Integration of Remote Sensing, Geophysics and GIS to Evaluate Groundwater Potentiality – A Case Study in Sohag Region, Egypt

Awad Abdel-Khalek Ahmed Omran
Geology Department, Faculty of Science,
Assiut University, Assiut, Egypt

Abstract

The present work performs an interpretation approach that integrates through a geographic information system (GIS), the data from remote sensing, geophysics and other hydrogeologic phenomena to characterize groundwater resources for the identification of candidate well locations. The area between longitudes 31o 15' and 32o 15'E and latitudes 26o 00' and 27o 00'N, located in Sohag region, Egypt, was considered as a case study. The area is characterized by arid climate of low rainfall and high evaporation. The sands and gravels of Pleistocene age cover the surface of the old alluvial plains, which are subject to the new reclamation activities.

The lithostratigraphic section represents units belonging to Lower Eocene, Pliocene, Pleistocene and Holocene times. Structurally, the area is affected by faulting, folding and major joints. The prevailing trends of the faults are N-S, E-W, NE-SW and NW-SE.

Methodologically, the available remote sensing data (Landsat TM images), the 1:50,000 scale topographical maps and Bouguer gravity map in Sohag region are used for analyzing slopes, lineaments and the hydrogeomorphologic attributes of the drainage basins dissecting the Eocene plateaus and draining towards the Nile valley. These are carried out to reveal the opportunities for downward recharge to the existing aquifer and/or flooding probabilities.

As well, subsurface information inferred from geoelectrical survey can give more realistic picture of groundwater potentiality. Four major geoelectrical zones with subsurface structure could be detected from the interpreted geoelectrical model sections of the 203 VES stations executed in the investigated area. The second zone, which is represented by water bearing layers related to the Quaternary aquifer, has been concerned. This aquifer, which is consisting of Pleistocene sand and gravels of semi-confined or free water table conditions, is the main water bearing formation existed in Sohag region. Accordingly, contour maps for the depth, thickness and true resistivity of the aquifer were constructed.

Hydrogeologic phenomena, including soil composition, soil infiltration, water flow, hydraulic conductivity and transmissivity of the aquifer besides the hydrochemical properties distribution maps based on the data from 107 drilled wells have been constructed and studied. The positions of boreholes and VES stations were accurately plotted on the Landsat imagery, aerial photographs and thematic maps using GPS receivers.

To find out the more realistic ground water potentiality map of the area, the relevant layers which include lineaments, slopes, hydrogeomorphologic drainage attributes as well as the aquifer depth, thickness and true resistivity were integrated in ArcGIS 8.3 and ILWIS 3.2 grid environment. Criteria for GIS analysis have been defined on the basis of ground water conditions and appropriate weightage has been assigned to each information layer according to relative contribution towards the desired output. The ground water potential zone map generated through this model was verified with the yield data to ascertain the validity of the model developed.

Three groundwater potentiality zones in the Quaternary aquifer in Sohag region could be demarcated from integration of the previously discussed thematic layers using a model developed through Geographic Information System (GIS) technique. The verification showed that the demarcated ground water potential zones through the model are in agreement with the bore well yield data.

The study has evidently demonstrated the capabilities of the integrated approach in delineation of the different ground water potential zones. Significant recommendations towards improving the efficiency of desert reclamation are also acquired to accomplish the sustainable development plan in Sohag region. As a result, the given approach can be successfully used elsewhere with appropriate modifications for identifying candidate well locations and in creating a GIS-based hydrogeologic model of a selected area.

Introduction

1. Study Area

Sohag governorate constitutes an important hydrographic part in the Upper Egypt Nile Valley. It occupies a region including both the floodplain and the desert fringes between longitudes 31° 15' and 32° 15'E and latitudes 26° 00' and 27° 00'N (Fig. 1) and has a total area of ~ 11022 km^2. The Nile valley, in Sohag area, is bounded from east and west by the Eocene Limestone plateau which is dissected by many wadis draining towards the Nile Valley (about 30 catchments in the eastern side and 32 catchments in the western side).

2. Purpose and Scope

Most of the flood plain areas in Sohag have 60–70 m elevation range; part of these is susceptible to flooding. In the past several decades,

urbanization, reclamation land, and other projects spread over low desert lands. The new development extends to include up to 160 m elevation and part of these are initially took place in flood free zones. This necessitates more exploration activities for groundwater resources.

The overall goal of this work is to show how GIS technique can assist with remote sensing and geophysics for evaluating groundwater resources in Sohag Governorate. This could be achieved by determining the hydrogeologic potentiality map for the study area using thematic information layers (the geomorphology, drainage, lineaments, geoelectrical and other spatial distributed hydrogeologic phenomena) and weighted index overlay via GIS environment.

In weighted index overlay, the individual thematic layers and also their classes are assigned weightage on the basis of their relative contribution towards the output. The classes with higher values indicate the most favorable sites for groundwater potentiality. This is followed by verification of results and finally suggesting appropriate locations for drilling new wells.

Geologic Setting

The area under consideration represents a part from the Nile valley zone of Egypt. Geologically the area has been studied by a variety of authors (e.g. Wendorf and Said, 1967; Wendorf and schild, 1976; Said, 1975, 1981, 1983, 1990; Issawi et al., 1978; Paulissen and Vermeersch, 1987; Issawi and McCauley, 1992; Omer, 1996; Omer and Issawi, 1998). Generally, the geology of Sohag area can be outlined as follows (Fig. 2):

1) Thebes Formation (Eocene); the widely used formal name (Thebes Formation) was first introduced by Said (1960) for the lower Eocene limestone of the Nile Valley. He described the Thebes Formation as massive to laminated limestone with flint bands or nodules and marl rich with Nummulites and planktonic foraminifera. Amer et al. (1970) and Said (1971), subdivided the Eocene rocks exposed between Luxor and Assiut into two formations, namely the Thebes Formation at the base and the Manfalut Formation at the top. The Thebes Formation includes the massive to laminated limestone with flint bands and concretions. The exposed part of the formation decreases gradually toward the north due to the regional gentle sloping northward.

2) Muneiha Formation (Pliocene); Issawi et al., 1978, mentioned that Muneiha formation includes the estuarine fine clastic sediments accumulated due to the invasion of the Mediterranean Sea which create a long gulf from Cairo to Aswan in Pliocene time, these sediments are equivalent to the Madmoud Formation (Said, 1981). Omar 1996 divided this formation into two main divisions (lower and upper members) according to the facies and the depositional environment.

3) Issawia Formation (Pliocene/Pleistocene); Said (1981 and 1990) mentioned that, by the end of the Pliocene and beginning of the Pleistocene, arid climatic conditions prevailed over Egypt causing the cessation of the revering activities. This left local depressions, which received water only during seasonal rainy storms; lacustrine sediments were accordingly accumulated within these depressions. These lacustrine sediments were treated as the Issawia Formation (Issawi, et al., 1978; Omar, 1996). Sediments of the Issawia

Formation include two inter-fingered facies: the carbonate facies and clastic facies.

4) The Pleistocene Sands; they consist of a thick succession of the Pleistocene sand-gravel association, which is widely distributed along the Nile valley in both the surface and subsurface. These sediments have been studied by many authors (e.g. Wendorf and Said, 1967; Said, 1975, 1981; Paulissen and Vermeersch, 1987; Issawi and McCauley, 1992; Omer, 1996; Omer and Issawi, 1998). The porosity and permeability of the Pleistocene sandy sediments of the Nile basin are generally high that is because these sediments are friable.

5) Dandara Formation; During the Late Middle Pleistocene, the Ethiopian water coupled with the dry phase in Egypt resulted into an exotic suspended-load river depending mostly on the seasonal rainfall in Ethiopia (Said 1975; Omer, 1996; Omer and Issawi, 1998). Sediments accumulated during this stage (Dandara Formation) were thus entirely derived from the upper reaches of the Nile in Ethiopia and southern Sudan. These sediments are formed mainly of fluviatile fine sand-silt intercalation and accumulated at low-energy environment.

6) Recent Wadi Deposits; Generally, the intermittent activities of the transverse channels led to the accumulation of flashflood deposits covering the surface of the older sediments throughout the desert areas outside the cultivated land. These deposits vary greatly in both the thickness and texture depending upon the land morphology and the intensity and regime of the flashflood rainfall. They range in thickness from few centimeters to more than 30 meters. They are formed of the disintegrated product of the nearby Eocene carbonates, in addition to the reworked material from the pre-existing sediments.
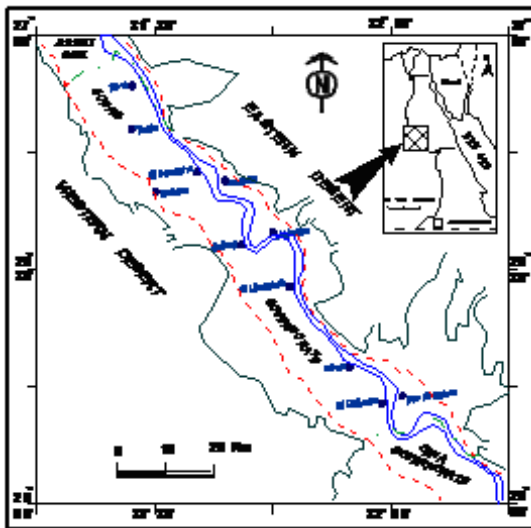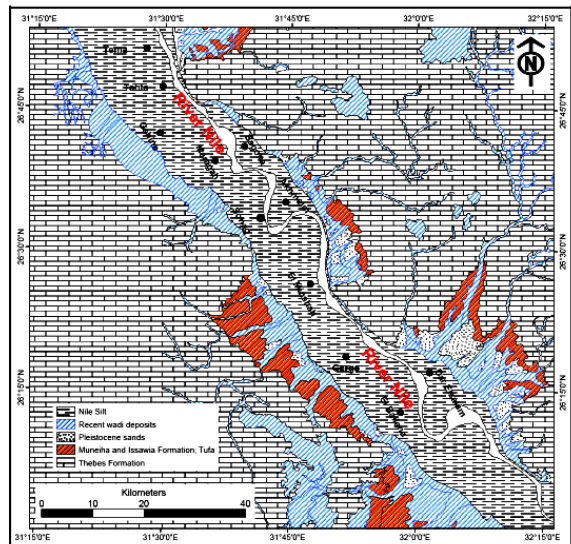

Fig. (1): Location map of the study area.

