THE USE OF TRI-GEOPHYSICAL METHODS FOR CONCEALED KARST CAVITIES LOCATION NEAR HAQLANYIAH TOWN

***Mohammad I. Abdul Razzak, **Mohammad S. Zaynal**
* National center of water Resources Management, Ministry of water Resources. Baghdad, Iraq.
** Department of Chemistry, College of Ibn AL-Haitham Education, University of Baghdad, ,. Baghdad-Iraq.

Abstract

The main objective of the present work is to find, locate and delineate some subsurface morphological structures at area near Haqlanyiah town lying in the western part of Iraq, either as an isolated karst cavity features or as buried channel features by using three different geophysical methods, representing by electromagnetic conducting method, VLF-Radiohm electromagnetic resistivity method and electrical resistivity method with horizontal profiling using wenner array. The study area accupies an area (100x300m) and the survey was carried out along thirty one traverses with (10m) separation and (10m) grid interval. The elaborated field data were subjected to the process of analysis, a great coincidence between method results is obtained, then the results show a presence of two anomalous zones in which its characteristic features gave an indication of a presence two possible elongated concealed channels trending in two different directions as in E-W and NW-SE

استخدام ثلاث طرق جيوفيزيائية في تحديد الكهوف الكارستية المدفونة قرب منطقة الحقلانية

***محمد إبراهيم عبد الرزاق،**محمد شكري زينل**
* المركز الوطني لإدارة الموارد المائية، وزارة الموارد المائية. بغداد - العراق
** قسم الكيمياء، كلية التربية ابن الهيثم، جامعة بغداد ،. بغداد – العراق

الخلاصة

أن الهدف الرئيسي للدراسة الحالية هو إيجاد وتعيين ثم تحديد أتجاه بعض التراكيب المورفولوجية التحت سطحية في المنطقة القريبة من مدينة الحقلانية الواقعة غرب العراق حيث وجودها يكون أما بشكل ظواهر تكهفية كارستية منفصلة أو على شكل قنوات مدفونة. أنجزت الدراسة باستخدام ثلاث طرق جيوفيزيائية مختلفة متمثلة بطريقة التوصيلية الكهرومغناطيسية، طريقة المقاومة النوعية الكهرومغناطيسية وطريقة المقاومة الكهربائية بترتيب فنر باستخدام تقنية المسح الأفقي. بلغت مساحة منطقة الدراسة (100 x 300m) وانجز المسح على طول واحد وثلاثين مساراً بمسافة فاصلة بين مسار وآخر (10m) وبين نقطة قياس وأخرى (10m). أخضعت البيانات المستحصلة من المسح الجيوفيزيائي الحقلي إلى عمليات التحليل والتفسير التي بينت التطابق الكبير بين نتائج هذه الطرق والتي اوضحت وجود نطاقين شاذين ذات ظواهر متميزة والتي اعطت الدليل على إمكانية وجود قناتين (ذات أمتداد طولي) باتجاهين مختلفين هما شرق- غرب، شمال غرب-جنوب شرق.

Introduction

Geophysical resistivity techniques are based on the response of the earth to the flow of electrical current. In these methods, an electrical current is passed through the ground and two potential electrodes allow us to record the resultant potential difference between them giving us a way to measure the measured impedence of the subsurface material. The apparent resistivity is then a function of the measured impedence and the geometry of the electrode array. The presence of water controls much of the conductivity variation especially in the shallow subsurface. Measurement of resistivity (inverse conductivity) is, in general, a measure of water saturation and connectivity of pore space. This is because water has a low resistivity and electric current will follow the path of the less resistance. Increasing saturation, increasing porosity of rocks (water filled voids), increasing water filled fractures and increasing salinity of the underground water all tend to decrease resistivity values. Air, dry rocks, porous rocks (air filled voids) results in the opposite response compared to water when filling voids. It can be said that, whilst the presence of water will reduce resistivity, the presence of air in voids should increase subsurface resistivity [1]. The context of this paper is primarily dealing with the concept given above in which such concept is associated with the three main surveying techniques, electromagnetic conductivity method, VLF - Radiohm electromagnetic resistivity and electrical resistivity method. Thus, the main objective of the present study is to use such various techniques that gave various physical properties measurements for finding, locating and delineating some subsurface features as karst cavities or as buried channels according to above mentioned concept. Several studies deal with electromagnetic and resistivity methods were carried out in different fields in the world and in Iraq such as:[2,3,4,5,6,7,8, 9, 10].

