km^2. The basin occupies an area of arid climatic condition where it is characterized by hot summer, warm winter, low precipitation and high evaporation rates.

Wadi Qena is considered as an obsequent wadi, where its drainage direction takes the southern direction, i.e. against the flow direction of the Nile River. It is initiated along a huge anticline, which has affected by complicated fault systems. This anticline extends in a N-S direction for more than 200km. The core of the concerned anticline lies at the outlet of Wadi Umm Omaiyed (in the NE side of the basin), where the basalt and diorites are exposed on the surface. The western limb of this anticline is mainly composed of Jurassic-Eocene rocks while the Upper Cretaceous-Eocene sedimentary rocks represent its eastern limb. Wadi Qena depression has been dissected by three normal fault systems, which are responsible in the initiation of Wadi Qena hydrographic basin. The E-W faults trend is concentrated in the extremely eastern portion of the basin, especially in the area which has been covered by the basement rocks between latitudes 26°30' and 27°30'. These faults are responsible in the initiation of the channel courses of Wadis Quriya and Fateira sub-basins. NW–SE fault system bounded widely the main channel of Wadi Qena from its western side for about 75 km from Gebel Aras to the outlet of Wadi Umm Lasife. There is a fault of this type extends from Wadi Umm Glu to Gebel Naqaa El Tir. There are four faults run in this direction bound Gebel Abu Had. Two of them bound the western side of Gebel Abu Had and throw to the eastern direction, while the other two faults bounded the eastern side and throw to the western direction. These four faults give Gebel Abu Had the synclinal form. NE–SW faults system is represented at the eastern side of Gebel El Sarain and extends for 5-7 km. They throw towards the west with about 10-20 m.

Wadi Qena Basin is occupied by different lithologic formations ranging in age from the Precambrian to the Quaternary. The Precambrian rock exposures run nearly in the NNE-SSW direction and widely distributed in the extremely eastern side of that basin, where those exposures are represented by basement rocks of igneous and metamorphic types. These basement rocks are overlain unconformably by the Phanerozoic sediments in both the eastern and western sides of the basin. The sedimentary rocks are made up of Sandstone, shale, limestone, chalk, conglomerates and alluvial sediments. Different workers have previously described the stratigraphic succession of the investigated area. Among them are made of Schwnfurth (1897), Frass (1900), Baron and Hume (1902), Ball (1913), Said (1962), Issawi and Jux (1982) and Klitzsch et al. (1989). Figure (2) shows a geologic map of the area and its vicinities.

There is nonconformity between the basement rocks and the overlying sedimentary rocks. A disconformity between the Thebes Formation (Lower Eocene) and the overlying Nakheil Formation (Oligocene) lies in the eastern inland hilly areas. There is also an angular unconformity between the Pliocene deposits and the Upper Cretaceous rocks at the lower reaches of Wadi Qena. This is recognized at the foot slopes of El Maaza and El Ababda plateaux.

The main aquifer in the area of study is the Nubia Sandstone aquifer and to a less extent the alluvial aquifer. The groundwater in the Nubia Sandstone aquifer is mainly fresh to brackish. The total average salinity value is 1500 ppm, while the total salinity in the alluvial aquifer is mainly 10,000 ppm (saline water). The alluvial sediments are the main source of salts in groundwater. The presence of $CaCl_2$, $MgCl_2$, NaCl salts are an intercalation of leaching marine salts. The hypothetical salts in the groundwater of the Nubia Sandstone aquifer are mainly terrestrial salts [Na_2SO_4 and $Na(HCO_3)$]. The presence of these terrestrial salts indicates continental source of salts in the Nubia Sandstone aquifer.

The main task of this work is studying the hydrogeologiclal setting of Wadi Qena basin by using both the geoelectric and aerial photographic techniques. Detailed morphometric analysis was made by using topographic maps scale of 1:100,000 for the whole Qena basin area. For the aerial photographic study, a mosaic from 740 photogeologic sheets was made covering almost of the study basin. The mosaic was processed, analyzed and interpreted. In the geoelectric resistivity study of 43 vertical electric soundings (VES) were conducted along the main stream of Wadi Qena (for about 120 km) and two main tributaries (wadis Qerdy and Fateira sub-basins). The interpretation of these soundings leads to constructing four geoelectric cross sections.

GEOMORPHOLOGIC SETTING

- Landforms

The existing land features in Wadi Qena Basin are developed as a result of the combined influences of both endogenetic and exogenetic processes. Such land features have a direct impact on the hydrogeologic conditions of the concerned area; watershed areas, water collectors and discharging basins.

Geomorphologically, the surface of the study area can be subdivided into five main geomorphologic units (DRC, 1995) as follows (Fig. 3):

1- The high mountainous terrain.

2- El Maaza Plateau.

3- The isolated hills

4- The pediplains.

5- The hydrographic sub-basins.

1- The high mountainous terrain is considered as the main catchment area for the eastern tributaries of Wadi Qena hydrographic basin, where it is drained by wadis Quriya, Qerdi, Fatira, Hammad and Abu Had. These tributaries are initiated from the main water divide between the Red Sea and Nile River mega-basins (El Shazly et al., 1991).

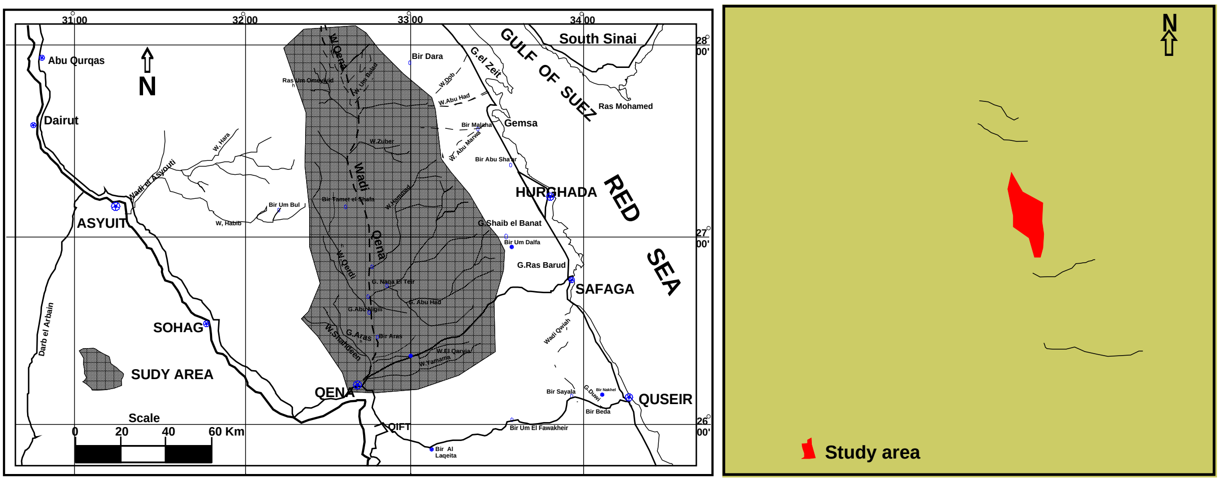

Fig. (1): Location map of the study area (Wadi Qena).

