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INTEGRATED GRAVITY AND RESISTIVITY ANALYSIS FOR GROUNDWATER OCCURRENCES IN ASSUIT AREA, UPPER EGYPT

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دراسة تكاملية بين التحليل الكهربى و التثاقلية لتواجدت المياه الجوفية بمنطقة أسيوط بصعيد مصر

الخلاصة: لقد تم عمل دراسة تكاملية بين نتائج المسح الكهربى و نتائج تحليل التثاقلية لتقييم مصادر المياه الجوفية و العوامل المؤثرة فى توا جداتها. لقد تم تحليل خريطة بوجيير للشواذ التثاقلية مع تحليل ٣٣ جسه كهربية رأسية لتحديد امتدادات خزان المياه الجوفى و التراكيب الجيولوجية التحت سطحية. لقد أظهرت الدراسة التثاقلية الامتدادات الأفقية و الراسية للخزان والذى يتميز بقيم تثاقلية منخفضة بوادى النيل وأظهرت أيضا تأثر القطاع الصخرى بمجموعة من الصدوع التى تلعب دورا مهما فى تغذية الخزان الجوفى بمياه سطحية أو بمياه من الخزان النوبى العميق. أما الجسات الكهربية فقد أظهرت أن خزان المياه الجوفى التابع لعمر البلستوسين–الحديث يتكون من ثلاث طبقات كهربية بالإضافة إلى تحديد السطح العلوى و سمك و التوزيع الافقى و الراسى للخزان. من النتائج أيضا أن سمك الجزء المشبع بالمياه فى الخزان يتراوح ما بين ٧٠ و ١٧٠ متر وان قيم المقاومة الكهربية الحقيقية للخزان تتراوح بين ١٠ و ٨٠ اوم.متر اعتمادا على محتواه الصخرى و ملوحة المياه.

ABSTRACT: *Integrated geophysical investigation has been carried out using both gravity and electrical resistivity techniques to evaluate the groundwater resources and the geologic factors affecting their occurrence. The geophysical survey includes analyzing the Bouguer anomaly map and thirty three VES'es to delineate the Pleistocene-Recent aquifer extension, and the subsurface geologic structures. The gravity study shows the expected horizontal as well as vertical extension of the subsurface aquifer, which corresponds to the general low gravity effect within the Nile Valley. Also, the gravity study reveals the existence of a number of faulting features that are dissecting the sedimentary sequence and play an important role in replenishment the upper Pleistocene groundwater aquifer either through surface infiltration or subsurface discharge from the deeper Nubian aquifer. The interpretation of the resistivity data indicated the presence of three main geoelectrical units of varying resistivity ranges. Using the results obtained from the interpretation of the resistivity data, the depth to the top of the aquifer unit, its thickness and the distribution of the interpreted true resistivity have been mapped to show their horizontal as well as the vertical variations within the study area. The average thickness of the water bearing horizon is ranging from 70 to 170 meters within the close proximity to the Nile River. The aquifer's interpreted resistivity ranges from 10 to 80 Ohm.m depending generally on its lithological composition and groundwater salinity.*

Keywords: *Residual and regional gravity, first & second vertical derivatives, VES.*

INTRODUCTION

Egypt is facing the challenge of developing new agricultural lands to support its increasing population (Davis and Bernstam, 1991). Accordingly, Egypt has adopted aggressive policies to develop new agricultural communities outside the Nile Delta and Nile River valley (*for example*, Tushka Project and El-Salam Canal Project). Networks of minor wadies dissect the Red Sea Hills and the surrounding Cretaceous and Tertiary outcrops and join into the main valleys that ultimately drain into the Red Sea or the Nile Valley (*for example*, El-Assuity, Qena and Hammamat; Figure 1).

Groundwater constitutes an important source of water for various purposes like domestic needs, supply for industries and for agriculture,… etc. in the strip of the desert fringes on both sides of the Nile Valley, which has been partially reclaimed and completely irrigated with groundwater. The conventional approaches for groundwater investigation are time consuming, uneconomical and sometimes have poor success rate. The concept of integrated multidisciplinary approach has proved to be an efficient tool for groundwater exploration. Keeping this in mind, the present study attempts to delineate groundwater aquifer conditions using integrated approach of gravity and resistivity techniques, in addition to some hydrological and hydrogeological information, covering the study area.

The Quaternary aquifer is the major exploited aquifer in the area and it is considered as alluvial deposit aquifer. The purpose of this study is to use and interpret the Bouguer gravity and resistivity data and the available geologic and hydrologic information to study the aquifer conditions; such as depth and nature of the alluvium, boundaries and location of the aquifer and groundwater quality.

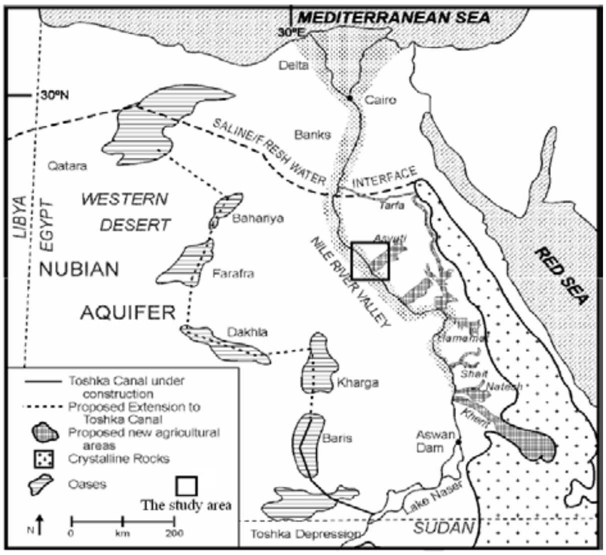


Figure (1): Map showing the location of the study area, including Wadi El-Tarfa, El-Assuity, Hammamat and Qena. Also shown are the locations of other main valleys of the Eastern Desert that drain into the Nile River and could have hydrologic settings similar to those investigated in this study.

However, the use of geophysics for both groundwater resource mapping and for water quality evaluation has increased dramatically over the last years in large part due to the rapid advances in microprocessors and associated numerical modeling solutions. The vertical electrical sounding (VES) technique has proved very popular with groundwater studies due to simplicity of the application. Disadvantages of such investigations are that can be labor-intensive and expensive (Kalinski et al. 1993).