Location and geology of the study area

The area under study is located in the western part of Iraq about (4km) north – west of Haqlaniyah town bounded by latitude 34° 4´ 37´N and longitude 42° 17´ 40´E, fig (1). Geologically, the main considerable rocks both exposed and subsurface succession in the study area is sedimentary rocks. These types of rocks range in age from late Oligocene to early Miocene. The Oligocene age is represented by Anah formation. It is exposed near Haqlaniyah town along the right bank of the Euphrates river as small patches extending downstream to the AL-Baghdadi. Also, it is exposed in deep cutting wadies like chabab to the west and in wadi AL-Fhaimy to the east. This formation is lithologically uniform composed mainly of massive, coralline , creamy, very hard limestone and dolomitic limestone , which are locally strongly karstified leading to cavities and caverns of different sizes. The exposed thickness of the formation is about (6 – 10m), although in many localities it is not more than (1-2m). This formation is overlain unconformably by the Euphrates formation. The contact is very sharp and clear based on basal conglomerate. On the other hand, the early Miocene sediments are widespread in the western part of Iraq representing by Euphrates formation. It is exposed along both banks of the Euphrates river and in deeply cut valleys, south of the Euphrates river. Lithologically, this formation is not uniform changing both in horizontal and vertical directions. It is divided in to two members. The first one is the lower member consists of basal conglomerate followed (upwards) by dolostone and dolomitic limestone which is chalky like, white in color, its thickness ranges from (5 – 25m).The lower part of this member is massive upwards become well thinly bedded. The thickness of this part ranges from (15 – 20m). The second one is the upper member. The lower part of this member consist of bracciated and highly deformed limestone, dolostone and dolomitic limestone with horizons and lenses of green mad. The thickness of the part ranges from (7 – 15m). Above this succession there is well bedded limestone , highly undulated , most probably due to the deformation of the underlying succession. The thickness of this part is (2 – 5m) [11]. From the lithological point of view , thin to thick layered limestone, dolomitic limestone of sub-horizontal structure is appeared (fig.2) which occurred and recognized in the Haqlan facies (fig.3). This facies is covered by residual soil and / or colluvial soil and consists of white and grey, fossilliferous dolostone[13]. The thick carbonate complex is karstified and primary porous medium allowing for the ground water storage and transition. karst phenomena are numerous in the investigated area being developed both at surface and underground. Surface karstification is manifested by numerous small solution cavities, canals and shallow depressions. Shallow karstification is important characteristic carbonates , represented by numerous sinkholes and shallow holes of regular shape and vertical wells. [14 ,15].