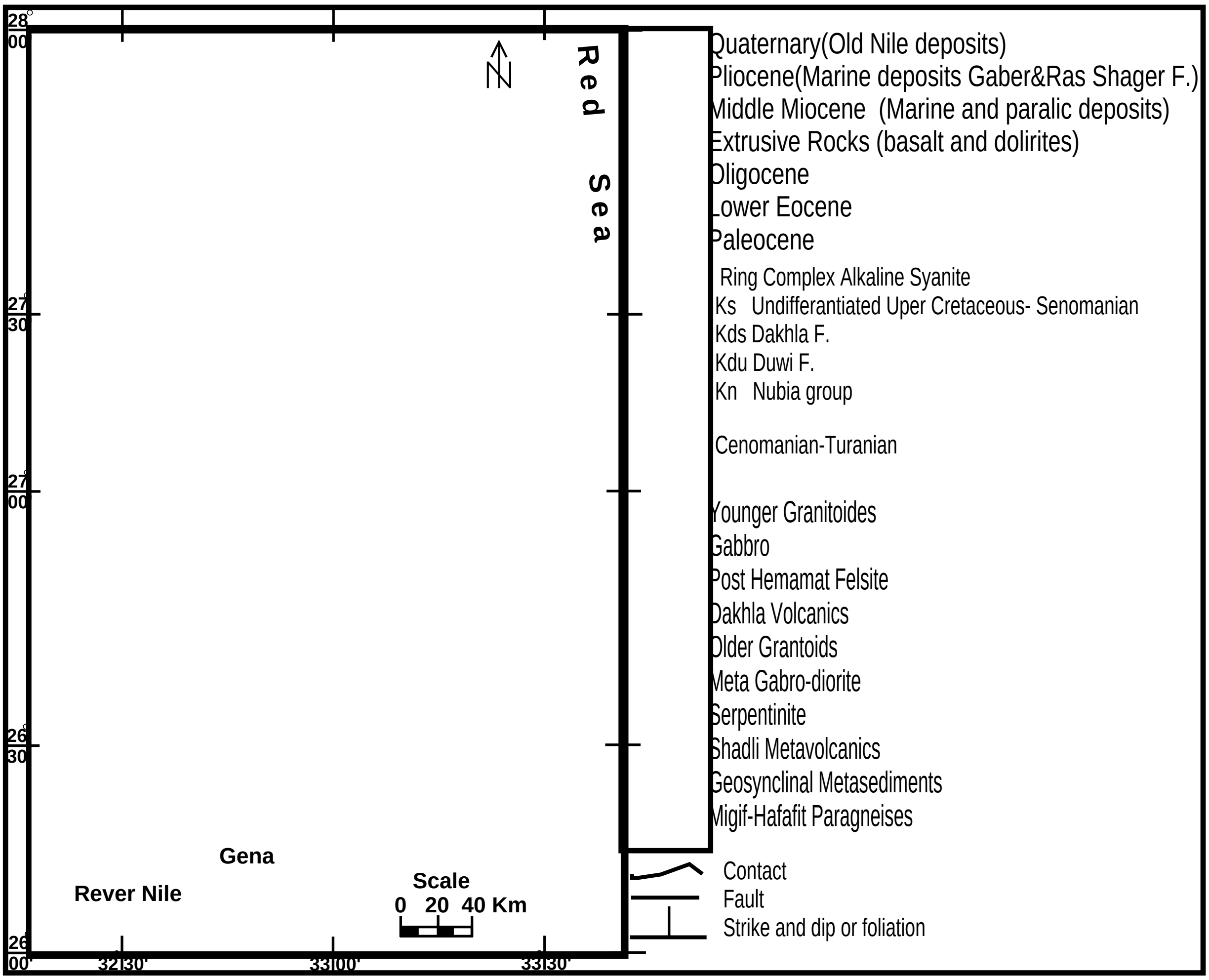

Fig. (2): Geologic map of Wadi Qena area and its vicinities (after the geologic survey of Egypt 1978).

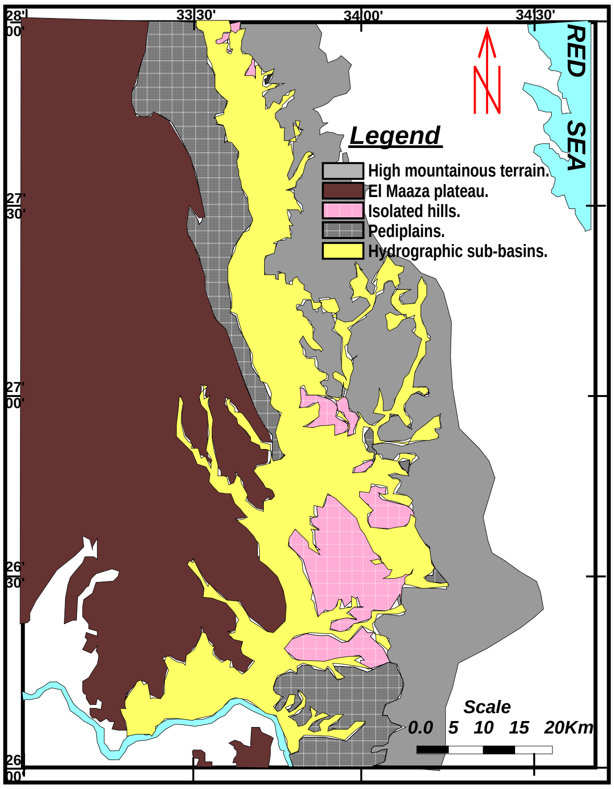

Fig. (3): The main geomorphologic units of Wadi Qena basin (after DRC, 1995).

2- El Maaza plateau is composed mainly of carbonate rocks with Sandstone, shale and marl interbeds, which related to the Upper Cretaceous, Paleocene and Eocene ages. Its strata dip gently towards the western direction. The top surface of this plateau is built up of Thebes Formation, which is affected by dense joints and faults network. This formation shows karstic features as sink holes and caves, due to the action of the ancient fluvial periods. El Maaza plateau is drained by some tributaries of Wadi Qena running nearly in N-S and NW-SE directions, e.g. wadis Shahadine, Gerdi, Umm Glu and Qena.

3- The isolated hills are dominated in the downstream portion of Wadi Qena and concentrated in its eastern side, e.g. Gebels Nagaa El Tir, Abu Had and El Sarai. These hills are built up mainly of Upper Cretaceous (Sandstone, shale and phosphate), Paleocene (shale and chalk) and Lower Eocene limestone (Thebes Formation). They form local catchment areas, where they are drained by some tributaries and debouch directly into the trunk channel of Wadi Qena, e.g. wadis Nagaa El Tir, Abu Had, Quriya and Umm Silimate.

4- The pediplains represent the foreland areas, which flank the western side of the high mountainous terrain and the eastern cliffs of the Maaza Plateau (the downstream portions of the sub-basins of Wadi Qena). Generally, they slope gently towards the main trunk of Wadi Qena. These pediplains are built up of Quaternary gravels, which are made of basement and carbonate fragments. These sheets are dissected by some broad drainage courses.