Fig. (2): Geological map of Sohag Governorate (after the Egyptian Geological Survey and Mining Authority 1989).

Hydrogeologic Setting

1 Climatic Characteristics

Climatologically, Sohag Governorate belongs to the arid belt of Egypt where it characterized by long and hot summer, warm winter, and scarce rainfall except the occasional storms. Rain is generally rare and is randomly precipitated over the area. During the period between 1960 and 1998, the average value of precipitation in Sohag Governorate, was recorded as 2.25 mm/year (MAE, 2000).

2 Ground Water Conditions

In the floodplain of the River Nile, the Quaternary aquifer system consists of fluvial sands with minor conglomerate and clay (Prenile, Qena Formation). It is capped with the Neonile silt and fine-grained sands that constitutes the base of the cultivated lands. Along the eastern and western fringes, the Neonile silty layer is replaced by the recent sediments. Therefore, the aquifer system in the floodplain is under semi-confined condition (silty cap), but in the desert fringes it is under unconfined condition. The penetrated thickness of the aquifer system varies from 150 m in the central part of the flood plain to about 50m in the desert fringes. The average hydraulic conductivity of the aquifer is about 70 m/day; while it reaches 4 cm/day for the silty top layer (Omran et al., 2006).

The Quaternary aquifer is recharged mainly from the dominant surface water, especially from the irrigation canals that play an essential role in the configuration of its water table. Some wadis having high bifurcation ratio and low drainage density and drainage frequency may have good chance for downward recharge to the existing aquifer. The discharge of the groundwater from this aquifer is taken place through: the underlying aquifer, the river that acts as an effluent stream in most of its parts, the irrigation drains, the irrigation canals during the winter closure period in addition to the evapotranspiration processes.

The main flow direction in the floodplain is to the northwest. On the other hand, the second trend of groundwater flow is oriented in the direction from west and east to the River Nile due to the influence of canals recharging.

In the old cultivated lands, the piezometric surface ranges between 50 and 65 m above sea level, but it ranges between 65 to 85 m in the reclaimed areas. The hydraulic gradients are relatively moderate and regular, except the areas of water depressions, where these gradients become steeper in north-eastern and south-western portions.

3 Hydrochemical Characteristics and Quality Evaluation

The groundwater chemistry in the considered area (Korany et al., 2006) shows that the pH value of groundwater ranges from 7.1 to 7.8 indicating the alkaline nature of water. The total dissolved solids (TDS) ranges from 524 to 5131 ppm and increase generally toward the Eocene scarp.

Groundwater of the studied aquifer has two chemical types. The first type reflects groundwater of mixed water facies. The second type is detected in all the remaining water wells with dominance of HCO3 — Na and SO4 —Na, reflecting water of continental origin.

The comparison between the groundwater chemistry in the area of study and the WHO drinking water standards indicated that water in the area is generally suitable for drinking; meanwhile the groundwater located near the limestone scarp shows high chemical concentration of the different chemical components and is not suitable for drinking purposes. Evaluation of groundwater suitability for irrigation based on the US Salinity Laboratory diagrams, SAR and RSC indicated that water in the area is generally suitable for use except at some localities where it is suitable for plants of moderate salt tolerance.

Analysis and Discussion

1 Generation of thematic layers

In order to demarcate the groundwater potential zones of the study area different thematic layers (maps) were derived (i.e. hydrogeomorphology, lineaments, drainage, slope, geology, subsurface maps of aquifer geometry and quality). The remote sensing, topography, geology, gravity, geoelectrical sounding interpretation and well log correlation are used. The methodology adopted in the study is represented schematically (Fig. 3) and described as follow:

1.1 Hydrogeomorphologic map

The studied area is bounded from east and west by the limestone plateau in which there are many wadis dissect the plateau and has a main direction NE-SW; follow these plateau inwards, there are low desert land areas then the agricultural areas surrounding the River Nile. The main *geomorphological features* found in the area include four main units (Fig. 4) and each unit has its own characteristics, shape, pattern, and relief. The geomorphology of Sohag area can be summarized as follows:

1) The Nile flood plain; the cultivated lands are in both east and west side of the River Nile, represent the Nile flood plains. They include mud and silt deposits at the top surface dissected by the irrigation canals and drains. The most characteristic feature of the flood plain that is almost flat and sloping very gradually from south to north, its altitude ranges between 55 and 65m above mean sea level. The River Nile is running from south to north more close to the eastern margin of its valley. The cultivated lands on the western side of the river are generally much wider than those on the east side.
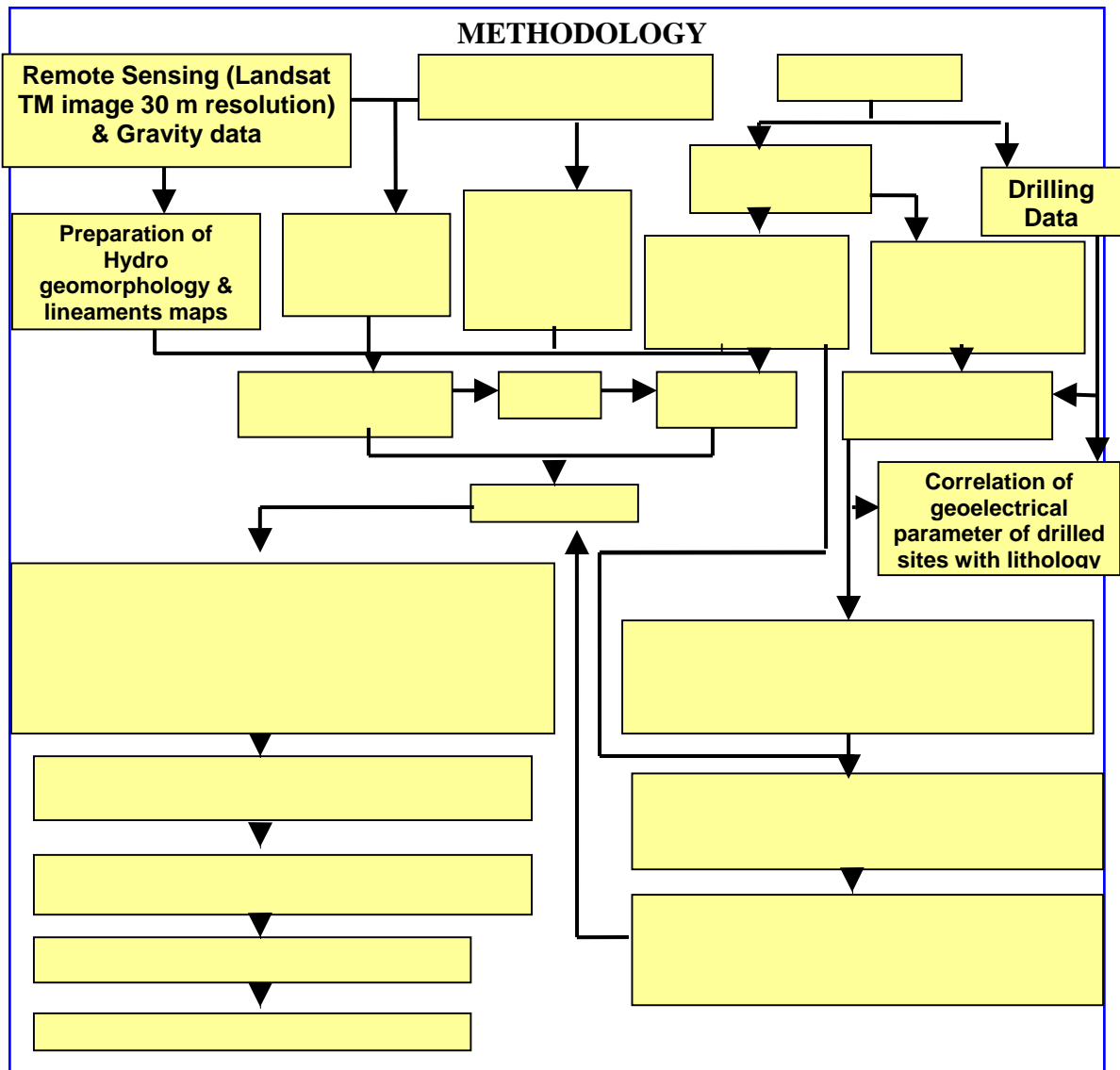
METHODOLOGY

Fig. (3): Flow chart showing data flow and different GIS analysis operations followed in the present study.

2) The low land desert areas; the low land desert areas are fringing along both sides of the Nile flood plain and form gently elevated areas located between the agricultural lands and the edges of the Limestone Plateau. These areas form the old alluvial plains and represented by a series of old Nile terraces mixed with alluvial fans and terraces of desert drainage basins with different altitudes. These low land deserts are located at an altitude ranging between 70 and 160 m above mean sea level.

3) The Limestone plateau; the Limestone plateaus, in Sohag district, border the low land desert from west and east and represent part of the major Eocene Limestone plateau of the Eastern and Western Deserts of Egypt. It rises about 200 to 300 m above sea level and generally decreases toward the north. The surface of this plateau on both sides of the river is irregular owing to the effect of the weathering and the structures.