STUDY AREA AND SCOPE OF WORK

The subject of this study is the detection of groundwater in the relatively shallow alluvial Quaternary and limestone aquifers of Wadi El-Assuity, one of the promising desert fringes at both sides of the Nile Valley (Fig. 1). Here, Quaternary deposits comprise wadi and flood plain deposits of sand, gravel and clay components. The alluvial deposits were eroded from the dissected plateau and the Red Sea hills, and were drained within the valleys. In general, the flood plain deposits of the Nile valley are made up of relatively thin Holocene units of fine mud and silt (agricultural layer) deposited by repeated seasonal floods during the past 8,000 years. The sediments are underlain by thicker deposits of Middle Pleistocene sands and gravels under the Nile Valley. The Quaternary deposits rest on karstified carbonates of Eocene and Late Cretaceous ages. The carbonates are underlain by Paleozoic-Mesozoic Nubian sandstones that host nonrenewable fossil waters under high pressure (Fig. 2) (Sultan et al, 2000).

In the study area, Assuit tract constitutes an important hydrographic part in the Nile Valley in Upper Egypt. It occupies an area including both the flood plain and the desert fringes between longitudes 31^{o} 00’ and 31^{o} 30’ E and latitudes 27^{o} 00’ and 27^{o} 30’ N (Fig. 1). The Nile valley, in Assuit area, is bounded from east and west by the Eocene Limestone plateau. These plateaus are dissected by a number of drainage basins that drains towards the valley from the east and west. The strip of the desert fringes on both sides of the Nile valley has been partially reclaimed and irrigated partially with groundwater. The predominant method used of irrigation is flooding. In the last ten years, rapid increase in the use of groundwater in the desert areas has occurred and that can affect the sustainability of the supply both quantitatively and qualitatively. Climatologically, the study area belongs to the arid belt of Egypt, where it characterized by long and hot summer, warm winter and scarce rainfall except the occasional storms.

Wadi El-Assuity starts in the form of tributaries, the most important of them is the area that starts in the south from Wadi Qena and directed to north. Among them is Wadi Habib that ends in the plateaus on the two sides. Wadi El-Assuity then extends west to meet the Nile valley in the form of a delta, whose base is parallel to the River Nile and its area is about 50,000 feddans. Also, Wadi El-Assuity is one of the major four wadis in the northern part of the Eastern Desert (wadi El-Tarfa, Hammamat, El-Assuity and Qena). These four watersheds collect a large proportion of the precipitation; they cover approximately 50% of the total area of the northern part of the Eastern Desert and approximately 70% of the total area occupied by the watersheds that drain toward the Nile River (Naim, 1995). The estimated average annual recharge for the Tarfa, El-Assuity, Qena, and Hammamat alluvial aquifers at 4.7×10^{6} m^{3}, 6×10^{6} m^{3}, 14.7×10^{6} m^{3}, and 17.7×10^{6} m^{3}, respectively. Sultan et al (2000) modeled the hydrology of Wadi El-Assuity as receiving precipitation of 75.3×10^{6} m^{3}, with 50.3×10^{6} m^{3} as initial losses (66.8 % of the total precipitation), 20×10^{6} m^{3} as Transmission losses (26.4 % of the total precipitation), and 5×10^{6} m^{3} Downstream runoff (6.8 % of the total precipitation).

GEOLOGY OF THE STUDY AREA

The Nile Valley is a structurally /erosionally-controlled basin cutting through the limestone plateau. According to Said (1981 and 1990) and others, the Nile Valley was exacavated during the Late Miocene age. In the study area, the Nile Valley is filled with Pliocene and Quaternary deposits, while its side walls are built up of the Eocene limestone. The sedimentary sequence in the study area (from top to base) is shown on the geologic map (Fig. 3) and the generalized stratigraphic section (Fig.4), as the followings:

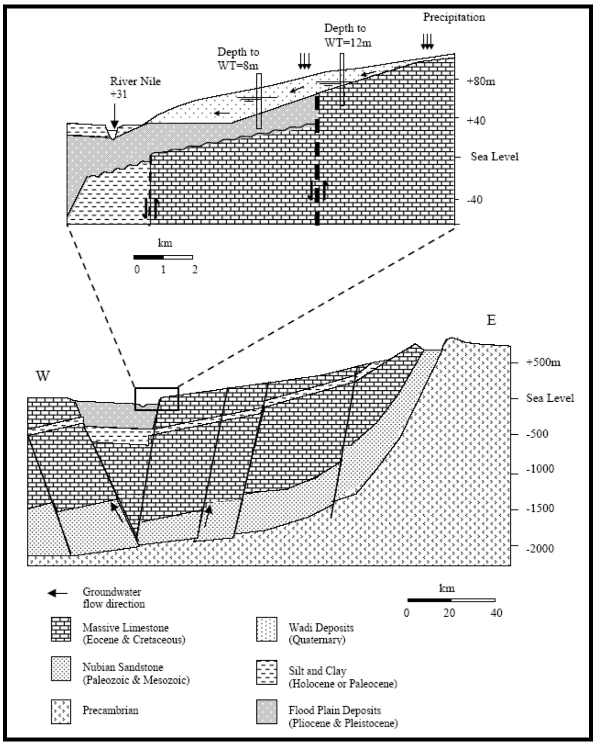


Figure 2. Schematic west-to-east cross section (top) showing the major stratigraphic units and water table elevations, in relation to the Nile River surface elevation. Also shown (bottom) is a schematic west-to-east cross section from the Nile River (west) to the south of the study area to the Red Sea hills (east). (RIGW, 1988; Sultan et al., 2000).

1- Holocene:

The Holocene sediments include the recent wadi deposits and Arkin Formation. The wadi deposits comprise the sands and gravels of wadi filling, outwash and fanglomerate. These sediments cover a great part of the surface of Wadi Al-Assuity. The Arkin Formation is made up of silty clay deposits with a maximum thickness of about 20 meters. This silty clay layer forms the traditional agricultural soils in the Nile Valley of Assuit area that is interfingered with the surface and shallow sediments in Wadi El-Assuity.