5- The hydrographic sub-basins represent the main water collector and the principal sources of annual fresh water supplies. These sub-basins can be easily distinguished into eastern and western sub-basins groups. The eastern sub-basins group drains mainly the high mountainous terrain and are represented by wadis Quriya, Fatira, Hammad and Abu Had. The western sub-basins group, which drains the eastern cliffs of the Maaza plateau and are represented by wadis Shahadine, Gerdi and Umm Glu.

The drainage lines constituting the afore-mentioned sub-basins, exhibit low average gradient value (1:335) and show different types of drainage patterns. The dendritic drainage pattern is prevailing at the high mountainous terrain, while the sub-parallel drainage pattern is well distinguished at the middle reaches of the hydrographic sub-basins. On the other hand, the radial drainage pattern is represented at the top surface area of the isolated hills, whereas the braided pattern is prevailing in the downstream portion of Wadi Qena hydrographic basin.

Morphometric Analysis of Wadi Qena Drainage Basin:

Wadi Qena is one of the most outstanding water collectors in the Eastern Desert. It consists of numerous tributaries, which are differentiated into eastern and western ones (Fig. 4). These tributaries have steep to gentle steeply well-defined channels and join together to form the main trunk of Wadi Qena. Along its course, which attains about 270 km in length, it exhibits variable morphologic features. This variability is attributed to the impact of the local lithologic, tectonic and topographic features (Aggour, 1997). The morphometric analysis of Wadi Qena hydrographic basin is estimated based on the drainage network map scale 1:100,000 (Fig.3). The drainage system is classified according to Strahler ordering system (1964), while its morphometric parameters are given using Horton (1945), Melton (1957) and Schumm (1956) methods. These morpholometric parameters will be described briefly as:

2.1- Stream order:

The stream order of Wadi Qena hydrographic basin attains order 8 (Tab.1) and the total number of the drainage line segments equals 8234 lines. Accordingly, Wadi Qena Basin has high stream order and high number of drainage line segments, which means that it has a wide watershed area and high capability for the basin discharge.

2.2- Bifurcation ratio (R_b):

The bifurcation ratio is defined as the ratio of the number of a given order (Nu) to that of the next order (N_{u+1}) i.e. (Nu / Nu+1). Wadi Qena hydrographic basin has a mean bifurcation ratio of 3.8. This is related to shape outline. This basin shape allows the surface runoff to pass with moderate downward infiltration. Most of the sub-basins related to Wadi Qena hydrographic basin has bifurcation ratios range between 2.9 and 3.98, except Umm Selimate sub-basin (Tab. 3).

2.3- Drainage density (D):

It is defined as the relationship between the total length of all streams and the basin area (D = ∑L/A km^{-1}); (Tables 2 and 3). It is a good indicator to the permeability of the sub-soil material and also to the relief of the basin terrain. Accordingly, high drainage density reflects impermeable sub-soil material and rugged mountainous relief. Wadi Qena Basin shows a low drainage density value (0.867 km^{-1}), which indicates that it has mild topographic relief and its surface runoff water infiltrates downward through the areas covered by Sandstone rocks.

2.4- Stream frequency (F):

The stream frequency is the ratio of the total number of stream segments within a given basin to the total area of that basin (Horton, 1945). i.e. $F = \Sigma Nu / A_k\ km^{-1}$; (Tables 2 and 3). Basins of high stream frequency value tend to collect more surface runoff water, which increases the rate of water flow and discharge out of the basin. Generally, Wadi Qena hydrographic basin has low stream frequency value (0.457 km^{-1}). This means that this basin has less possibility to collect surface runoff water. Accordingly, this situation give more chance to the downward infiltration, especially the basin tends to be elongated, where it has a relatively high bifurcation ratio.

Table (1): Morphometric parameters of Wadi Qena hydrographic drainage basin.

St. Order	St No.	Stream Length km.	Average Stream length	Basin Area km^2	Frequency (F)	Total No. of Tributaries	Basin Density (D)	R' (m)	R m/km	Relief difference	Elongation Ratio Re
1^{th}	5893	8840	1.5	18000	0.457	8234	0.867	577			
2^{ed}	1816	4105	2.266								
3^{rd}	406	2273	5.6								
4^{th}	93	242	1.6								
5^{th}	15	63.3	4.22								
6^{th}	8	65	8.12								
7^{th}	2	15.8	7.9								
8^{th}	1	43	43								
total	8234	15647.1	1.9	18000	0.457	8234	0..867	577	0.0214	2.137	0.3893

Table (2): The bifurcation Ratio characteristics and cumulative number and its % of the analyzed basin.

Stream Order (U)	St. No.(Nu)	Bifurcation Ratio (Rb).	No. within each ratio No.	Average Stream Length	Rb.x No	Cumulative Number	Cumulative %
1^{st}	5893	--	--	1.5	--	8234	100
2^{ed}	1816	3.66	6599	2.266	24152	2341	28.43
3^{rd}	406	4.47	2222	5.6	9932.3	525	6.376
4^{th}	93	4.36	535	1.6	2332.	119	1.44
5^{th}	15	6.2	129	4.22	626.16	26	0.32
6th	8	1.88	26	8.12	15.26	11	0.134
7th	2	4	11	7.9	44	3	0.036
8th	1	2	3	43	6	1	0.012
Total	8234	Average 3.8					

Table (3): Geomorphological parameters of the hydrographic sub-basins in the study area using topographic maps of scale 1: 100,000.

Sub-basin	N_u								ΣN_u	Order k	Rb	Ak km^2	F km^{-2}	D km^{-2}	Lu km
	1	2	3	4	5	6	7	8							
1 .Umm Selimat	126	39	10	2	1	-	-	-	178	5		188.2	2.44	2.04	69
2 .Quriya	788	217	51	15	4	2	1	-	1078	7		1707	3	1.88	68
3 .Abu Had	98	21	5	1	-	-	-	-	125	4		163.5	2.63	2.08	135
4 .Fateira	1964	524	110	25	6	2	1	-	2532	7		3499	3.55	1.95	817
5 .Hamad	659	180	41	9	2	1	-	-	892	6		943.5	4.01	2.26	893
6 .Upper W.Qena	902	248	61	14	2	1	-	-	1228	6		1482	3.34	2.4	466
7 .Glu	98	25	3	1	-	-	-	-	127	4		172	2.67	2.19	188
8 .Girdi	866	266	73	18	5	1	-	-	1229	6		1377	2.71	1.96	165
9 . El Shahdine	394	114	28	7	1	-	-	-	544	5		652.9	3.56	1.98	594
Qena Basin	8234	1816	406	93	15	8	2	1	8234	8	0.389	18000			

Nu = Number of tributaries in each order F = Stream frequency Rb = Bifurcation Ratio
Ak = Total area of the basin D = Drainage density Lu = Stream length