4) The transverse channels; the surfaces of the limestone plateau are dissected by dry drainage channels (*wadies)* that filled by sands and gravels and generally run toward the floodplain areas.
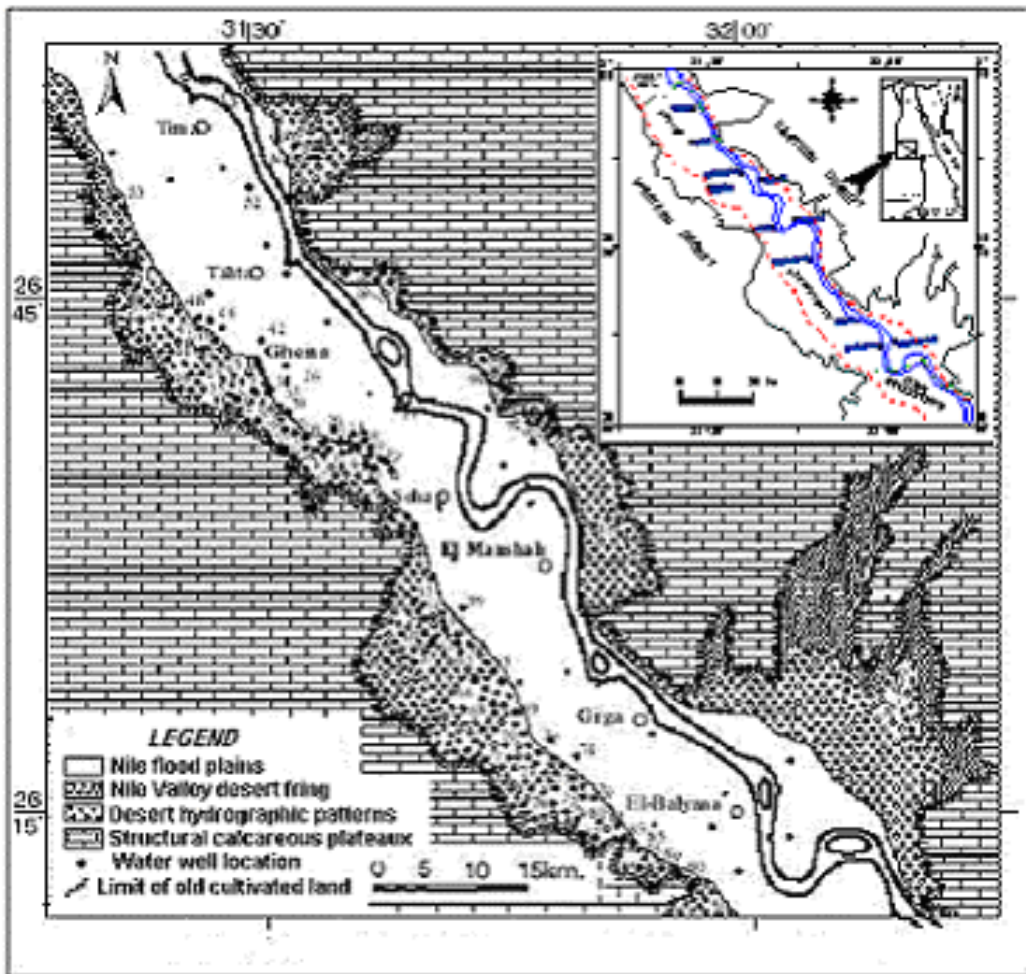

Fig (4) : The main geomorphological features in the area.

1.2   Surface Lineaments map

Figure (5) clearly distinguish major fractures and/or faults (heavy lines), and minor fractures (light lines) which affected the study area as traced by Philobbos et al. (2000) from the geological map of Egypt, scale 1:500 000 (EGPC and CONOCO, 1986, 1987).

1.3   Subsurface Lineaments map (Gravity detected faults)

Subsurface faults (contacts) (Fig. 6) were traced by Omran et al. (2000) at zones of maximum horizontal gravity gradients (Vxz_{max}) from the Bouguer anomaly map of the study area (Fig. 7) established by the General Petroleum Company of Egypt (GPC) in 1980, with scale 1:500,000 and contour interval 1 mGal. The subsurface lineaments have been traced again using the digitized gravity field.
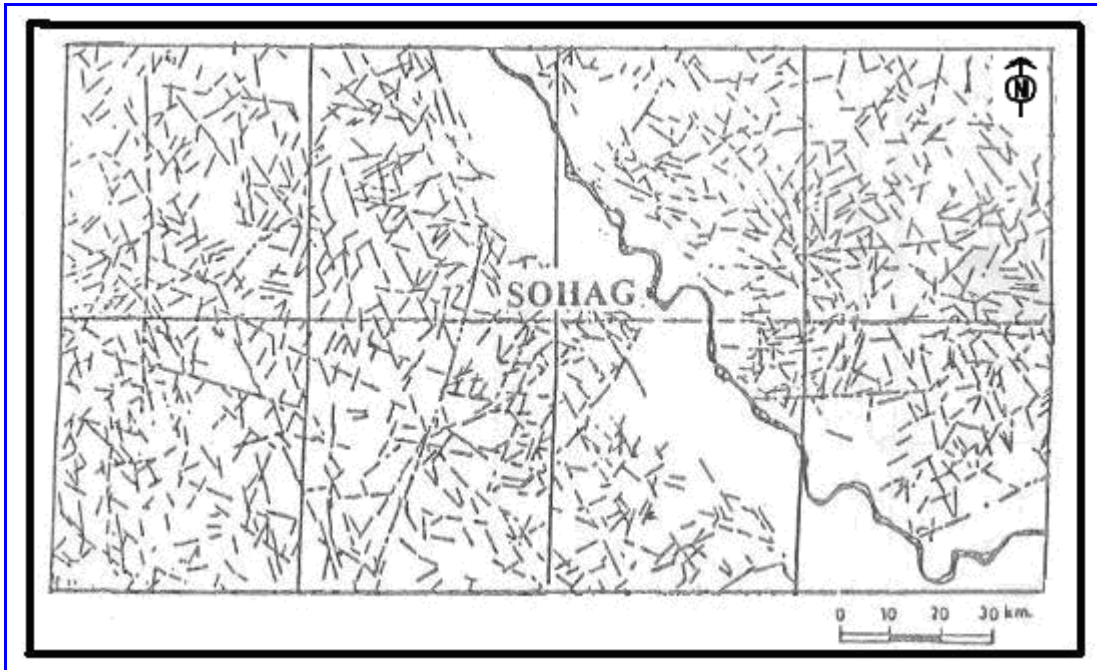
Fig. (5): Surface lineaments (fractures and/or faults) traced from geological map of Egypt after EGPC and CONOCO (1986 & 1987).
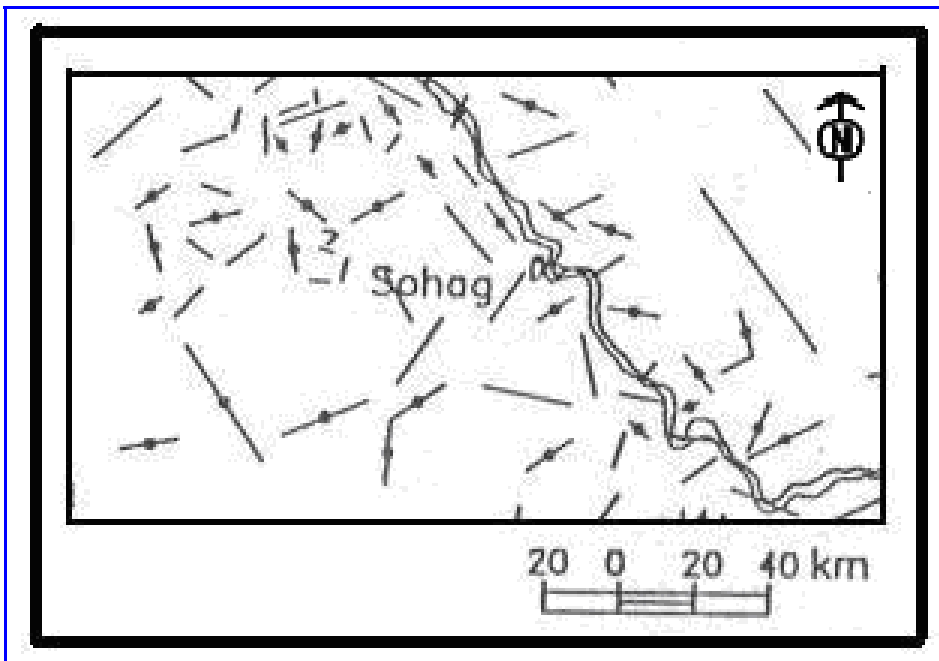

Fig. (6): Subsurface lineaments (gravity detected faults) in the study area as interpreted from Bouguer gravity map (after Omran et al., 2000).
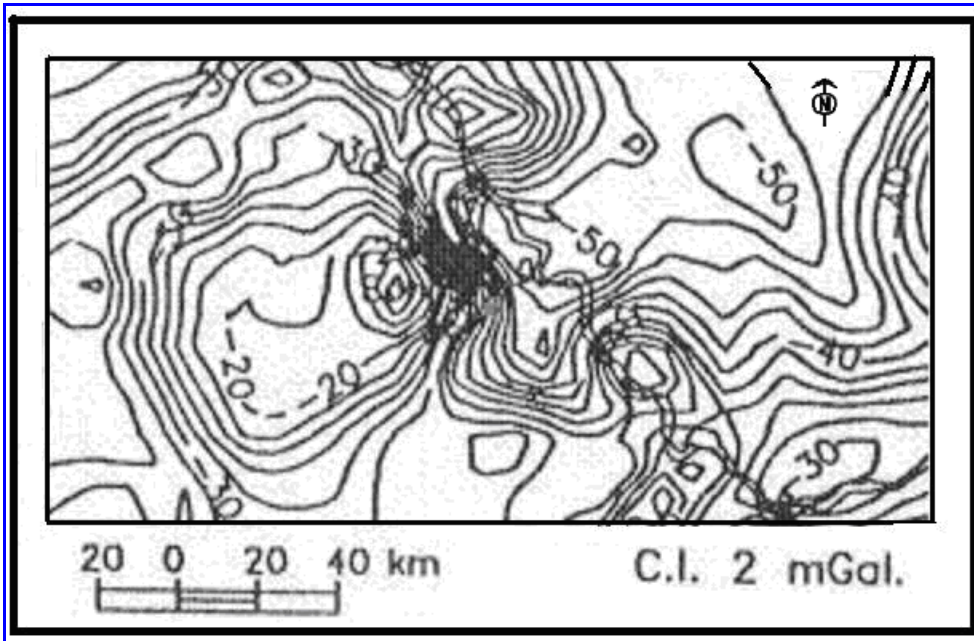
Fig. (7): The Bouguer gravity map of in the study area (after GPC, 1980).