2- Middle-Late Pleistocene:

The sand and gravel of Pleistocene age cover the surface of the old alluvial plains, which are subjected to the new reclamation activities. The Pleistocene sediments of the Nile basin are generally friable and highly porous and permeable. They represent the main aquifer, which yields large quantities of groundwater in the Nile Valley.

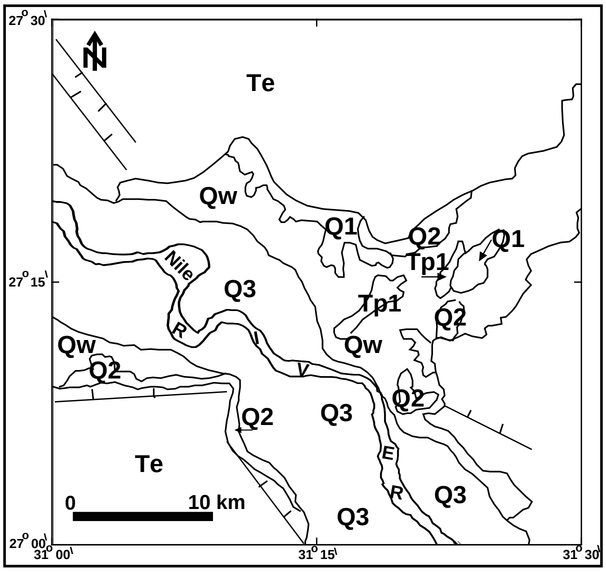
The Middle and Late Pleistocene rocks comprise the Abbassia, Dandara and Qena Formations (Fig. 4). The Abbassia Formation consists of gravels with little sands. The Dandara Formation is made up of sandy silt intercalated with silt. The Qena Formation is composed of, cross-bedded and graded sands, and gravels with clay lenses. The Middle and Upper Pleistocene sediments unconformably underlie the previously near-surface silty clay layer. They are considered as the main Quaternary aquifer in the study area. These sediments are also exposed at the mouth of Wadi El-Assuity.

3- Early Pleistocene:

According to Said (1981 and 1990), the Early Pleistocene rocks comprise the Issawia, Armant and Idfo Formations (Fig. 3). The Issawia Formation is built up of sand and clay beds capped by red breccias and travertine layers. The Armant Formation consists of clay, sand, and conglomerate beds. Both the Armant and Issawia Formations are exposed in Wadi El-Assuity (Fig. 3). The Idfu Formation is composed of cobbles and gravels in a clay matrix.

4- Pliocene:

The Pliocene rocks are highly enriched in clay facies with few sand lenses. These rocks are located in the central part of Wadi Al-Assuity (Fig. 3) and are found overlying the Eocene limestone.



Q_1: Plio-Pleistocene sand

Q_2: Plio-Pleistocene clay

Q_3: Silty clay layer (Recent)

Q_w: Wadi sediments

T_e: Eocene carbonate

Figure 3. Geologic map for the area under study (Said, 1983).

5- Eocene

The Eocene limestone and Paleocene marl and shale build the two plateaus at both sides of the Nile Valley. The Lower and Middle Eocene rocks consist of limestone and chalky limestone with chert bands in the study area. Also, these rocks are found under the Pliocene-Quaternary sediments in the trough of the Nile Valley.

Age			River Stages	Formation	Lithology	Description
Quaternary	Holo-cene		Neonile (Q3)	Wadi Outwash		Gravel & Sand
				Arkin		Silty Clay of cultivated lands
	Pleistocene	Middle-Late	Prenile (Q2)	Abbassia II		Conglomerate
				Dandra		Sandy Silt & Silt
				Abbassia I		Conglomerate
				Qena		Massive Cross-bedded Sand with Clay lenses
		Early	Proto./ Prenile (Q1/Q2)	Issawia		Tuffa, red breccias & Sand
				Armant		Clay, Sand & Conglomerate
			Protonile (Q1)	Idfu		Cobbles & Gravels in red Clayey Matrix
Tertiary	Pliocene	Late	Paleonile	Madamud		Red Brown Clay, Sand, Silt and Marl
		Early		Marine Sequence		Clay and Sand
	Eocene	Early-Middle	Te			Chalky Limestone bed with Chert bands

Fig. (4): Generalized stratigraphic section (Said, 1983).

Structurally, the studied area is affected by faulting rather than folding and major joints. The prevailing trends of the faults are NE-SW, NW-SE, NNW-SSE, and E-W trends (Fig. 5a). The NE oriented faults controlled the formation of the Wadi El-Assuity graben and horst blocks, whereas the NW to NNW trending faults bound the Nile Valley and affect its side plateaus. The E-W oriented fault extends from the western side of the Nile Valley and could be coalesce with the NE faults (Manqabad fault) bounding the Wadi El-Assuity. The sinuosity pattern of the two sides of the Wadi El-Assuity is mostly related to their affecting faults that were modified later by erosions. The horst and graben of Wadi El-Assuity are considered by Abd-Allah (2008) as a transfer zone between the NW faults that elongated from the southern region of the study area northward to El Minia region.

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GEOMORPHOLOGY OF THE STUDY AREA

The study area represents a segment of the Nile valley in the northern part of Upper Egypt.

Three main geomorphic units (Fig. 5b) are distinguishable inside the study area, which are:

1- Young Alluvial Plain.
2- Old Alluvial Plains.
3- Structural Plateau.

The young alluvial plain occupies the central part of the Nile Valley in Assuit area. It is consisted of the silty clay layer resulting from the successive floods of the present Nile River. The surface of this plain is generally flat, having an average elevation of about 50 meters above the mean sea level and slopes very gently northward.