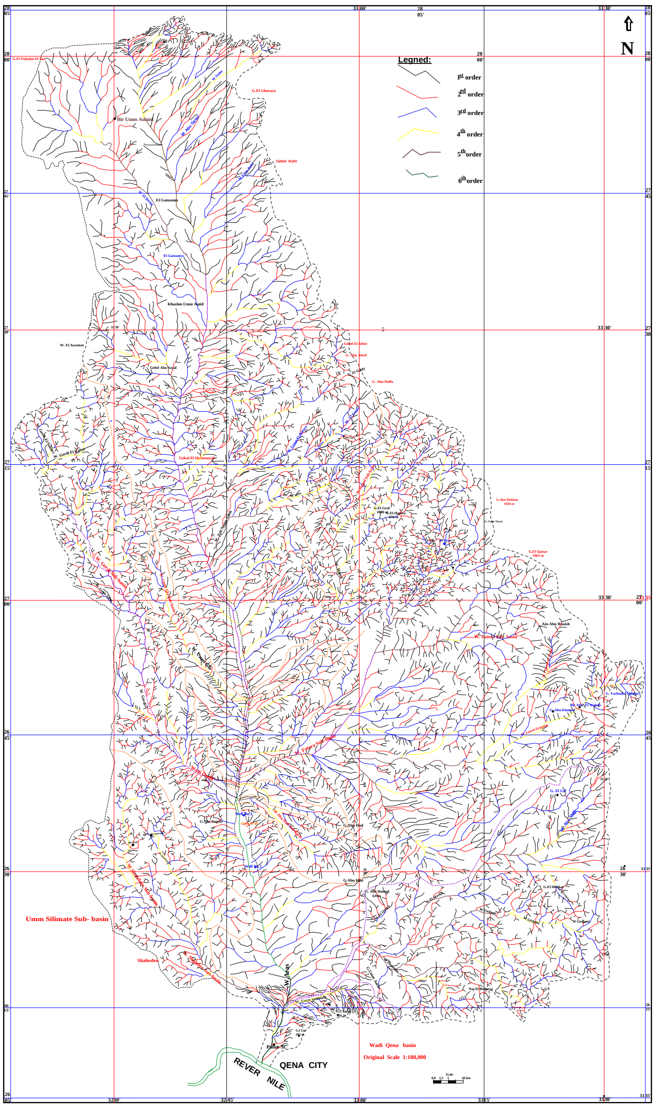

Fig. (3): Morphometric analysis of Wadi Qena hydrographic basin based on Topographic map scale 1:100,000.

2.5- Basin shape:

Wadi Qena basin tends to be elongated rather than circular shape, where it has an elongation ratio (Re) value of 0.62 and its circularity ratio (Rc) value attains about 0.45. These high values led to give chance to more water infiltration downward and recharge the existing aquifer if the sub-soil sediments are permeable. The basin has a vast area and receives annually too much water quantities to infiltrate all downward, accordingly this hydrographic basin is considered as one of the dangerous basins among the Eastern Desert in its flash flood phenomenon.

- The relief characteristics of the drainage basin (slope):

Relief ratio (R) = R'/L, where R' is the difference in the elevation between mouth of the basin and its headwater divide and L is the maximum length of the basin measured in the same units. The relief ratio is an expression of the drainage relief in a 2-dimensional form. The table (2) shows that the calculated value of the relief ratio in the studied basin equals 2.137 which referee to be elongated basin. The elongation ratio is found to be 0.3893 which means that this basin is elongated and far from circular. The shape of any basin is expressed by the elongation ratio (Re), between the diameter of a circular with the same area and the maximum length of the basin as measured for the relief ratio (R). The Table (3) shows that the calculated value of the relief ratio in the studied basin equal 0.0214 which refers to be elongated basin.

THE AERIAL PHOTOGRAPHIC STUDY

A systematic study of aerial photographs usually involves several basic characteristics of features shown on a photograph. The exact characteristics useful for any specific task and the manner, in which they are considered, depend on the field of application (Lillsand and Kiefer, 1987). In this study, the structure lineation of fractures and faults are the only considered features because of their importance for groundwater recharge.

Tone (or hue) refers to the relative brightness of objectives on photographs so the different sheets are processed under histo-equalization to eliminate the tonal differences between the photographic sheets where the interpreter can distinguish between features with similar reflectance based on their texture differences.

For the aerial photographic study, a mosaic based on 740 aerial photographic sheets was made covering most of the study basin. These sheets were scanned and mosaiced to get final scene these sheets and mosaicing them to get the final scene. The mosaic was enhanced processed, analyzed and interpreted.

The structural lineaments:

Each lineament, in the study area, was identified in terms of one of the following categories:

1- Topographically negative straight lineaments, representing joints, faults, fractures and shear zones.

2- Topographically positive straight lineaments, interpreted as dykes, dyke swarms and sometimes due to hydrothermal activity.

3- Slightly curved and sub parallel lineaments, indicating foliation and bedding trends, and

4- Circular features, delineating ring dykes.

The study of negative lineaments is concerned which reflects the fractures and faults affecting the study area. The lineaments' intensity (Fig. 4) shows that Qena basin can be divided into three zones. The lowest intensity zone is represented along the main trunk of the wadi that reflect the effect of clastics as Sandstone exposures and due to sealing effect of wadi fillings and alluvium cover. A second zone of medium intensity lies to the east due to the presence of brittle rocks of basement complex in the Eastern Desert. The third zone has a high intensity of lineation lies to the west where El Maaza plateau of intensive fractured limestone.

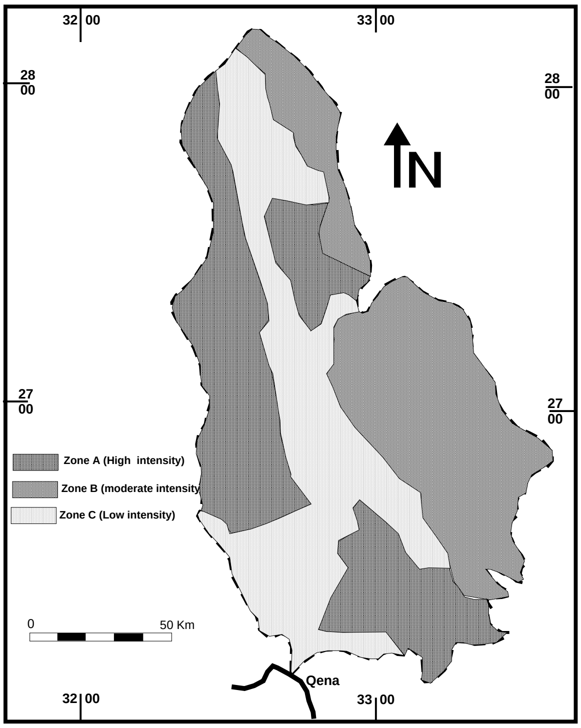

Fig. (4): Structure lineation intensity zones map for Wadi Gena basin

The study of fractures and faults trends (Fig. 5) reveals the presence of three zones. The first zone (A) presents in the east and middle parts of the basin. It has the main trend of El Aqaba (NE-SW) which is concentrated in the middle part of Qena basin. According to El Khateeb, (2004), Wadi Qena basin area is highly affected by the faults of NE-SW direction (Aqaba trend), especially in its eastern side, which is occupied by the basement rocks. This structural trend plays a principal role in recharging the Nubia Sandstone aquifer in Wadi Qena. The second zone (B), presents in the southern and northwestern parts of Qena basin. The fractures and faults in this zone has the Gulf of Suez trend (NW-SE). The third zone (C) presents in the northern part of Qena basin. The lineaments in this zone have both directions of Suez and Aqaba Gulf trends (NW-SE and NE-SW respectively). This may give a more chance for groundwater recharge in this zone.