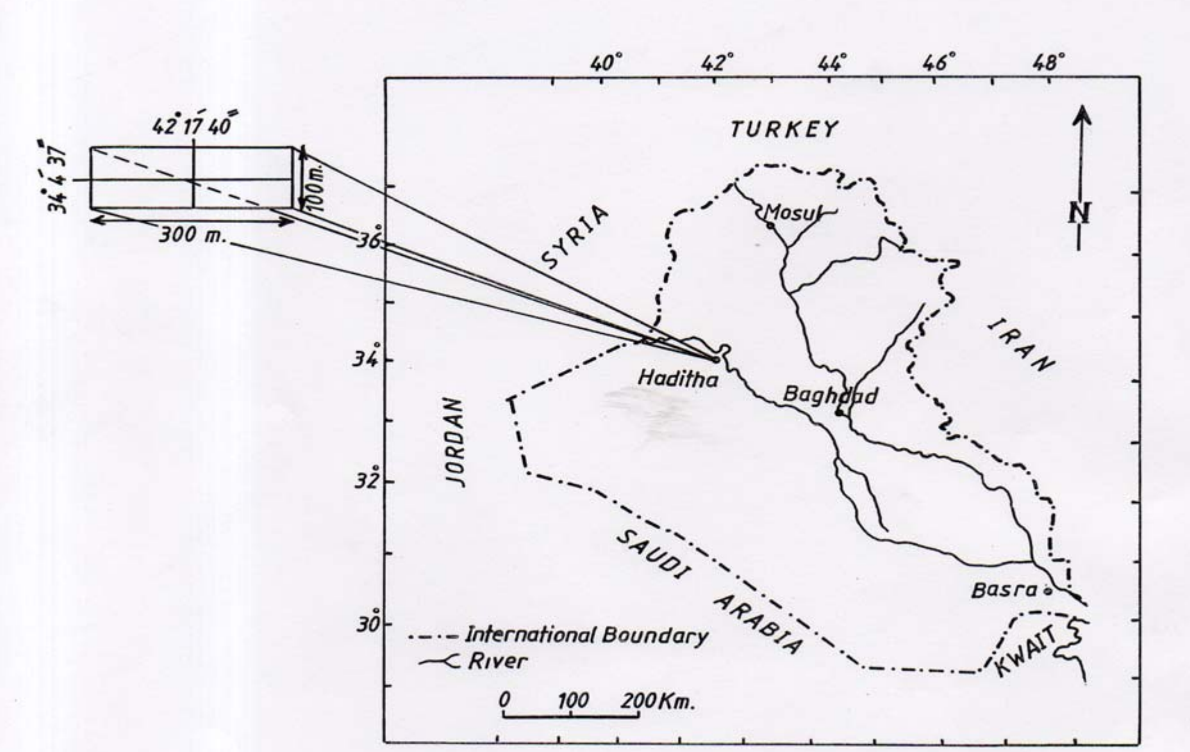

Fig.(1) Location map of the study area.

Methodology and instruments

The main geophysical methods which utilized in this study were firstly, electromagnetic conductivity method using instrument of Geonics EM 34 – 3 with accuracy equal to (± 0.25%) and measurement precision of (± 2%) of full scale deflection. This instrument consists of a transmitter coil, energised with an alternating current at a specific frequency, and a receiver coil located at a short distance from the former. The transmitter creates a primary magnetic field (*Hp*) that induces eddy currents in the subsurface. These currents generate a secondary magnetic field (*Hs*) which is detected together with the primary field, by the receiver coil. Under certain conditions, defined as operation at low values of induction number, the ratio of the imaginary component (out phase) of the secondary magnetic field to the free – space strength of the primary magnetic field is proportional (in a homogeneous medium) to the terrain conductivity. This fact enables the construction of a direct – reading terrain conductivity meter by simply measuring that ratio [16]. Given *Hs* / *Hp* the apparent conductivity (σ_a) indicated by the instrument is represented by:-

$$\sigma_a = \frac{4}{\omega \mu_0 S^2} \left(\frac{H_S}{H_p}\right)$$

Where:-

Hs = secondary magnetic field at the receiver coil.

Hp = primary magnetic field at the receiver coil.

ω = angular frequency (radians) = $2\pi f$

f = frequency (Hz).

μ_o = magnetic permeability of free space ($4\pi\ 10^{-7}\ H.m^{-1}$).

σ_a = ground apparent conductivity (mhos/m)

S = intercoil spacing (m).