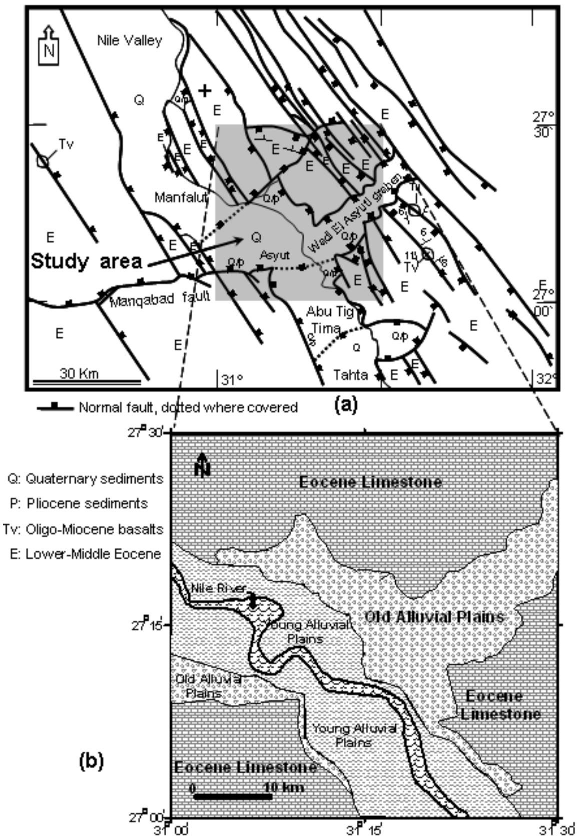

Fig. (5): Geomorphology of Wadi El-Assuity and surrounding area (b) and its affecting faults (a) (Geology map after Abd-Allah, 2008)

The old alluvial plains skirt the young alluvial plain on both sides and are underlain by mixed sand and gravel, which are developed into successive terraces rising to 20 meters above the present level of the flood plain. These terraces are dissected by complex wadis as Wadi El-Assuity. The floor of this wadi is occupied by the sediments of this plain that received the surface water drained from the surrounding high lands. The upper surface of this plain is dissected by several slightly shallow wadis and their tributaries.

The structural plateau bounds the Nile trough on both sides. The surface of this plateau is rough and underlain by Eocene carbonate rocks. This plateau terminates with faulty-controlled escarpment, which rising by about 280 meters above mean sea level, whereas its body is enriched with karstified carbonate beds. These karst features have been resulted from the rain fall on the plateaus and enhanced by the effect of the faults and joint affecting these beds.

GEOPHYSICAL TOOLS

Gravity Mapping:

Bouguer Gravity Map:

The gravity data used in this work involves the Bouguer gravity anomaly map (original scale of 1:100,000; provided by EGPC, 1977), as shown in Fig (6). The Bouguer gravity values in the study area range from –5 milligals (at the middle zone of the northern part) to –51 milligals in the central zone of the southern half of the study area. Such large closed negative anomaly (–51 milligals) represents a major gravity low. Visual inspection of Figure (6) shows that, the area is characterized by low gravity zone (ranging from –50 to –40 milligals) of a delta shape, where its base is almost parallel to the Nile River structural trend. The apex of this triangular delta-shaped contour area extends northeast-southwest. This negative, delta-shaped low, gravity zone is surrounded from all directions by lesser negative gravity gradients till the northern part of the study area, where the gravity values reach about –10 milligals or less. Diagonally, the gravity gradients in the northeastern half of the study area is characterized by a general northeast-southwest trend, while the southwestern half is portrayed by a general contour trend of northwest-southeast direction. The largest negatively-dominated zone within the central part of the study area may reflect a graben-type feature within the sedimentary section overlying the basement rocks.

Regional and Residual Maps:

In this work, the Bouguer gravity map (Figure 6) is used to study shallow and relatively deeper conditions in the studied basin. The gravity data in the study area are separated into regional and residual gravity anomalies. As a first step of the analysis of the gravity data set, and in order to establish the main geological features, the author undertook a regional-residual separation. The Bouguer anomaly map was manually interpolated to obtain a 0.5 km equi-spaced grid of 100 per 50 km (study area width). This gridded data set was used to conduct the regional-residual separation based in least square fitting of polynomial surfaces. The fundamentals from the use of the least squares method in the regional-residual separation problem have long been well established. A thorougful description can be found elsewhere (i.e., Simpson, 1954; Schoeffler, 1975; Thurstan and Brown, 1992; Parasnis, 1997; Ndougsa, 2004). The corresponding residuals were controlled for the presence of unreal anomalies. A close correlation was sought between the residual anomalies and the geology, in particular the coincidence between the gravity lows and the surface geological features (as Wadi El-Assuity low land). This control helped to check if the obtained residuals were biased by the least square method. The residual anomalies corresponding to the second degree polynomial surfaces comprised anomalies not observed in the Bouguer anomaly map. So, this polynomial, evaluated at the analyzed points, provided the regional. The residual was then obtained in a straight-forward way by subtracting the obtained regional from the Bouguer anomaly. The regional and residual anomalies maps were contoured using Surfer (Golden Software, 1994). The regional field was calculated and subtracted from the original Bouguer gravity data set. Figures 7 and 8 show the regional and residual anomaly patterns. The regional and residual anomalies obtained are then interpreted qualitatively.

Qualitative interpretation is based on the geophysical information that can be extracted from the regional and residual anomaly maps and their relationship with the geology of the area. In general, each regional anomaly is considered to be due to the density contrast which exists between the deeper section of the continental crust and the underlying denser material, while on the residual Bouguer anomaly map, the residual anomaly is due to the density contrast between the relatively shallow sediments and the underlying basement (if any) or the existing of uplifted blocks (horsts). The shape, size and magnitude of these anomalies also depend on the local geology of the area.

It can be seen that the regional anomalies close to the north and southwestern parts of Figure 7 are positive compared to those to the east, middle and southern parts of the map. In addition, the negative anomaly around the centre is elongated and extends approximately NW–SE making a T-shape structure with the other negative anomaly trending northeast-southwest. The values of the regional changes within a range of about (–10 to –49) milligal from the north to the middle part of the map. In the upper half of the map, the gravity gradients are higher than the rest of the map. All these observations can be interpreted in terms of the Pliocene-Quaternary fluvial sediments, that are filling the Nile Valley and Wadi El-Assuity, and have lower density that the surrounding Eocene carbonate rocks building the plateaus.

Since the anomaly decreases from the north towards the south, it is probable that the crust beneath the basin is thinner in the south or may be due to deep lithological variations.