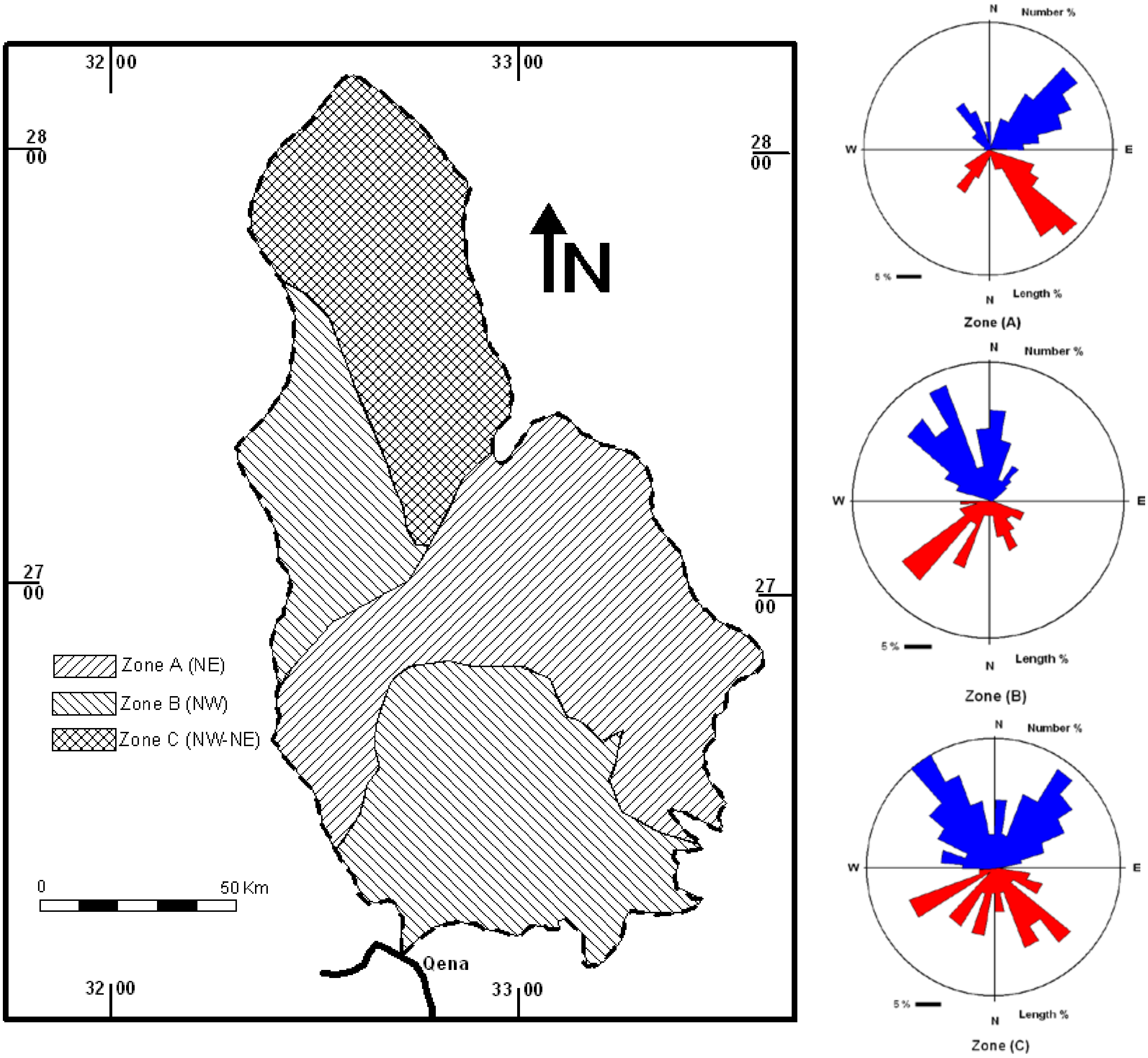

Fig. (5): Zones of strucyure lineation trends and their rose diagrams for Wadi Qena Basin.

Geo-electrical Resistivity Survey:

A total number of 43 vertical electrical sounding (VES) stations carried out in the study area. The sounding stations were distributed along the main channel of Wadi Qena, in such a way that a reasonable coverage can be obtained for the middle and lower stream portions of the wadi. Seven VES'es were carried out traverses Wadi Qena in some localities where the wadi is wide (Fig.6). Some of the sounding stations are located beside the water wells that existed in the main stream (6 wells). The Schlumberger 4-electrode configuration (array) was used with maximum distance between the current electrodes (AB) ranges from 2000 to 4000 m. According to the available geologic and hydrogeologic information, the current electrodes spacing is the most suitable and sufficient to reach at the Nubia Sandstone (water-bearing formation) and reach the basement rocks specially in the middle portions of Wadi Qena. The distance between the successive soundings stations varies from 4 to 6 km. The vertical electrical sounding curves were drown in the field from the relation between the apparent resistivity (ρa) and the half spacing between the current electrodes (A&B) on bilogarithmic papers each cycle is 6.25 cm.

The interpretation of the vertical electrical sounding curves deals with the followings:

- Subsurface formations and structures.
- Lateral and vertical variations of the subsurface formations.
- Lateral and vertical variations of the water-bearing formation.
- The type of the ground water aquifer
- Suggestion of drilling new water wells.

Qualitative interpretation:

In order to build preliminary picture of the concerned goelectrical layers a qualitative interpretation through a rapid outlook of the resistivity layers. This can be achieved by comparing the type of the apparent rsistivity curves allover the area which depicting the probable variations of the apparent resistivities and thicknesses of the different geoelectric layers. The general shapes of these curves along the main stream of Wadi Qena are mainly KH, AAH and KAH types and secondary AA, AKH, KHA and QH types. Along Wadi Gerdy the general curve types is AAH and less extent the KAAH, KQA and KAH curve types, while along Wadi