1.4 Morphometric Analysis and Hydrologic Aspects of drainage basins

a- The drainage basins, drainage networks, and their geomorphometric parameters were analyzed from the topographic maps (scale 1:50 000), where all the elements have been digitized, coded, measured, and extracted using GIS programs (ArcGIS 8.3 and ILWIS 3.2). These elements were verified using Landsat TM image 30 m resolution (Figs. 8, 9, 10 and 11),. The following characteristics have been used to describe each basin:

1) The estimated linear drainage basin characteristics include stream ordering (Strahler 1952); mean of the bifurcation ratio; total drainage length; drainage frequency (Horton 1945); and drainage density (Melton 1957).
2) Areal drainage basin characteristics include drainage basin area, length, width, perimeter, and length of the overall flow (Horton 1945). In order to evaluate the hazardous probability of the different basins in the area, the drainage basins boundaries were digitized, the area (Fig. 11-a), includes nearly 62 drainage basins. Same thing happened for the drainage networks (Fig. 11-b),

Detailed analyses of the studied morphometric parameters of the considered drainage basins indicate that some wadis have high bifurcation ratio and low drainage density and drainage frequency. They have good chance for downward recharge to the existing aquifer that may form important water resource. On the other hands, most of the other wadis show low bifurcation ratio and high drainage density and drainage frequency. These wadis involve areas of moderate groundwater potentiality and high flooding probabilities.
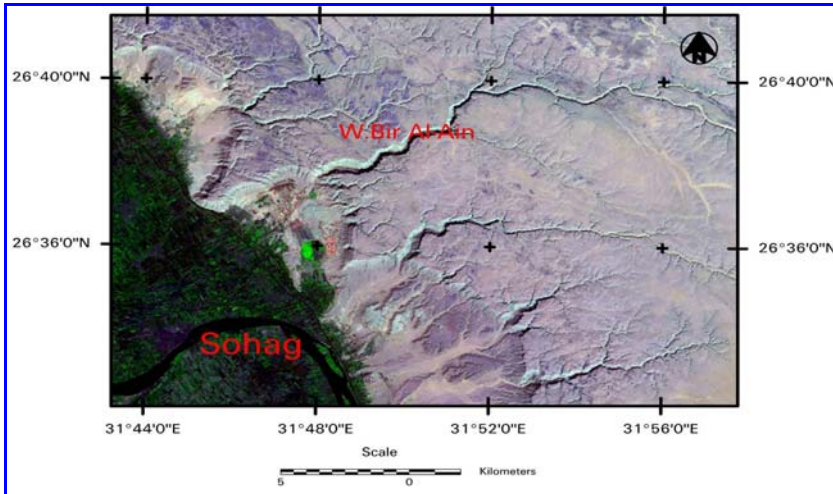
Fig. (8): Color-composite image including Wadi Beir El-Ain and Wadi Ayoub basins, East Sohag. Image based on Landsat-7 ETM bands 7, 4, and 2 as RGB, of subscene.
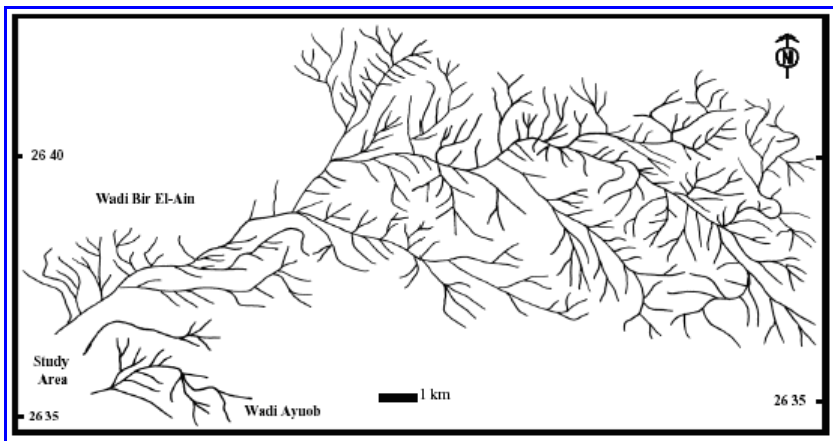

Fig. (9): Drainage lines of the Wadi Beir El-Ain and Wadi Ayoub basins, East Sohag.

.An exceptional rate of precipitation occurred in the area in November 1994 where the average rate of precipitation reached about 25 mm (Geological Survey of Egypt, 1994). It caused a flood in the region and led to huge loss of property and cultivated lands. The runoff in the considered area causes also subsurface effects resulted from the infiltrated water. The infiltrated water increases the recharge regime of the aquifer. The surface fractures joints and faults as well as the alluvial cover dominated by loose and gravely constituents activate the infiltration and percolation processes. Thus it is expected to affect the groundwater quality.

On the other hand, the hydrometric attributes as well as a quantitative analysis of the hydrologic elements of the rainstorm of November 1994 have been calculated and analysed (Abdel Moneim et al., 1999). The result indicated that about 50.96 % (41.385 x 106 in^3) of the total precipitated water (81.2 x 106 in^3) resulted in runoff. The infiltrated water is about 35.1 % (28.5 x 106 in^3) whereas the evaporated water is estimated to be 13.9% (11.333 x 106 in^3) (Abdel Moneim et al., 1999).
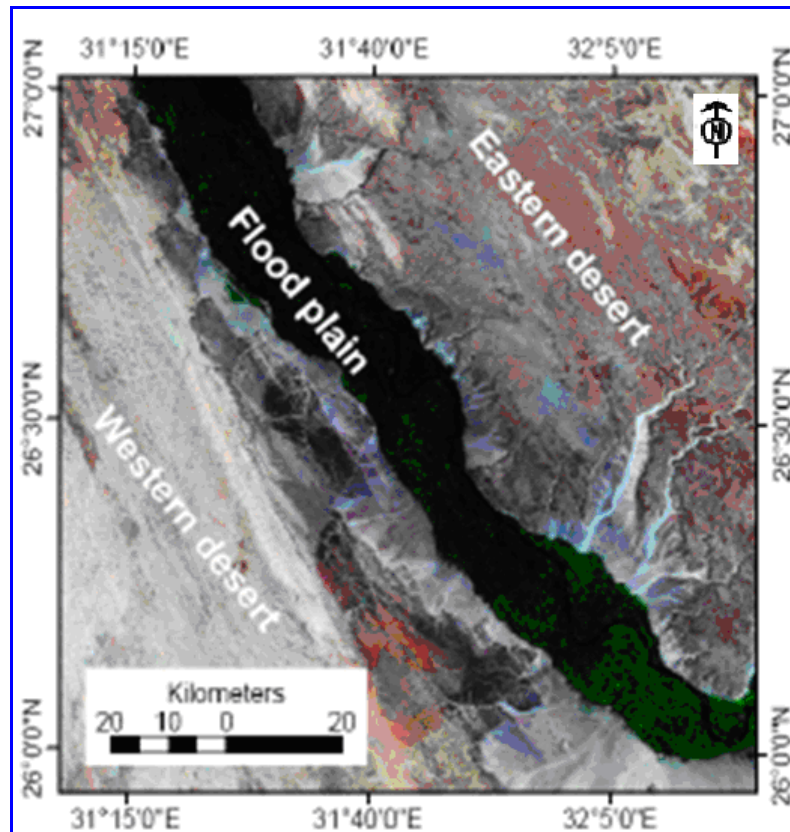
Fig. (10): Landsat Image of the studied area.

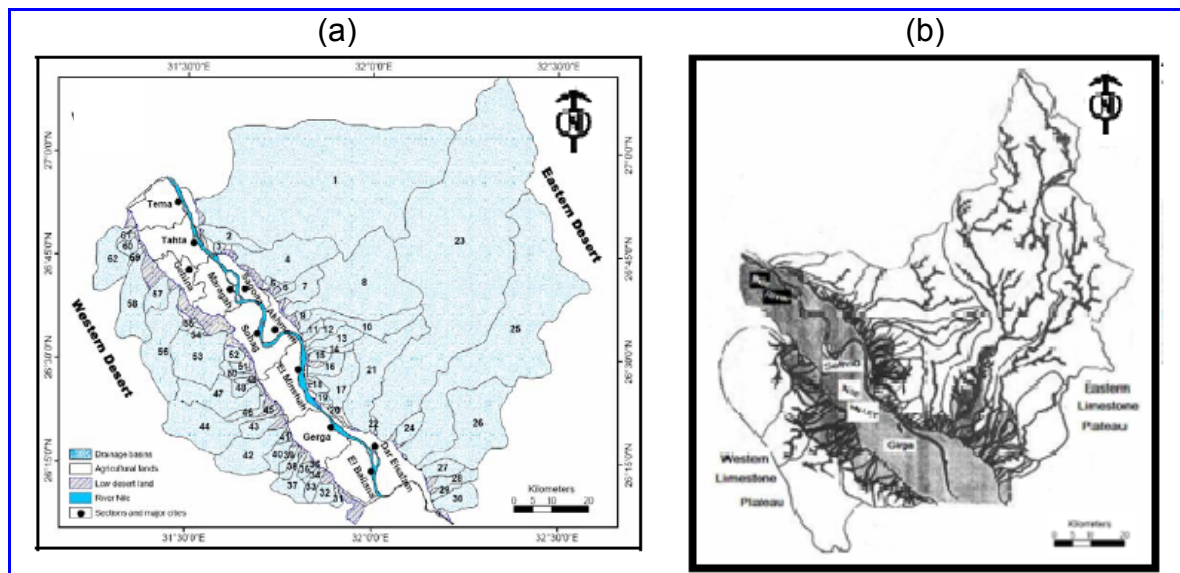Fig. (11): Drainage basins (a) and drainage network (b) in the study area *(after Youssef et al., 2005).*

The hazardous probability of the different basins in the area was determined using El-Shami's model (1992b) considering the relation between bifurcation ratio, drainage density, and drainage frequency. Two different diagrams were used to determine the hazard degree for each basin in the area.