The main features of the residual anomaly map (Figure 8) are different to those of the Bouguer anomaly map (Figure 6). On this map (Fig. 8), the residual gravity values form elongated stripes of alternated positive and negative anomalies.

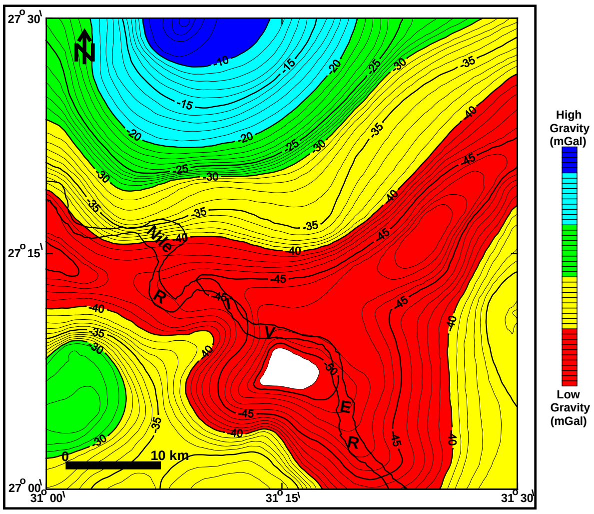

Fig. (6). Bouguer Gravity map (original scale 1:100,000 - after EGPC, 1977).

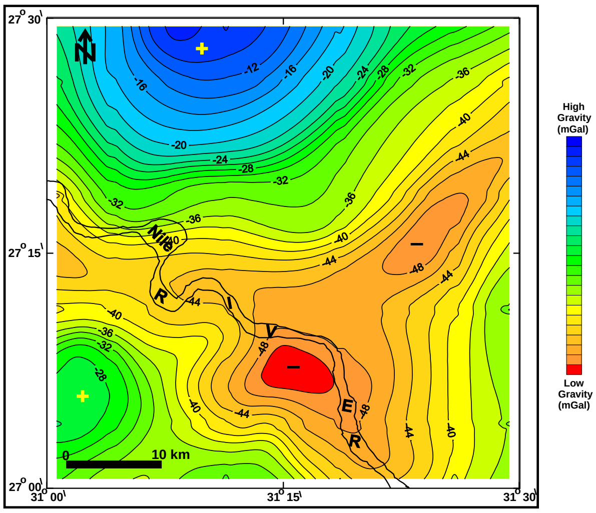

Fig. (7). Regional gravity map.

The majority of this map shows variations in the residual gravity values in the range from –0.4 to +0.4 milligal, with minor linear stripes of higher values at the northern half and southwestern parts of the map. The shapes of these anomalies vary from circular to elliptical. On the basis of geological considerations, the positive anomalies can be interpreted in terms of the faulted uplift features of denser rocks or local denser occurrences. The relative dominancy of the intermediate residual gravity values can be due to the fact that most of the study area is underlained by the Eocene limestones that might be uplifted with some eminent blocky limestone bodies. The negative residual anomalies found in the area are also accompanied by somehow large gravity gradients suggesting some shallow faulting features; have mainly the same fault trends affecting the surface (Figs. 5a and 8). So, the whole residual gravity picture reveals the presence of an aquifer foundation between higher density rocks that are mainly related to the Eocene limestone of more than 500 m thick.

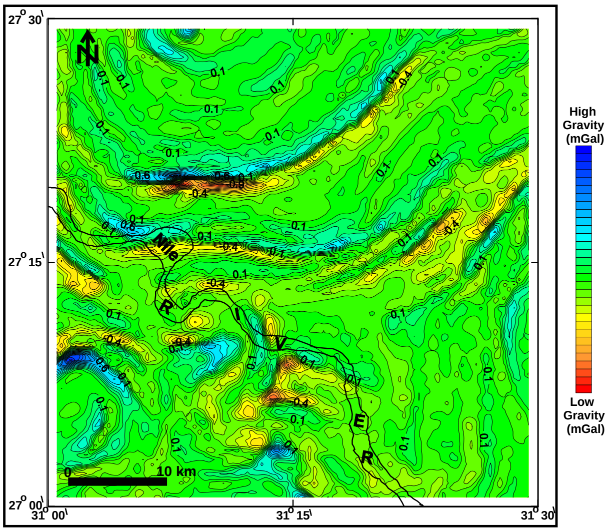

Fig. (8). Residual gravity map.

Vertical Derivatives of Gravity Data

Gradients and higher derivatives of geophysical data enhance the anomaly resolution by recording shallow and more sensitive signatures at the expense of the deep-seated sources. The double derivative method of screening gravimetric data assists regional geological interpretations. According to theory, the "second vertical derivative" maps the rate of curvature of potential fields. The zero-contour has a special importance in such maps and might coincide with the mineralized or denser boundaries and fault zones.

In general, taking the first and/or second order derivatives have some advantages, for example, enhances the shallow bodies and suppresses the deep ones, removes the regional, can reveal the sense of contacts, and, can calculate the limiting depths (the "Smith rules"). The derivatives disadvantage is that they enhance noise. But using some proper coefficients can reduce the amount of noise effect or carrying out the derivatives calculations on upward-continued maps. The coefficients developed by Beranek (1965) were used in calculating the derivative responses. The derivatives calculations were implemented by the author using a simple subroutine developed for calculating the first and second vertical derivatives from the Bouguer gravity data.

The profiles of the derivatives (Fig. 9) show the differences between the first and second vertical derivatives. Near-vertical boundaries between different lithologies can be more clearly delineated by the second vertical derivative, whereas the first vertical derivative enhances the geophysical signatures of shallow objects. First and second vertical derivative maps for the current study (Figs. 10 and 11) were constructed.