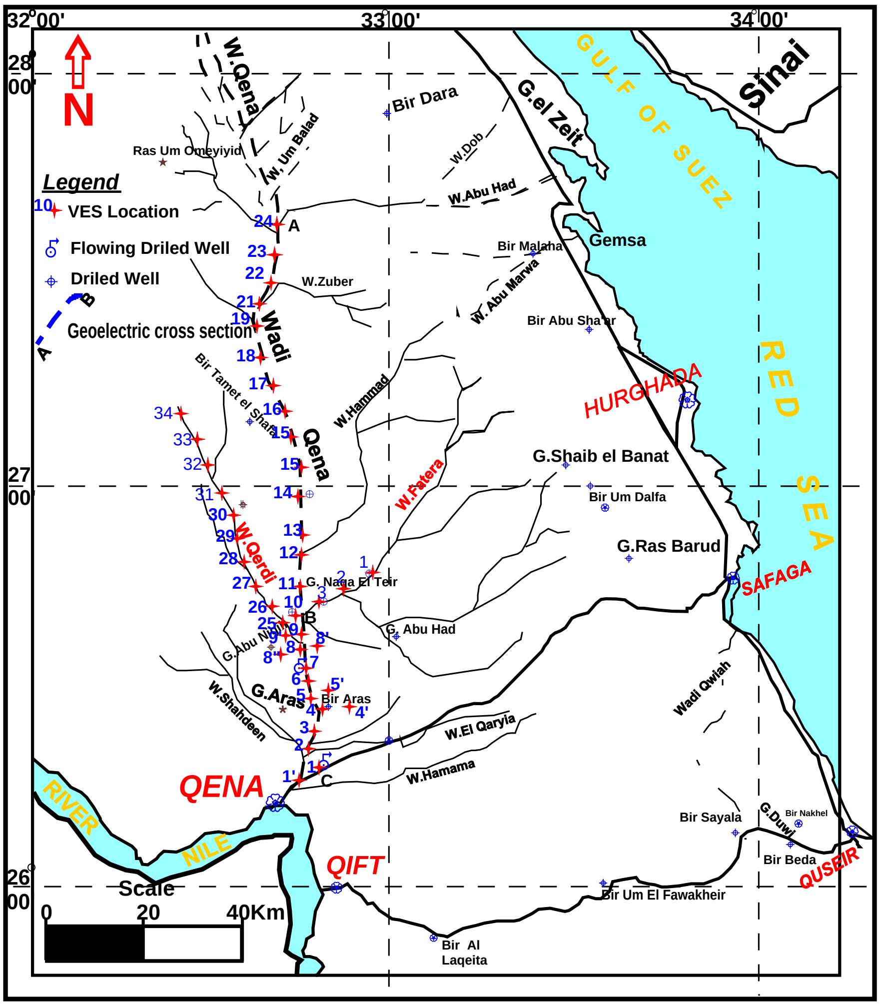

Fig. (6): Location map of the VES stations and locations of the geoelectric cross sections.

Fatera the curve type was KQH. These shapes correspond to the geologic sequence of the subsurface formations of limestone, shale, Sandstone and the basement.The shape of the sounding curves reflects the following:

- The sedimentary rock *succession* increases towards the south of Wadi Qena.
- The thickness of the shaly beds decreases towards the north of Wadi Qena as well as the basement rocks were recorded where *both* directions of Suez and Aqaba fracture trends presents that give a more chance for groundwater recharge.
- The sedimentary succession was affected by structures.

These curve types can be used to build the preliminary geelectrical model for quantitative interpretation. The results obtained from qualitative interpretation of the different regions, the number of the geoelectrical layers and their directional variation, are of great help in carrying out the quantitative interpretation.

Quantitative interpretation

Quantitatively, the vertical electrical sounding (VES) curves were interpreted by using two computer programs (Zohdy (ATO), 1989 and Van Der Velpen (Resist), 1988) to obtain the best results from the field curves and to construct the proper geoelectrical and hydrogeological sections in the study area. The interpreted data of each VES was represented as layers exhibiting resistivities and thicknesses for the vertical succession at each VES station.

The interpreted data of the VES curves were plotted as four geoelectrical cross sections, two along the main stream of Wadi Qena and the third along Wadi Qerdi, while the fourth along Wadi Fatera. These sections were constructed to estimate the geologic sequence and the lateral variations for different geoelectrical layers.

Geoelectrical cross sections along Wadi Qena:

Two geoelectrical cross sections along the main stream of Wadi Qena were constructed connecting 24 VES stations with distance reach 115 km long from Qena- Safaga road towards the upstream of the wadi (Figs. 7 & 8). These two sections can be described as a generalized geoelctrical succession of 4 to 6 geoelctrical layers as follows:

- *The surface layer (wadi fill)* has resistivity ranges from 70Ω.m to 2100Ω.m. The presence of the low resistivity at the location of some soundings is due the nature of the soils on the surface and the presence of plants and humidity. The thickness of this layer ranges from 6 to 14 m.
- *The second geoelectrical layer* has electrical resistivity values *vary* from 2.5 Ω.m to 1300Ω.m and its thickness ranges between 135 and 175 m. It is correlated to be an intercalation of sandy clay to clayey sand bed.
- *The third geoelectrical layer* is characterized by resistivity ranges from 31 Ω.m to 400 Ω.m and thickness ranges from 50 m. to 75 m. Its thickness can be correlated to limestone bed.
- *The fourth geoelectrical layer* is a thick bed with low *resistivity* (which ranges from 2.5 Ω.m to 15 Ω m). Its thickness ranges from 60 m. to more than 80m. It can be correlated to intercalation of shale, clay and limestone beds which acts as a confining layer over the underneath Nubia Sandstone aquifer.
- *The fifth geoelectrical layer* has resistivity ranges from 11 Ω m to 400 Ω m and it is full penetrated only at three VES sites only at the upstream portion which ranges from 220 to 240m. In the downstream portions (between the sites of VES No. 10 to VES No. 13). This layer was not full penetrated and represents the bottom of the geoelectrical sections where the depth to its upper surface increases towards the downstream of Wadi Qena. This layer is correlated to be Nubia Sandstone which is the main water bearing aquifer in the region.
- *The sixth* geoelectrical layer was detected only at the upstream portion at the VES sites where the Nubia Sandstone is full penetrated (between the sites of VES No. 14 to No. 24. This layer has resistivity values exceeds 1000 Ω m and considered as the bottom of the Nubia Sandstone aquifer. It can be correlated to the basement rocks.

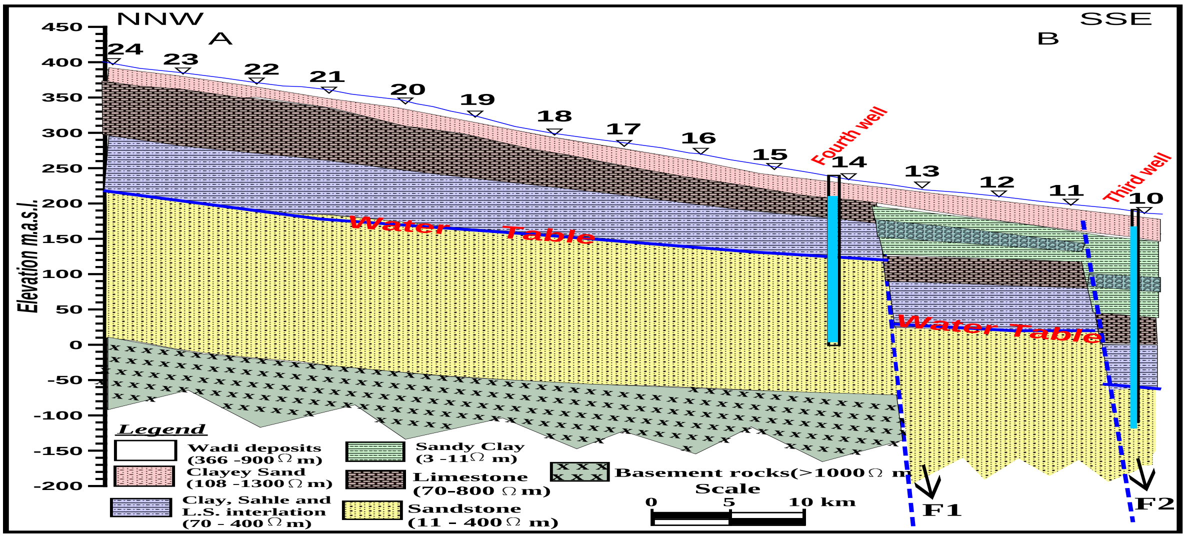

Fig. (7): Geoelectric cross section (A-B) along the main stream of Wadi Qena.