The first diagram shows the relation between bifurcation ratio and drainage density and the second diagram represents the relation between bifurcation ratio and drainage frequency (Fig. 12). Both diagrams include three fields A (high possibility for floods), B (moderate possibility for floods), and C (low possibility for floods).

b) Flash flood hazard map of the area

Flash flood prone *wadis* (dry channels cut into the terrain) can be assessed and delineated through the use of GIS. This methodology was used to determine the hazard of flash floods in each basin in Sohag area. For the analysis and creation the hazard map, Youssef et al. (2005) used the drainage basin maps with the extracted data and Fig. (12). The attribute table for the drainage basins was added to the GIS database in building the drainage basin hazard map and is classified into high, moderate, and low hazard basins (Fig. 13-a).

From the hydrological point of view the following points can be deduced:

1- The study area is classified as an active catchment for enabling the formation of sizable quantities of runoff and a plan is required to make use of the rainfall water, which could lead to flood hazards if it is mismanaged.

2- Runoff in the area is an exceptional case, but this event should be kept in mind to avoid the occurrence of such. In November 1994 rainstorm event, the value of runoff in the study area was about 50.96 % of the total volume of the precipitated water (81.2 x 106 in^3).

3- The study area is classified according to the potential for flood hazard, deduced from the geomorphometric attributes, into three zones; the strongly hazard, hazard and non-hazard zones. The location of these zones was considered in constructing the groundwater potentiality map given later (Fig. 19).

c) Vulnerability Maps for the study areas

Using map calculator in GIS, the isolation of the most prone areas to flash floods has been done. The determination of the vulnerability degree is according to two factors 1) final landuse and future projected maps 2) the hazard map for the drainage basins. The resultant vulnerability map was divided into three classes: high, moderate, and low vulnerable areas (Fig. 13-b).

1.5 Topographic and Slope maps

Slope map was prepared from digital elevation data.

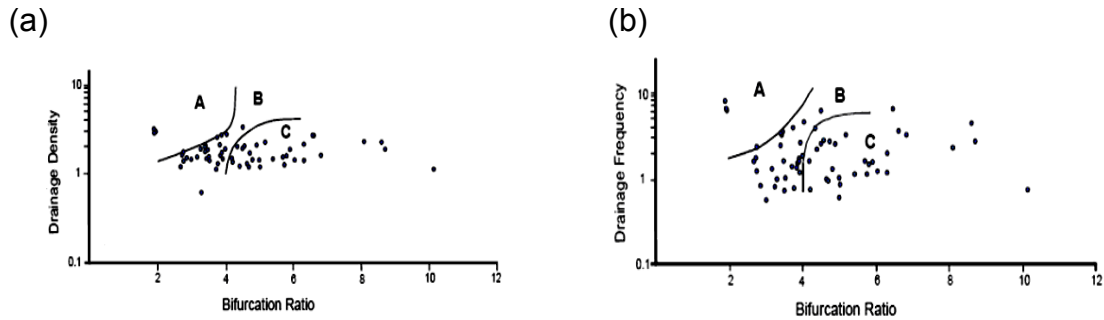(a)   (b)

Fig. (12): The Bifurcation ratio vs. Drainage density (a), and the Bifurcation ratio vs. Drainage frequency (b), Note: A (high possibility), B (moderate possibility), and C (low possibility) for floods (after Youssef et al., 2005).

(a)   (b)
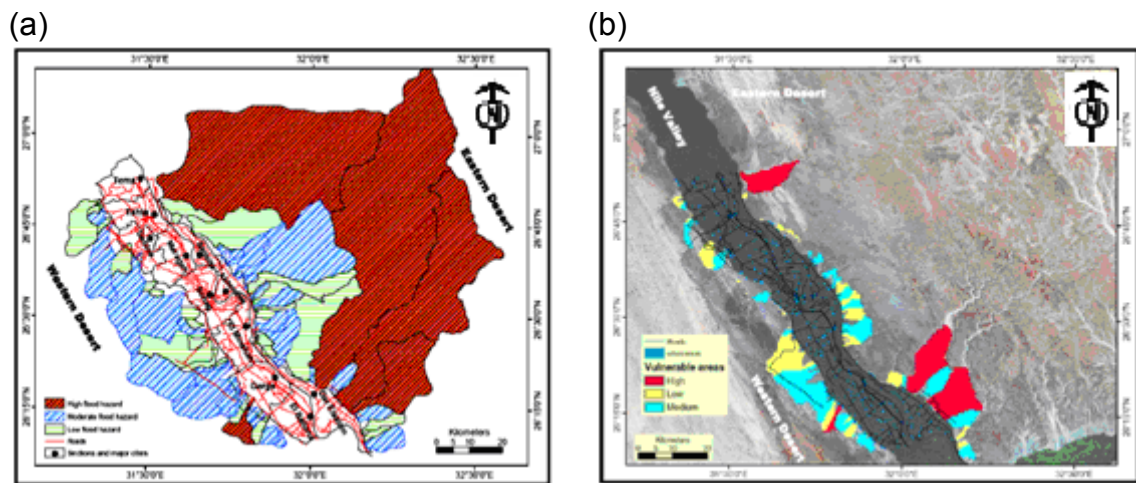
Fig. (13): Hazard map for the drainage basins (a), and the vulnerable areas that is most affected by floods (b) (after Youssef, 2004).

1.6 Subsurface aquifer configuration maps from electrical survey

The geophysical exploration for groundwater resources in the study area was carried out using the electrical resistivity technique. A total of 203 VES soundings were carried out applying the Schlumberger electrode configuration and using GPS instrument for detecting their locations (Fig. 15). Interpretation of the VES data were carried out using the software of Zohdy (1989) to get the preliminary parameters of geoelectrical layers (true resistivity and thickness). Subsequent adjustment of the deduced layer parameters from all soundings was made using the IPI2Win computer software (Bobachev et. al., 2001). The interpreted layered models of drilled sites were then carefully correlated with the lithologic logs.

Based on the above correlation, lithology was inferred at other sounding locations for identifying horizontal and vertical variation in subsurface lithology and estimating depth to the aquifer and to the hard bed rock. Using these parameters at respective locations, aquifer layer thickness and depth maps were prepared through GIS.

Generally, the results from the geoelectrical interpretation indicated that five to eight geoelectrical layers are detected in the investigated area. They are grouped into four main zones (Table 1). These are (from top to bottom) (see also Fig. 14):

-The surface zone, characterized by high resistivity values and variable thickness (semi-permeable zone). This zone belongs to Holocene period.
-The second zone is characterized by resistivity values ranging from 2.8 to 9.4 ohm-m. This zone, which has different thickness varying from 2 to 15 m, corresponds to silt deposits that belong also to the Holocene period.

Table (1): Geoelectrical Parameters and Their Hydrogeological Significance.

Resistivity Stratification		Inferred Lithology	Hydrogeological Significance
Resistivity (Ωm)	Thickness (m)		
409 – 10065	1 – 35	Silt and clay in the cultivated land, changed laterally to be wadi deposits (fanglomerates consisting of sand, gravel and rock fragments)	Completely dry.
6.5 – 40	2.4 – 51.3	Shale or intercalations of sand and shale	Generally lies in unsaturated zone, very poor aquifer at depth
20.5 – 192	12 – 289 (in desert fringes 12-15 in the east and 17-85 in the west)	Sand and gravels intercalated with lenses of clays belonging to Quaternary (Pleistocene aquifer, Qena Fm)	Main aquifer saturated with fresh to brackish water
> 395	Indeterminate (Bottom layer)	Pliocene clay or Eocene limestone in areas near to scarps in the desert fringes.	Expected base of the aquifer, bedrock, very poor aquifer