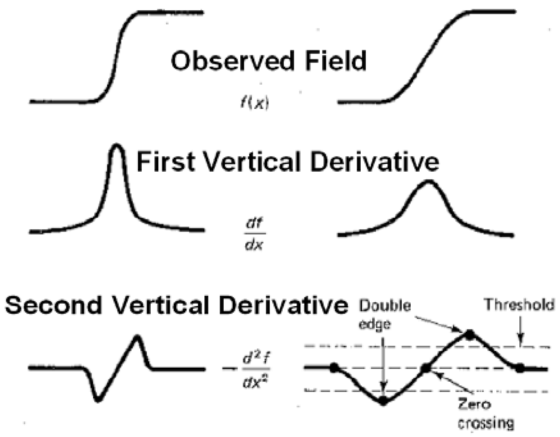

Fig. (9): Observed gravity field anomaly, first vertical, and, second vertical derivatives

Figure 10 is the first vertical-derivative map that derived from the relative Bouguer anomaly map of the study area. The first vertical derivative tends to highlight zones of strong density contrasts and also amplifies the higher frequency components of the signal. Localized and linear gravity highs shown define the zone of relatively shallow denser lithologies. Some of the finer structures in the first vertical derivative map correspond to density contrasts in the clastic section in the near surface section, such as the contrast between relatively denser material and less dense surrounding sand.

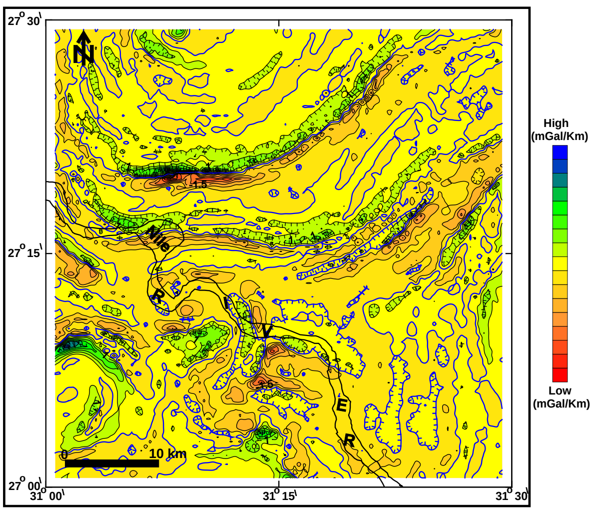

Fig. (10) Distribution of first vertical -derivative gravity.

The large number of closely spaced, intense positive and negative anomalies suggests that the bedrock lithology varies in density and mass due to either change in composition or degree of weathering. The alignment of these anomalies also suggests the presence of lineaments, both faults and lithologic boundaries, as is evidenced in the map of surface geology (Fig. 3). Linearly-trending positive anomalies in the northern half of the map may mark a boundary between the denser limestone and surrounding less dense lithologies. The second vertical derivative map (Fig. 11) generally enhances the resolution of anomalies recorded in the first derivative map.

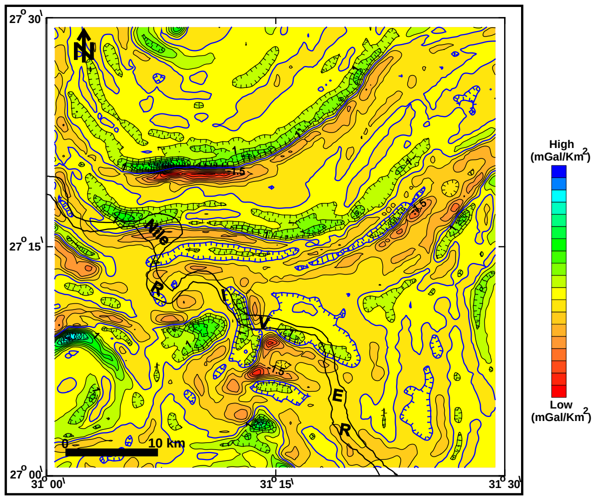

Fig. (11): Distribution of second vertical -derivative gravity.

The shallow, weathered, and water-saturated zone (effective density around 2.50 gm/cc) in the sandstones produces a prominent negative anomaly on the first-derivative map. The boundaries of this weathered zone, are not well defined in the first vertical derivative map. The second vertical derivative, which enhances the effect of shallow features, delineates the boundaries of the weathered zone with zero value. On the second-derivative map, positive values reflect higher density zones, and negative values reveal lower density parts.

So, it can be stated that, the resulted gravity maps (Figs. 8, 10 and 11) show the presence of the faults affecting the sedimentary section at different depths on the Precambrian hard rocks. The sedimentary aquifer is outlined by the general gravity low extending northeast-southwest as shown from figures 6 and 7, while the faulting effect is manifested by the relatively thin linear anomalous features in figures 8, 10 and 11. Hyrogeologically, this section of relative low gravity is differentiated into two main aquifer systems (Nubian at the base and Quaternary near surface) that are separated by a thick Upper Cretaceous-Eocene carbonate unit. The observed faults have mainly the NE trend, inside the Wadi El-Assuity, and NW to NNW oriented faults, in the south and west of the wadi. The interlinked E-W and NW faults characterize the southwestern part of the mapped area. These fault trends and styles are tightly resembled with those affecting the exposed Eocene rocks (Fig. 5a). In generally, the faults related gravity mapping and the exposed faults have affected the rocks that exist under the Quaternary aquifer in the study area and have no effect on the sediments of this aquifer.

Hydrogeologically, Yen et al (2000) estimated about 77% of groundwater in El-Assuity Quaternary system is replenished from the deep Nubian aquifer via faults, with 23% or less coming from the surface water runoff. These faults are inferred through the present gravity maps and have considerable influences on the recharge of the Quaternary aquifer by draining the surface water on and the water percolated the Eocene limestone on the two sided plateaus. As well, they provide a good contribution to the water charging the Quaternary aquifer from the deeper Nubian aquifer that has high peisometric levels.

Resistivity Investigations:

The Vertical Electrical Sounding (VES) survey is carried out by measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground (Dahlin, 2000).

The resistivity method is carried out to study the groundwater occurrence in the alluvium, mastic and another hard formation aquifer, as an inexpensive and useful method. Some uses of this method in groundwater rely on the determination of depth, thickness and boundary of an aquifer (Zohdy, 1969 and Young et al. 1998), definition of the interface between saline water and fresh water (El. Waheidi et al., 1992, and Choudhury et al., 2001), porosity of aquifer (Jackson et al, 1978), hydraulic conductivity of aquifer (Yadav, 1998, and Troisi et al. 2000), transmissivity of aquifer (Kosinski and Kelly, 1981), specific yield of aquifer (Frohlich and Kelly, 1987), hydrogeological mapping in karst terrains (Sumanovac and Weisser, 2001), contamination of groundwater (Kelly, 1976 and Kaya, 2001). Contamination usually reduces the electrical resistivity of pore water due to the increase of ion concentration (Frohlich and Urish, 2002). However, when resistivity methods are used, limitation can be expected, if ground inhomogeneties and anisotropy are presented (Matias, 2002).