There are two basic modes of operation: the horizontal and vertical dipole modes. In the first mode, both coils, the transmitter and receiver are orientated vertically and , in the second case, horizontally. Three different intercoil spacing can be used as (10, 20, and 40m) with fixed frequency for each of the three coil separations (6400Hz, 1600Hz and 400Hz respectively) so it directly vary the effective depth of exploration as (7.5m, 15m and 30m) for the horizontal dipole mode and (15m, 30m and 60m) for vertical dipole mode [16]. Therefore, the use of different intercoil spacing and operating modes allow to get an image of the ground conductivity distribution with depth. The second EM method is the VLF – Radiohm electromagnetic resistivity method. It uses , as a source, the primary magnetic field transmitted from already – existing radio transmitters in the very low frequency (VLF) band. These transmitters are used for long–distance communication that are situated in different parts of the world operating in the frequency range (10 – 30 KHZ). The detailed theory of the wave propagation and behavior of the electromagnetic field for this method are discussed by many authors such as: [17, 18, 19, 20, 21, 22]. The instrument used during the field work is the Geonics EM16R which is described by [23]. It consists of the Geonics EM16 unit and a case attachment to it containing electromagnetic circuits and controls to amplify the electrical field signal and a pair of ground electrodes with internal amplifiers, which are pushed into the ground (10m) apart , aligned in the direction of the station to receive the electrical field.

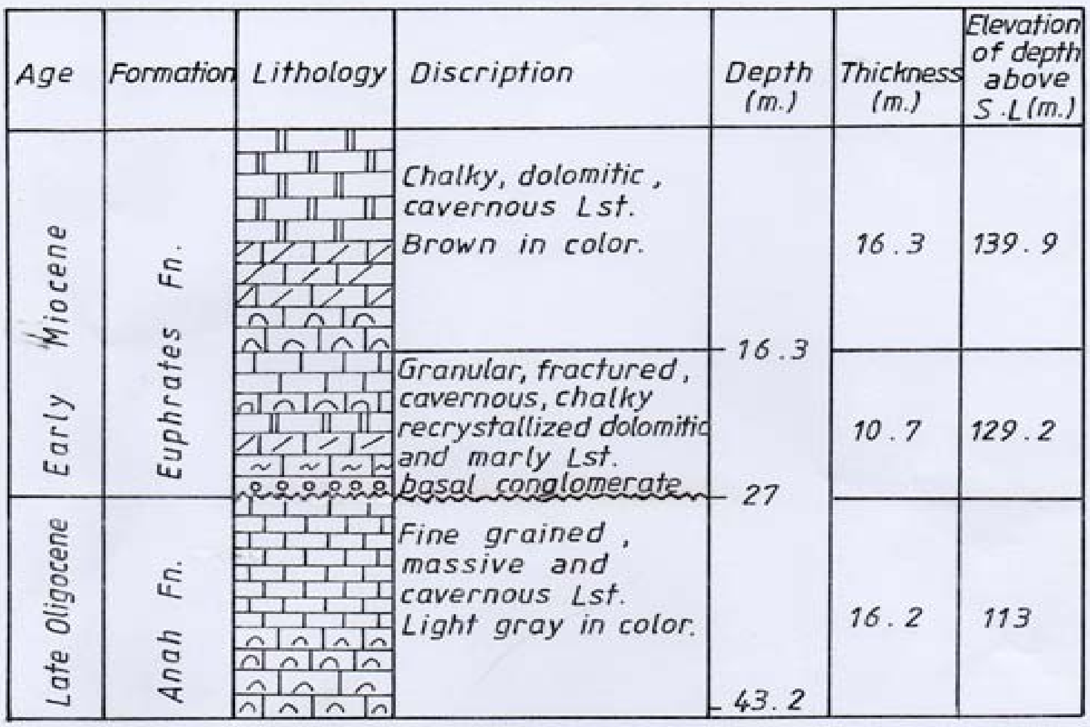

Fig. (2) Stratigraphic columnar section in bore hole no. (488). [12] .V. Scale 1cm = 4m.