-The third geoelectrical zone has resistivity value ranging from 25 to 180 Ohm-m, and its thickness varies from 47 to 240 m. It is characterized by the presence of sands and gravels and corresponds to the Pleistocene period. It is considered as the main water bearing formation in the study area. The interpretation results are presented as subsurface maps of depth, thickness and resistivity of the expected water bearing zone (Figs. 16, 17 & 18).
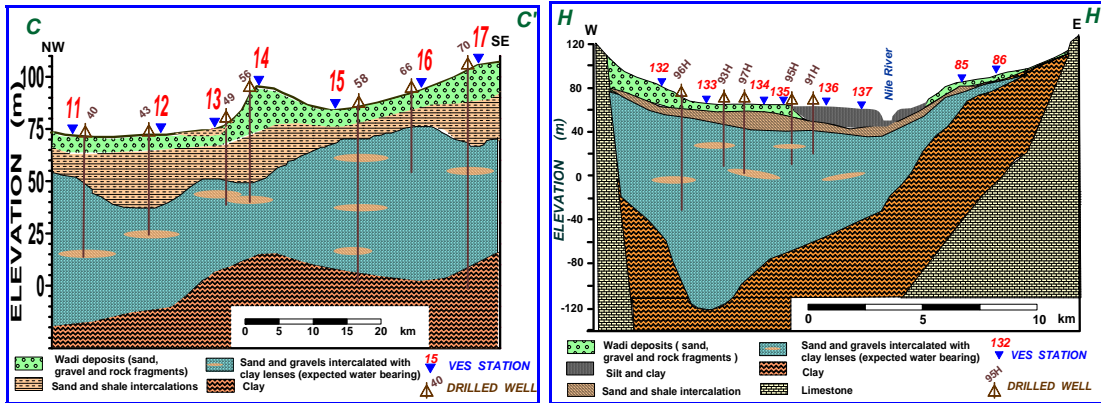
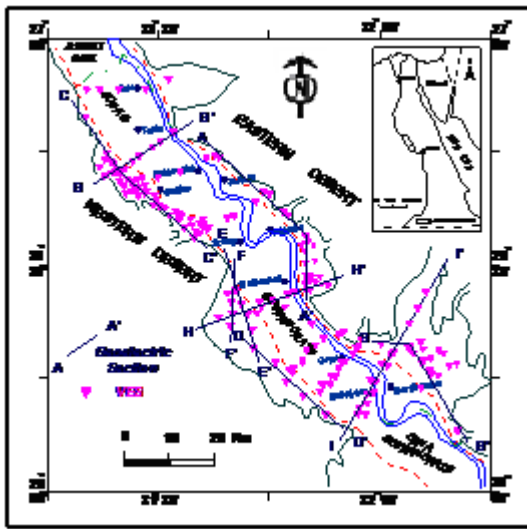Fig. (14) :Geoelectrical cross sections C-C' and H-H', Sohag Governorate.

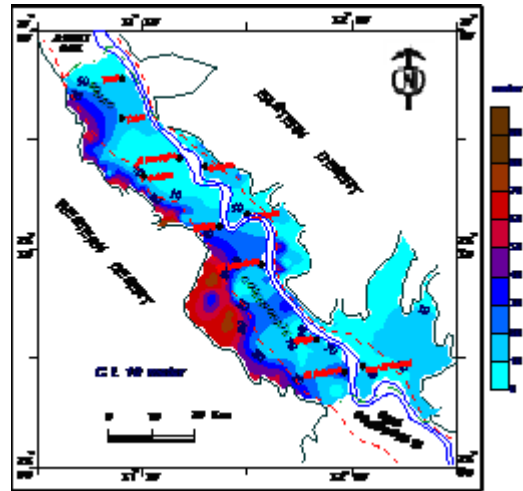Fig. (15): VES and cross sections location map.

Fig. (16): Contour map of depth to the Quaternary aquifer in Sohag area.
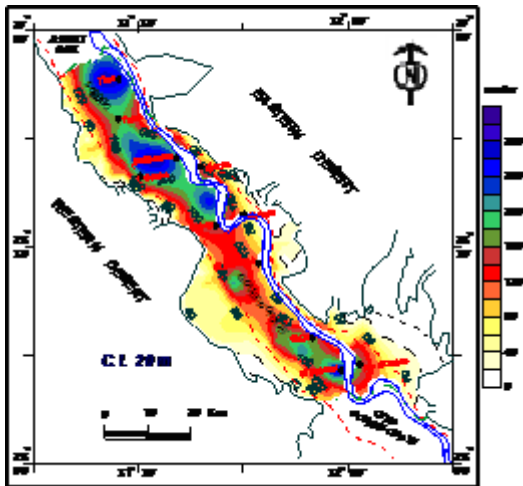

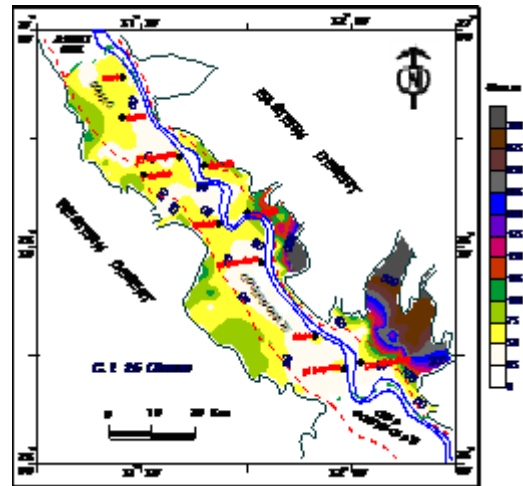Fig. (17): Thickness Contour map of the Quaternary aquifer in Sohag area.

Fig. (18): True resistivity contour map of the Quaternary aquifer in Sohag area.

- Finally, the fourth zone is characterized by low resistivity values corresponding to the Pliocene clay and is considered as the impermeable base of the Pleistocene aquifer. Sometimes this zone shows very high resistivity values, particularly in the localities adjacent to the Eocene scarps, corresponding to the dry limestone.

2 Integration of thematic layers and modeling for Groundwater Prospects and Potentials through GIS

In the initial stage of GIS spatial database development various analogue maps, which were in different scales obtained from different organizations, were converted into digital format by using manual digitization method in ILWIS 3.2 software. All primary input maps (hydrogeomorphology, lineament, spot elevation, drainage and geo-electrical sounding location) were digitized. Slope map was prepared from digital elevation data DEM.

All the above themes were brought into ArcGIS 8.3 for further processing and integrated analysis of multi-disciplinary data sets to construct composite information set to explain various queries in the spatial context.

The different polygons in the thematic layers were labeled separately and then they were registered. In the final thematic layer initially each one of the polygons were qualitatively visualized into one of the categories like (i) very good (ii) good to very good (iii) good (iv) moderate and (v) poor in terms of their importance with respect to groundwater occurrence and suitable weights have been assigned.

Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi-class maps. The efficacy of this method lies in that human judgment can be incorporated in the analysis. A weight represents the relative importance of a parameter vis-à-vis the objective. *Weighted index overlay method* takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Choudhury, 1997 and Saraf and Choudhury, 1998).

Determination of weightage of each class is the most crucial in integrated analysis, as the output is largely dependent on the assignment of appropriate weightage. Considering the hydro-geomorphic conditions of the area weighted indexing have been adopted (Table 2) to delineate *groundwater prospective zones* considering different parameters namely hydrogeomorphology, slope, drainage, soils and lineaments.

Finally *thematic layers* were converted in to *grid* with related item weight and then integrated and analysed, using *weighted aggregation method*. The grids in the integrated layer were grouped into different *ground water potential zones* by a suitable *logical reasoning and conditioning*. The *final ground water potential zone map* thus generated was verified with the *yield data* to ascertain the validity of the model developed.

The weights assigned to different classes of all the thematic layers are given in Table (2). To cite an example, the maximum weight assigned for the aquifer thickness was 5 for thickness greater than 35m, whereas the lower weight of value 1 was assigned to thickness less than 6 m. On the other hand,

in a hydrogeomorphology layer, a maximum weight of 5 was assigned for Nile flood plain and a minimum weight of 1 for Limestone plateau (Table 2).

The thematic layers which include hydrogeomorphology, lineament, slope, drainage, depth to aquifer and aquifer thickness were converted into grid with related item weight and integrated with one another through ArcGIS 8.3 grid environment. As per this analysis, the total weights of the final integrated grids were derived as sum of the weights assigned to the different layers based on suitability.

In the present study, *groundwater prospects map* has been generated by integration of hydrogeomorphology, lineament, slope, drainage and depth to water bearing zone. However, g*roundwater potential map* generated by integration of aquifer thickness, with hydrogeomorphology, lineament, drainage, water bearing zone and slope gives the more realistic picture. The delineation of groundwater potential zones was made by grouping the grids of final integrated layer into different potential zones, very good, good to very good, good, moderate to good, moderate, poor to moderate and poor.

Table 3 gives the way in which the upper and lower limits of the weights derived for demarcation of the ground water potential areas. Theoretically, the upper weight 25 and lower weight 7 could be possible, and derived by combining all the upper and lower categories in all layers. However, in the study area, 22 was the highest and 5 was lowest value obtained. By utilizing the above discussed model a map showing different groundwater potential zone was prepared (Fig. 19).

3 Model Evaluation and Results

The validity of the model developed was checked against the bore well yield data which reflects the actual groundwater potential. Groundwater potential zones prepared through this model are in good agreement with yield data and pumping tests.

Conclusions and Recommendations

In order to delineate the groundwater potential zones, in general, different thematic layers viz: hydrogeomorphology, lineaments, slope, drainage and depth to aquifer are integrated without considering aquifer thickness. This provides a broad idea about the groundwater prospect of the area. Presently groundwater potential zones have been demarcated by integration of aquifer thickness derived from surface electrical resistivity survey and drilling data with above thematic layers, using a model developed through GIS technique.

Table (2): Weightage of Different Parameter for Groundwater Prospects

S.No.	Criteria	Classes	Weight
1.	Hydrogeomorphology	Nile flood plain	5
		Transverse channels	3
		Low land desert areas	2
		Limestone plateau	1
2.	Slope (degree)	0 – 0.5	5
		0.6 – 2.0	4
		2.1 – 5.0	3
		5.1 – 10.0	2
		> 10.0	1
3.	Surface Lineament	Present	2
		Absent	1
4.	Subsurface Lineament	Present	2
		Absent	1
5.	Drainage	High possibility for floods (A)	3
		Moderate possibility for floods (B)	2
		Low possibility for floods (C)	1
6.	Depth to water bearing zone	> 25 m	3
		6.0 – 25.0 m	2
		< 6.0 m	1
7.	Aquifer thickness	> 35 m	5
		26.0 - 35.0 m	4
		16.0 – 25.0 m	3
		6.0 – 15.0 m	2
		< 6.0 m	1

Table (3): Integrated Groundwater Categories For Groundwater Potential With Lower And Upper Weight Value (Integration of aquifer thickness with other parameters : hydrogeomorphology, lineament, slope, drainage and Depth to water bearing zone).