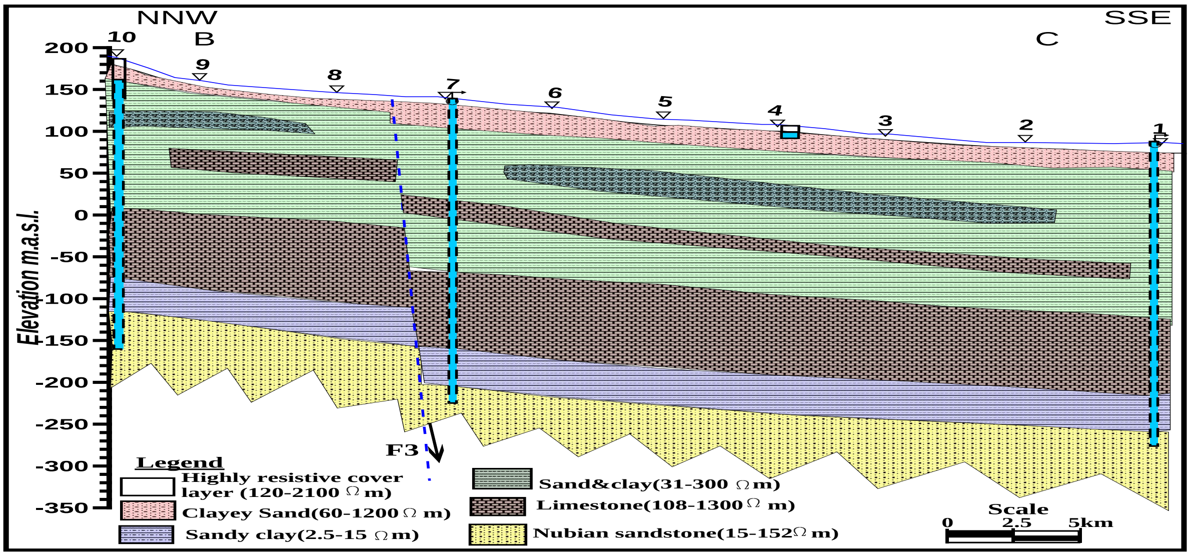

Fig. (8): Geoelectric cross section (B-C) along the main stream of Wadi Qena.

From the previous description the following main points can be concluded:

- The groundwater along that profile was detected as two aquifers; the shallow aquifer (at the wadi fill which detected at the delta of Wadi Qena between VES No. 1 to VES No. 5, especially at Aras hand dug well), and the second is the *deep* and the main aquifer (Nubia Sandstone) which detected along the profile.
- Three faults were detected F1, F2 and F3 which affected the *groundwater* level and thickness of the waterbearing formation along that profile.
- The main water bearing formation (Nubia Sandstone aquifer) is confining by the capping impermeable layers. The peizometeric water level is recorded to be about 300 m.a.s.l.
- The drilled wells at the southern portion of that profile is detected to be flowing (artesian); (between the sites of VES No.1 to *VES* No.7), while at the northern portion the aquifer is of free water table type.

- Geolectrical cross section along Wadi Qerdi:

This wadi is a main tributary of Wadi Qena and it runs in NW-SE direction. It drains its water to the main stream of Wadi Qena (at the location of Qena Wall) at km 45 from Safaga-Qena asphaltic road. Its length reaches about 60 km. 10 VES’es were conducted along the main stream of Wadi Qerdi. The distance between each two successive VES’es is about 5 km. The geoelectrical section along Wadi Qerdi can be described as follows (Fig. 9):

- *The dry surface geoelectric layer* has resistivity ranges from 600 Ω m to 2400 Ω m and its thickness ranges from 4 to 7 m. It may be composed of wadi deposits (silt, sand and boulders.
- *The second geoelectrical layer* has electrical resistivity varies from 6 Ω m to 19 Ω m and its thickness ranges between 135 and 275 m. It is correlated to an intercalation of sandy clay to clayey sand bed.
- *The third geoelectrical layer* attains resistivity between 110 Ω m and 1300 Ω m. Its thickness is about 90 m *and* it is composed of limestone rocks.
- *The fourth geoelectrical unit* has electric resistivity of 25 Ω m–43 Ω m and its thickness is about 50 m at the sites of VES No.'s 10, 25, 26 and 27, while, its *bottom* is not detected at the other VES sites. It may be composed of sand and clay deposits.
- *The fifth geoelectrical layer* (the last reached unit), has resistivity ranges from 11Ω.m to 33 Ω.m. It is detected *only* the down stream portion (sites of VES No.'s 10, 25, 26 and 27). Its lithology may be composed of saturated Nubia Sandstone and its bottom was not reached.
- *In Wadi Qerdy* the water bearing formation becomes *more* deeper due to the elevation of the ground surface and the penetrated depth reached that water bearing formation at the sites of the VES's No. 28 till No. 33, while it is detected at the locations of soundings No. 25, 26 and 27 (at the southern portion of that wadi).

- Geolectrical cross section along Wadi Fatera:

Wadi Fatera is one of the main tributaries of Wadi Qena. It runs in W-E direction and drains its water to the main stream of Wadi Qena (at the location 2 km from Qena Wall) at km 47 from Safaga- Qena asphaltic road. 4 VES’es were conducted along the main stream of this wadi. The distance between each two successive VES’es is about 6 km. The geoelectrical section along Wadi Fatera can be described as follows (Fig. 10):

- *The dry highly resistive cover* attains 250 Ω.m to 600 Ω.m *and* its thickness varies from 6 to 11m.
- *The second geoelectrical layer* has electrical resistivity varies from 6 Ω m to 45 Ω.m and its thickness is

about 135 m. It is correlated to be an intercalation of sandy clay to clayey sand.

- *The third geoelectrical layer* attains resistivity between 7 Ω.m and 55.Ω m. Its thickness is about 90 m. which is correlated to be limestone bed.
- *The fourth geoelectrical unit* has electric resistivity of 110–1300 Ω.m and its thickness is about 50 m. It may be composed of sand and clay deposits.
- *The fifth geoelectrical layer* (the last reached unit), has resistivity ranges from 25 Ω.m to 43 Ω.m. Its lithology may be composed of Nubia Sandstone where its bottom was not reached.
- *In Wadi Fatera* the groundwater was detected as Nubia Sandstone formation in all the sites of conducted soundings.