The resistivity data/survey used in the current study was performed through and obtained from RIGW (personal communication). The Schlumberger array is a popular method which is rather time consuming. The Schlumberger soundings were carried out with maximum current electrode spacing (AB/2) reached 1000 m. The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement.

In the current study area, a total of 33 VES'es were analyzed (Fig. 12). Computer programs for reducing the geoelectrical sounding curves into values of thickness and resistivity of individual layers are described by Zohdy and Bisdorf (1989). The field resistivity data were interpreted by the well-known method of curve matching with the aid of Zohdy and Bisdorf program (1989). However, thickness and characteristics of the aquifer are fairly known due to the availability of a number of wells to the center of the aquifer. A number of geoelectric stations were purposely located near some of such wells. The key to success of any resistivity survey is the calibration of the geophysical data with the hydrogeological and geological ground truth information.

The boundary of the aquifer, thickness and resistivity of subsurface layers were determined through the use of the geoelectrical study in this research. From the interpretation of the resistivity curves, generally, three main subsurface layers were indicated in this work. These layers consist of surface alluvium layer (topsoil), water-saturated layer, and bedrock. Depths and thicknesses of the subsurface layers were identified and the dimension of the aquifer and type of bedrock were also indicated.

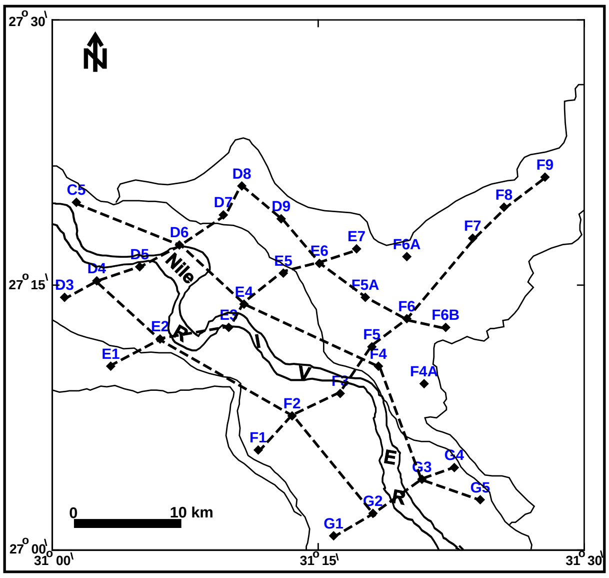

Fig. (12). Distribution of VES stations and profiles

The geoelectrical resistivity study revealed the following results:

1- The surface dry alluvial zone is characterized by high resistivity values (more than 200 Ohm.m) with some occasional localized lower resistivity values (5 to 40 Ohm.m). This zone belongs to Holocene surficial sediments. This zone, which has different thicknesses varying from 3 to 29 m, corresponds to surface shaly with some intercalations of sandy deposits that belong also to the Holocene period.

2- The second geoelectrical zone has resistivity values ranging from 7 to 77 Ohm.m, and its thickness varies from 4m (inside Wadi El-Assuity, at the remote areas from the Nile River) to about 300 m (within the Nile River zone). 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 maps of depth to the top of the aquifer, thickness and resistivity of the expected water bearing zone (Figures. 14, 15 and 16).

3- Finally, the third 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, especially in the localities adjacent to the Eocene scarps, corresponding to the dry limestone. Several geoelectrical cross sections were constructed in different directions (Fig. 12) for identifying horizontal and vertical variation in the subsurface lithology and their hydrogeological significance in the study area. Figure (13) is shows an example for one of the interpreted geoelectrical cross-sections.

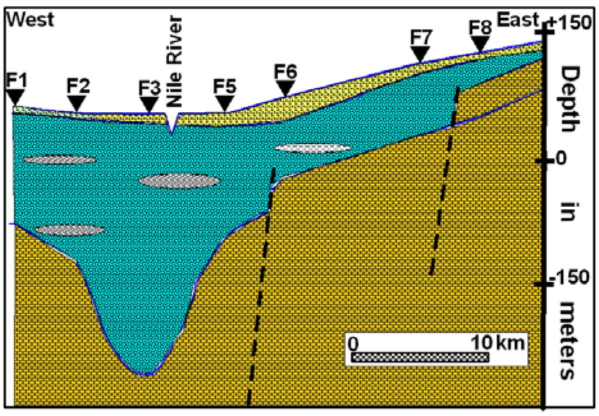

Fig. (13). Geoelectric section crossing wadi El-Assuity to the Nile Valley, see figure 12 for location.

From the resulted data, then three general maps were constructed to delineate the subsurface conditions. The three maps are:

- Depth to the top of the saturated section (aquifer) (Fig.14).
- The variations in thickness of the saturated section (aquifer) (Fig.15), and,
- The variations in interpreted resistivity of the saturated section (aquifer) (Fig.16).

From Figure 14, it can be noticed that the deepest spots to the saturated section may reach depths of around 28 meters (around VES'es D4, D6 and F6), while the shallowest depths are around VES F2 to the west of the Nile River and G4 & G5 to the east.