Sl. No.	Groundwater Category	Lower & Upper weight Value
1.	Very Good	20 – 22
2.	Good to very good	17 – 19
3.	Good	15 – 16
4.	Moderate to good	13 – 14
5.	Moderate	11 – 12
6.	Poor to moderate	9 – 10
7.	Poor	5 - 9

The final groundwater potential map (Fig. 18) emphasizes that the area of Sohag Governorate could be classified into three zones:

Fig. (19): Groundwater potentiality map, Quaternary aquifer, Sohag Governorate area.

The first zone occupies the central part and is more or less coincident with the old cultivated land bounded in both the northeast and southwest by Prenile sediment (Nile fringes). This is characterized by: (a) shallow water bearing zone, (b) the highest potentiality and (c) the good quality of groundwater that is suitable for the different purposes of use. The aquifers are consisted of the Pleistocene sand and gravels of semi-confined conditions. It is non-hazard for flood, except in places in the south-eastern part of this zone.

The second zone, which is generally represented by intermittent parts on both sides of the first zone, is generally characterized by: (a) soil suitable for reclamation (most of the land reclamation activities are restricted to this zone), (b) medium groundwater potentiality and acceptable water quality groundwater exists under unconfined conditions (brackish groundwater) and (c) non-hazard, hazard and, in places, strongly hazard for flood.

The third zone is normally overlooked by the limestone plateau in both sides of the study area. It is characterized by : (a) the lowest groundwater potentiality of high salt contents and bounded by no water zone that located adjacent to the limestone scarp, (b) soil, which are not suitable for reclamation, (highly brackish groundwater) and (c) non-hazard and strongly hazard, in some localities, for the flood. Careful considerations should be regarded in carrying

out any development activities in these areas, especially those with strong hazards floods.

The groundwater potential zone map generated through this model was verified with the yield data to ascertain the validity of the model developed and found that it is in agreement with the bore wells yield data. This illustrates that the approach outlined has merits and can be successfully used elsewhere with appropriate modifications.

The present study has demonstrated the capabilities of using remote sensing, geophysical data and Geographical Information System for demarcation of different ground water potential zones, especially in diverse geological setup. This gives more realistic groundwater potential map of an area which may be used for any groundwater development and management program.

References

Abdel Kareem, H.H., 1972: Geology of the area east of the Nile Valley between Sohag and Girga. M.Sc. Thesis, Geol. Dept., Fac. Sci., Assiut Univ., Egypt.

Abdel Moneim, A. A., 1987: Hydrogeology of the Nile Basin in Sohag province. M. Sc. Thesis, Geol. Dept., Fac. Sci., Sohag, Assiut Univ., Egypt 131 p.

Abdel Moneim, A. A., 1992: Numerical simulation and groundwater management of the Sohag Aquifer, the Nile Valley Egypt, Ph. D. Thesis, Civil Eng. Dept. Univ. of Strathclyde, Glasgow, U.K. 464p.

Abdel Moneim, A. A., 1994: Effect of groundwater extraction on the River Nile water using the numerical simulation technique. National Conference on the River Nile (10-14 Dec.) Assiut University Center for Environmental Studies (AUCES).

Abdel Moneim, A.A., 1999: Geoelectrical and hydrogeological investigations of groundwater resources on the area to the west of the cultivated land at Sohag, Upper Egypt. Egyptian Journal of Geology, V 43/2 1999 pp. 253-268.

Ahmed, A. A., 1997: Geophysical and hydrogeological studies in the area southeast of Sohag, Egypt. M.Sc. Thesis, Geology dept. Faculty of Science, Sohag, South Valley University.

Ahmed, S. M., 1980: Geology of the area east and southeast of Sohag. M. Sc. Thesis, Geol. Dept., Assiut Univ., Egypt.

Alexander, D. 1993 Natural disasters. London; UCL Press.

Amer, A. F.; Krintsov, M.L. and Hanna, F.L. (1970): The Egyptian carbonate rocks and the possibilities of their utilization. In: studies on some mineral deposits of Egypt. Geol. Surv. Egypt, p.195-208.

APHA, AWWA and WPCF, 1985: Standard methods for examination of water and wastewater. Joint publication of APIIA, AWWA and WPCF; 16th edition. Amer. Pub. Health Asso. Washington, 1268 p.

Ashmawy, M. H. 1994: assessment of flash flood potential of the Red Sea drainage basins along the Qena – Safaga highway, Eastern Desert, Egypt. ITC Journal, 2, p. 119-128.

Attia, F. R., 1985: Management of water systems in Upper Egypt. Ph. D. Thesis, Fac. Eng., Cairo Univ., Egypt 245 p.

Barber,W. and Carr, D.P., 1981: Water management capabilities of the alluvial aquifer system of the Nile Valley, Upper Egypt. Technical Report No. 11, Water Master Plan, Ministry of lirrig., Cairo, Egypt.

Bobachev, A. B., Modin, I. N. and Shevnin, V. A. (2001): IPI2Win Software - a program for ID automatic and manual interpretation of VES-curves, Moscow State Univ., Fac. Geol., Geophysics Dept., Moscow, Russia.

Burrough, P.A., 1986: Principles of Geographic Information Systems for Land Resource Assessment, Monographs on Soil and Resources Survey No. 12, Oxford Science Publications, New York.

Diab et al., 2002: Evaluation of water resources and land suitability for development in the southern part of Sohag, Upper Egypt, Annals Geol. Surv. Egypt, V. XXV, pp.487-512.

Duffield G. M. and Rumbaugh, J. O., 1995: AQTESOLV Software, Geraghty & Miller Modelling Group, Preston White Drive, Suite 301 , Reston, VA 22091, (703) 476 – 535.

EGPC and CONOCO, 1986, 1987, Geological map of Egypt, scale 1:500 000, Cairo.

EGSMA, 1996: Flood November 1994. Part 1 — Upper Egypt Governorate (in Arabic).

Egyptian Meteorological Authority 2000 database.

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

El- Shamy, I. Z., 1992b: New approach for hydrological assessment of hydrographic basins of recent recharge and flooding possibilities – 10th Symp. Quaternary and Development, Egypt, Mansoura Univ., 18 April, p. 15 (Abstract).

El- Shamy, I. Z., 1992c: Towerds the water management in Sinai Peninsula. Proc. 3rd. Conf. Geol. Sinai Develop. Ismailia, p. 63-70.

El-Etr, H. A., and Ashmawy, M. H. 1993: Flash lood vulnerability and mitigation of the Red Sea basins between Latitudes 24o 41' and 25o 26'; Egypt Proc. Inter. Conf. 30 years cooper., Geol., Surv., Egypt, Cairo, p. 335 – 351.

Environmental Systems Research Institute (ESRI). 1996: Working with the ArcView Spatial Analyst.

Finkl, C. w., Jr., and Myers, S. D. 1996: Evaluation of potential flood zones (PFZ) in southeastern Florida using remote sensing and GIS/LIS: Implications for storm water management and environmental protection. In South Florida section conference proceedings. American Society of Civil Engineerings. Reston, VA: American Society of Civil Engineers, p. 48 – 63.

Geological Survey of Egypt, 1994: Floods of Nov.1994. Internal report.

GPC, 1980, The Bouguer gravity map of Egypt. Scale 1: 500 000, Cairo.

Green, C. H. and Penning - Rowsell, E. C. 1989: Flooding and the quantification of intangibles. Journal of the Institution of Water and Environmental Management 3(1) 27-30.

Gregory, K.J. and Walling, D.E., 1973, Drainage Basins, Form and Process; A geomorphological approach. Edward Arnold London pp 456.

Hanna, F.S. 1986: Regional Report, Upper Egypt, Land Master Plan, Ministry of Development, General Authority for Rehabilitation project and Agricultural Development Cairo, Egypt, pp. 1-87.

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

Horton, R.E., 1945: Erosional development of streams and their drainage basins; Hydrogeological approach to quantitative morphology. Bull. Geol. Soc. Amr. V.56 p. 275-370.

Ibrahim , H.A., Bakhit, A.A. and Fahim, S.M., 1991: Earth resistivity and self-potential study on the area east of Sohag city and other groundwater implications, Bull. Fac. Sci., Assiut Univ., Egypt, V. 20, No. 2, pp.149-162.

Issawi, B., 1983: Ancient rivers of the Eastern Egyptian Desert. Episodes, V. 2, pp 3-6.

Issawi, B. and McCauly, J.F., 1993: The Cenozoic landscape of Egypt and its river systems. Ann. Geol. Surv. Egypt. V. XIX, pp 357-384.

Issawi, B. Hassan, M.W., and Osman, R. 1978: Geological studies in the area of Kom Ombo, Eastern Desert, Egypt. Ann. geol. survey, Egypt. v. VIII, p.187-235.

Issawi, B., and McCauley, J. F. 1992: The Cenozoic rivers of Egypt: the Nile problem. In: Freidman, R. And Adams, B., (Eds.), The Followers of Horus, Egypt: Studies Assoc.Public., no.2, Oxbow Monog. 20, Park End Place, Oxford, p.121-138.

Jensen, J. 1996: Introductory digital image processing: A remote sensing perspective, 2nd ed. Upper Saddle River, New Jersey: Prentice Hall.

Kareim M., S., 2000: Natural hazard on the east side of the River Nile between Awlad yahia on south and Salamoni on the North; Sohag, Faculty of Arts Journal, Sohag, special issue, No. 23, Vo. 1, 102 p (in Arabic).