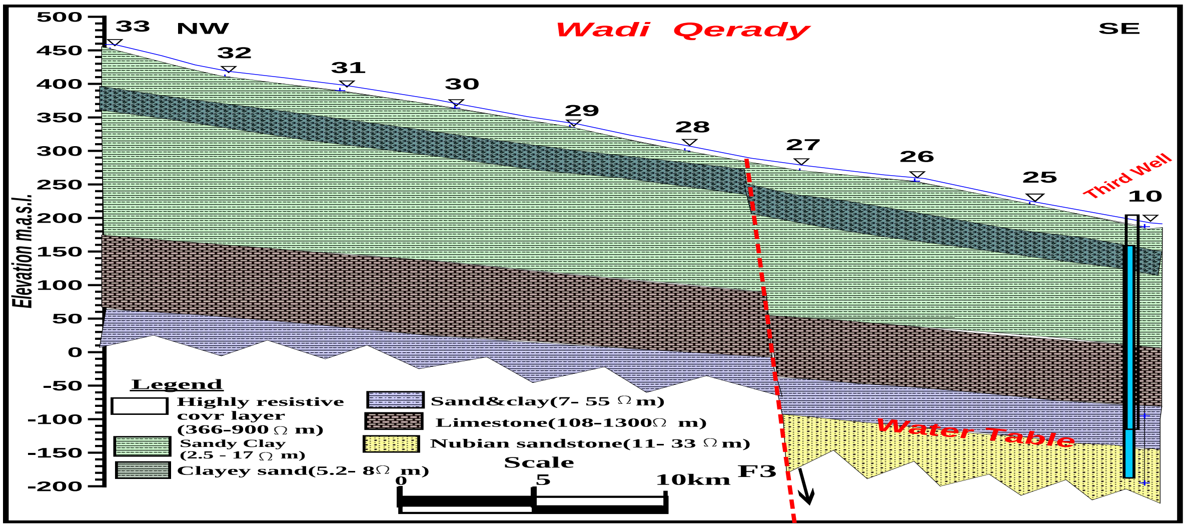

Fig. (9): Geoelectric cross section along the main stream of Wadi Qerdi.

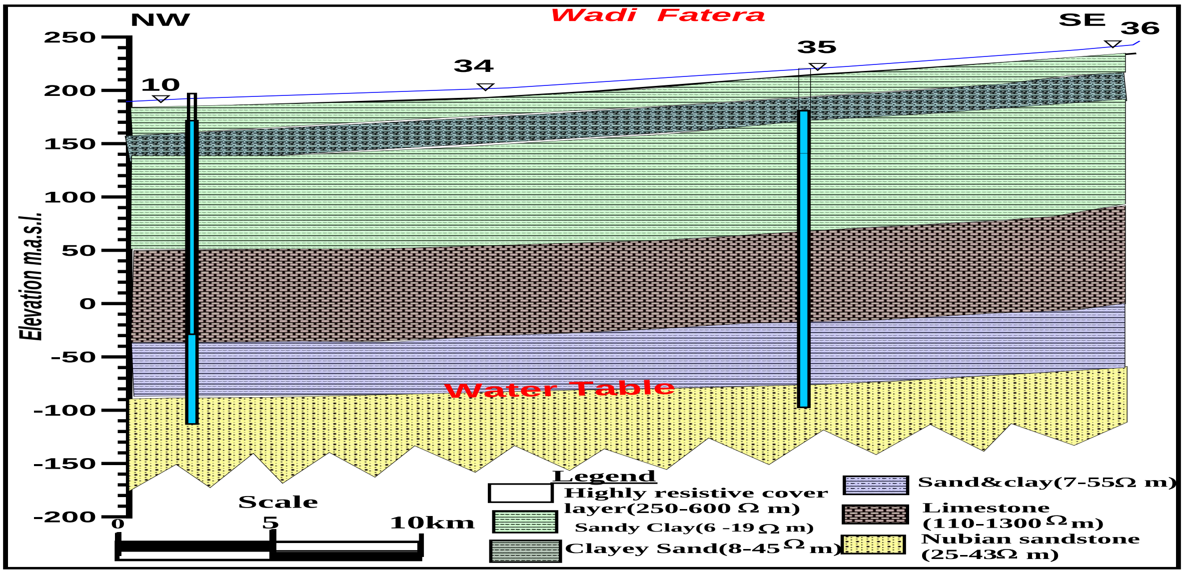

Fig. (10): Geoelectric cross section along the main stream of Wadi Fatera.

SUMMARY AND CONCLUSION

Wadi Qena is one of the most outstanding water collectors in the Eastern Desert. It covers an area of about 18000 km^2, and its headwaters originate in the high mountainous terrain (medium intensity basement complex) and El Maaza Plateau at altitude ranges from 500m to 2100m.a.s.l. which has intensive fractured limestone.

The basin shape allows the surface runoff to pass with moderate downward infiltration. Most of the sub-basins related to Wadi Qena hydrographic basin have bifurcation ratios range between 2.9 and 3.98, except

Umm Selimate sub-basin. Wadi Qena basin shows a low drainage density value (0.457Km^{-1}), which indicates that it has mild topographic relief and its surface runoff water infiltrates downward through the areas covered by Sandstone rocks. Wadi Qena hydrographic basin has low stream frequency value (0.867 km^{-1}). This means that this basin has less possibility to collect surface runoff water and the rate of water flow and water discharge out of that basin are low. Accordingly, this situation give more chance to the downward infiltration, specially the basin tends to be elongated, where it has a relatively high bifurcation ratio. The basin has a vast area and receives annually too much water quantities to infiltrate all downward, accordingly this hydrographic basin is considered as one of the dangerous basins among the Eastern Desert in its flash flood phenomenon.

The basin has a vast area and receives annually too much water quantities to infiltrate all downward, accordingly this hydrographic basin is considered as one of the dangerous basins among the Eastern Desert in its flash flood phenomenon.

The lineaments' intensity map shows that Qena basin can be divided into three zones. The lowest intensity zone is represented along the main trunk of wadi Qena that reflect the effect of clastics as Sandstone exposures and due to sealing effect of wadi fillings and alluvium cover. A second zone of medium intensity lies to the east due to the presence of brittle rocks of basement complex of the eastern desert. The third zone has a high intensity lies to the west where El Maaza plateau of intensive fractured limestone. The study of fractures and faults trends reveals the presence of three fault zones. Wadi Qena Basin area is highly affected by the faults of NE-SW direction. The dominant trend of Aqaba (NE-SW) structural trend plays a principal role in recharging the Nubia Sandstone aquifer in Wadi Qena.

Wadi Qena basin was studied using the geoelectrical resistivity technique through 43 VES'es which conducted along the main stream channel (up to about 120 km long) of the wadi and two main tributaries (Wadi Qerdi and Wadi Fatera). The Following results can be reached:

- Two aquifers along the main profile of Wadi Qena were detected as; the shallow aquifer and the second is the deep and the main aquifer (Nubia Sandstone).
- Three faults were detected along Wadi Qena which affect the ground water level and thickness of the water bearing formation along that profile.
- The main water bearing formation (Nubia Sandstone aquifer) is confining by the capping impermeable layers. The water level (rising level) is recorded to be about 300 m.a.s.l.
- *In Wadi Qerdy* the water bearing formation becomes more deeper due to the elevation of the ground surface.
- *In Wadi Fatera* the detected groundwater was Nubia Sandstone formation in all the sites of conducted soundings
- The groundwater potentiality in the investigated sites is fair due to the reasonable thickness of the aquifer beside its high hydraulic properties.
- The main aquifer in Wadi Qena basin is the Nubia Sandstone with about 300 m thick.
- The drilling of the deep wells must be under the control of governmental out arties to avoid the hazards of extensive drilling which deplete the aquifer.
- A detailed hydrogeological studies must be achieved for quantitative estimation of the groundwater potentiality in the basin for the sustainable development region.

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