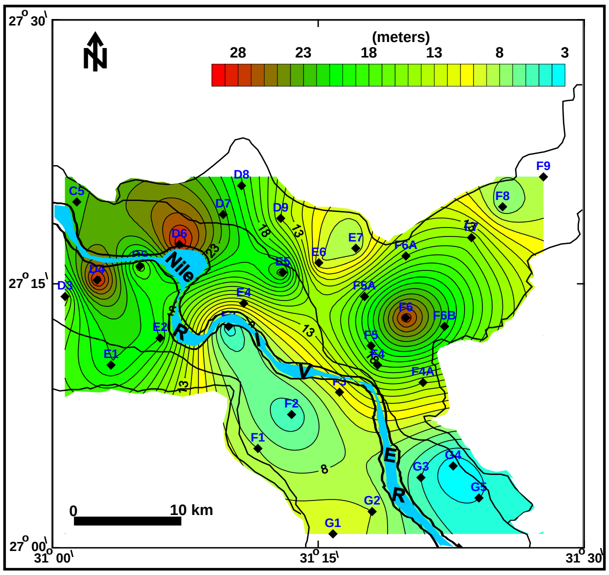

Fig. (14) shows the variations in depth to the top of the saturated section (aquifer),

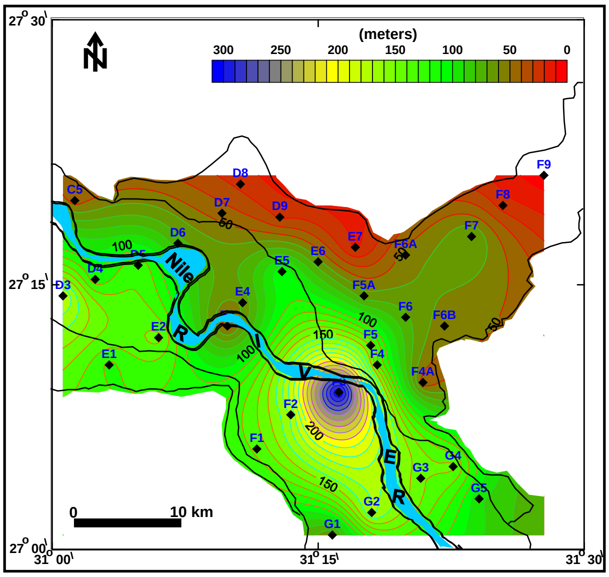

Fig. (15) shows the variations in thickness of the saturated section (aquifer).

From figure 15, it can be observed that the thickest part of the saturated section lies to the west of the Nile River around VES F3. The minimum thickness values can be seen far from the Nile River to the east, where the subsurface uplifted bedrock causes the aquifer thickness to diminish gradually. Also, it can be concluded that the thickest part of the aquifer in the area around F3 reveals the close coincidence between the interpreted resistivity and the basin-like feature shown on the Bouguer gravity data (Figure 6).

From Figure 16, it can be noted that, the interpreted resistivity values for the aquifer that range from about 10 to 80 Ohm.m. The relative lower resistivity values are toward the eastern and western limestone plateaus that may reflect the effect of leaching of some limestone blocks through the existing fractures by the existed sub- surface water. This increases the amount of dissolved salts, reducing the water's resistivity. Fresher water can be observed, relatively, towards the Nile River and its immediate close areas. To the southwest, the limestone high blocks offset the aquifer's extension and it can be concluded that the effect of the western limestone rocks on the aquifer's groundwater quality is less than its effect from the eastern blocks (to the east of the Nile River). This might be due to the less fracturing effect within the western limestone plateaus that resulted in less contamination with the dissolvable solids from limestone.

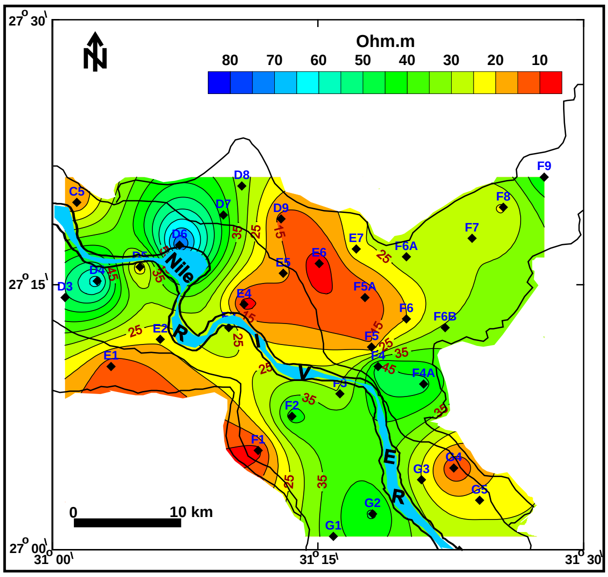

Fig. (16) shows the variations in interpreted resistivity of the saturated section (aquifer)

CONCLUSIONS

The gravity method, either independently or in combination with other geophysical methods, is a useful tool for groundwater prospecting in hard rocks. Interpreting the available Bouguer gravity data, through regional, residual as well as first and second vertical derivatives revealed, in general, that the negative residual gravity anomalies observed over the entire Assuit area can be attributed to Pleistocene sediments, with thicknesses reaching about 300 meters (in its deepest spot), while the positive anomaly can be interpreted in terms of the shallowness of the denser bedrocks. The thickness of sediments is expected to be not uniform. The gravity study showed that the expected basin is wider and deeper to the west of the Nile River than at its eastern side. Faulting effect can be seen along the linear features within the first and second vertical derivative maps.

Then, thirty three VESes have been used to evaluate the subsurface hydrogeological conditions to a depth of about 300 m. Based on the interpretation of geoelectrical data, the following conclusions are drawn:

1- The use of geoelectrical soundings provides an inexpensive method for characterizing the groundwater conditions of the region.

2- VES tests also revealed three main subsurface geoelectric layers; relatively thin surface alluvial layer, aquifer and the bedrock, respectively. The aquifer thickness increases towards the southwest of the Nile River, which is the regional direction of increasing deposition in the basin. The average thickness of the saturated alluvial aquifer has been estimated of about 200 m.

3- Interpretation of the VESs indicates the presence of an alluvial aquifer, that mainly consists of gravels and sands, with some parts made up of sand and silt mixed with clayey materials. The resistivity of the aquifer decreases towards the east due to increasing the salinity of water and/or clay content.

4- The boundary of the aquifer has been estimated and zones with high yield potential should be determined for future development in the basin and for choosing the drilling sites.

5- This study concludes two possible water sources for the shallow groundwater aquifer: (a) surface water infiltration from runoff caused by sporadic precipitation and (b) upward discharge of deep groundwater from the Nubian aquifer through the sub-vertical faults and sub-parallel faults to the Nile River graben.

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