Kareim M., S., 2001: Geomorphology of the east side of the River Nile; Sohag. Bull. Geog. Soc. Egypt, v. 37, p. 295-358. (in Arabic).

Korany, E. A., Omran, A.A., and Abdel-Aal, A. A. (2006): Hydrogeochemical approach for the assessment of the recharge routes of groundwater in the Quaternary aquifer, Nile Valley of Sohag area, Egypt, Proc. of the 7th Int. Conf. on Geochemistry, Alexandria, September (2006).

Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rihnd, D. W. , 1999: Geographical Information Systems: Principles, Technical Issues, Management Issues, and Applications. John Wiley and Sons. Inc,New York,2nd Ed.,1101p.

Mahran, T.M. and El Haddad, A. 1992: Facies and depositional environments of upper Pliocene — Pleistocene Nile sediments around Sohag area, Nile Valley, Egypt. Journal of Saharian studies V.1, No.2 , pp. 11-40.

Mahran, T.M., 1992: Sedimentological development of the Upper Pliocene-Pleistocene sediments in the area of El Salamony and El Sawamha Sharq, NE Sohag, Nile Valley, Egypt. Sohng pure & App. Sci. Bull. Fac. Sci., Assiut Univ., Egypt, V. 8, pp 25 1-276.

Mahran, T.M., 1993: Sedimentology of Upper Plioccne-Pleistocene sediments of the Nile Valley area. A model around A~vlad Toq Sharq environs, SE of Sohag, Egypt. Bull, Fac. Sci., Assiut Univ., Egypt, V. 22, No. 2-F, pp l~25. manual; Interpretation of resistivity sounding curves, Interpex Limited.

Melton,M., 1957: An Analysis of The Relations among Elements of Climate, Surface Properties and Geomorphology, Project NR 389-042, Tech. Rept. 11, Columbia Univ.

Meteorological Authority of Egypt (MAE), 2000: Meteorological database, Cairo, Egypt.

Mostafa, H. A.. 1979: Geology of the area Northeast of Sohag. M.Sc Thesis ,Geology Dept. Faculty of Science, Sohag. South Valley University, 259 p.

Mousa, S., Attia, F. A. and Abuel Fetouh, A. M., 1994: Geoelectrical and hydrogeological study on the Quaternary Aquifer in the Nile Valley between Asyut and Sohag Governorate, Egyptian Journal of Geology, V. 38, No. 1, pp.1-20.

Omara. S., El Tahlawi, M. R. and Abd El Kareem, H. 1973: Detailed geological mapping of the area between the latitudes of Sohag and Girga, East of the Nile Valley, Bull. Fac. Eng., Assiut, Univ., V.1, pp. 149-166.

Omara, S., El Tahlawi, M. R., and Hafez, H. 1970: The geology of the environs of Assiut. Bull. Soc. Geograph. Egypt, p. 43.

Omer, A. A. 1996: Geological, mineralogical and geochemical studies on the Neogene and Quaternary Nile basin deposits, Qena-Assiut stretch, Egypt. Ph.D. thesis, Geology Dept. Faculty of Science, Sohag, South Valley University, 320 p.

Omer, A. A. and Issawi, B. 1998: Lithostratigraphical, mineralogical and geochemical studies on the Neogene and Quaternary Nile basin deposits, Qena-Assiut stretch, Egypt. The 4 th International conference on Geology of the Arab World, Cairo. (Abstract).

Omer, A.A.M. and Abdel Moneim, A.A, 1998: Influence of the Nile basin deposits on the groundwater chemistry at Sohag area, Nile Valley Upper Egypt. 36th Ann. Meeting. Met. Geol. Soc. (abstract). V.36, 17 p.

Omran, A.A., Korany, E. A., and Abdel-Rahman, A. A. (2006): An integrated approach to evaluate groundwater potentiality – A case study, Proc. of the 3rd Int. Conf. of Applied Geophysics, ESAP, 18-20 March 2006, National Research Center, Cairo, Journal of Applied Geophysics , Vol. 5, Part 1.

Omran, A. A., Riad, S. Philobbos, E. R. and Othman, A. B., 2000: Subsurface structures and sedimentary basins in the Nile Valley area as interpreted from gravity data. Egypt. J. Geol., V. 45, No. 1, pp. 48-75.

Paulissen, M. and Vermeersch, P. M. 1987: Earth, man and climate in the Egyptian Nile Valley during the Pleistocene: In: A. Close (Ed.), Prehistory of North Africa. Southern Methodist University Press, Dallas, p. 29-67.

Philobbos, E. R., Riad, S., Omran, A. A. and Othman, A. B., 2000, Stages of fracture development controlling the evolution of the Nile Valley in Egypt. Egypt. J. Geol., V. 44, No. 2, pp. 503-532.

RIGW 2000: Regional Institute for Groundwater, El- Qnater Cairo, data base.

Said, R. 1960: Planktonic foraminifera from the Thebes Formation, Luxor, Egypt. Micropaleontology, V.16, pp. 227-286.

Said, R. 1962: The Geology of Egypt. Elsevier Pub. Cornp. Amsterdam, 377 p.

Said, R. 1971: Explanatory notes to accompany the geological map of Egypt 1:2,000,000.Geol. Surv. Egypt. Paper 56,123p.

Said, R. 1975: The geological evolution of the River Nile In: Problems in prehistory of Northern Africa and the Levant. Wendorf, F. & Marks, A.F. (eds). Southern Methodist University press. Dallas, Texas, pp. 1-44.

Said, R. 1981: The geological evaluation of the River Nile. Springer-Verlage, New York, Heidelberg, Berlin, 151p.

Said, R., 1983: Proposed classification of the Quaternary of Egypt. Jour. of African Earth Sciences. V.1, p.41-45.

Said, R. 1990: The Geology of Egypt. S.A., Balkema, Rotterdam, Brookfield, 731p.

Saleh, A. S. 1989: Flash floods in deserts; a geomorphic study of desert wadis. Institute of Arab research, Special studies series, No. 51, 93 p (in Arabic).

Sayed, M.A., Mabrouk, M.A., and Hosny, H. 1991: Delineation of the Quaternary aquifer in a part of the Nile Valley using D.C electrical Soundings. Egypt. 1. Geol. V 35, 1-2 pp. 119-132.

Saraf, A. K. and Choudhury, P. R., 1997: Integrated Application of Remote Sensing and GIS Groundwater exploration in hard rock terrain, Proceedings. Int. Symp. on Emerging trends in Hydrology, Department of Hydrology, Roorkee, September 25-27, 1997, Vol. I, 435-442.

Saraf, A. K. and Choudhury, P. R., 1998: Integrated Remote Sensing and GIS for Groundwater Exploration and Identification of artificial recharge sites, International Journal of Remote Sensing. 19(10), 1825-1841.

Shumm, S.A., 1956: Evaluation of drainage system and slops in Badlands at Perth Amboy, New Jercy. bull, Geol. Soc. Amer. Vol. 67 pp 597 - 646.

Strahler, A. N., 1952: Dynamic basis of geomorphology, Bull. Geol. Soc., amer., V. 63, p. 923-938.

Strahler, A.N., 1957: Quantitative analyses of watershed geomorphology. Trans. Amer. geophy. Union 38 p 913 - 920.

Strahler, A.N., 1964, Quantitative geomorphology of drainage basins and channel network, In VT Chow (ed) handbook of applied hydrology. Section 4-1 1.

Tomiln, D & Johnston, K 1988: "An experiment In landuse allocation with GIS" In Proceedings Of A National Meeting Of The American Congress On Surveying And Mapping, Vol. 5, 1988.

Tomlin, D., 1990: Geographic Information Systems and Cartographic Modelling, Prentice-Hall Inc., New Jersey, 352 p.

U.S. Salinity Laboratory 1954: Diagnosis and improvement of saline and alkaline soil. U. S Dept. of Agriculture Handbook, No. 60. 160 p.

UBSR (1953). Bureau of Land Reclamation Manual, V. 5 Irrigation Land Use Part 2 Usd for Interior Washington DC USA

Van Der Velpen , B. P ,1993: Resix-IP user's

Wendorf, F., and Said, R. 1967: Paleolithic remains in Upper Egypt. Nature, v.215, p.244-247.

Wendorf, F., and Schild, R. 1976: Prehistory of the Nile Valley: Academic Press, New York and London. 404p.

Whitley, D, Xiang, W & Young, J. 1993: "Using A GIS as a melting pot to assess landuse suitability" In GIS World, Vol. 6 No. 7 Pp. 48-52, Co.

World Health Organization, 1984: Guidelines for drinking water quality 1, Recommendations Geneva, .WHO.

Yaakup A. B., & Johar. F. 1996c: GIS for integrated planning decision for the development of Sungai Lembing Historical Park, Pahang, Malaysia, Paper presented at the GeoInformatic'96 Wuhan : International Conference on GIS, GPS, Remote Sensing and Spatial Analysis. Wuhan.

Youssef, A. M., Abdel Moneim, A. A. and Abu El-Maged, S. A., 2005, "Flood hazard assessment and its associated problems using geographic information systems, Sohag Governorate, Egypt" In The 4th International Conference on The Geology of Africa, Nov. 2005, Assiut, Egypt, Vol. 1, pp. 1-17.

Zaki, S.R. 2001: Hydrogeological studies and application of geographical information system for evaluation of water resources and land use projects in the southern part of Sohag Governorate. M.Sc. Thesis, Geology Dept. Faculty of Science, Minufiya University, Egypt.

Zohdy, A. A. R. and Bisdorf, R. S., 1989: Programs for the automatic processing interpretation of Schlumberger sounding curves in Quick Basic. 40: U.S. Geol. Surv. Open File Rep. 89-137 A and B. 64 plus disk.