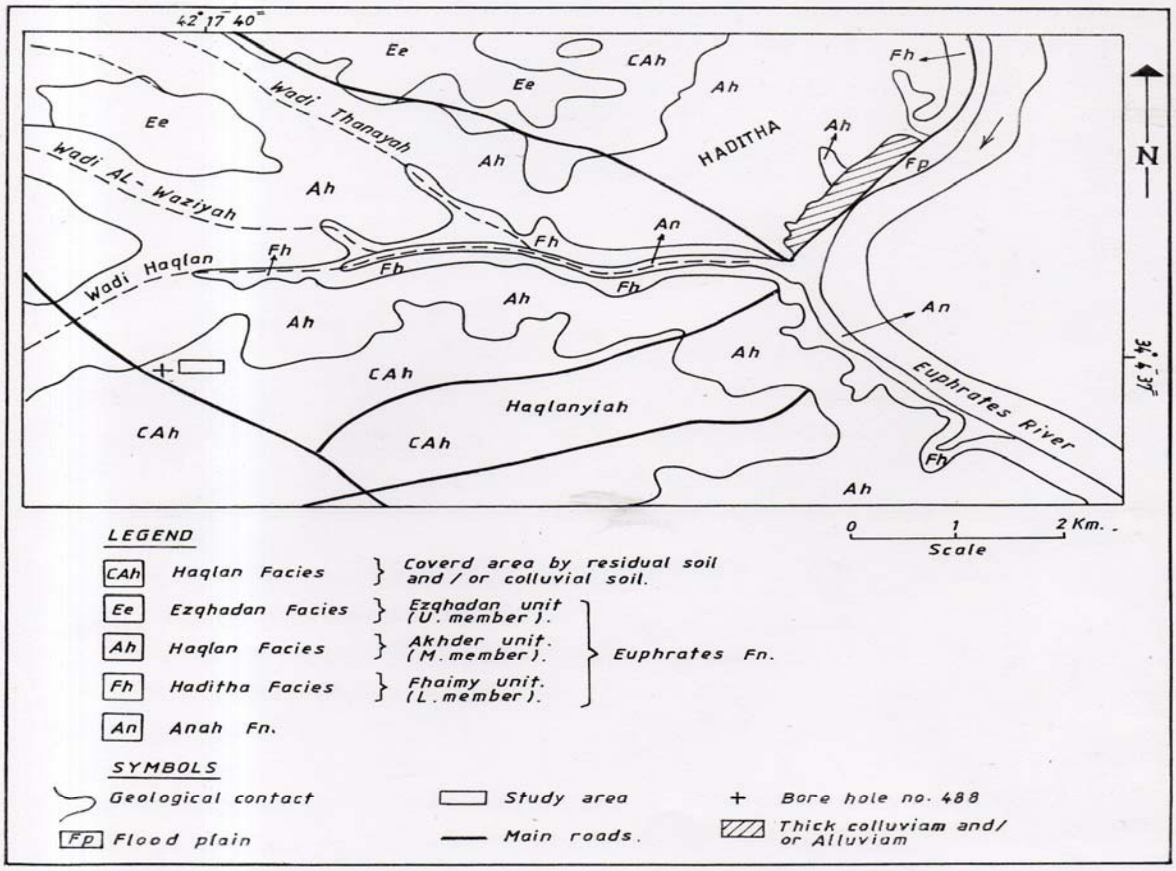

Fig (3) Geological map of the study area and surroundings.[13]

The measuring device gives direct readings of apparent resistivity in (ohm.m) and phase shift angle between the horizontal electric and magnetic fields. However, when the instrument is well oriented in the right sense with respect to the VLF transmission station, and by using the magnetotelluric relation given by [24], the apparent resistivity of the earth can be derived using the ratio between the horizontal electric field (in the direction of propagation) and the horizontal magnetic field (perpendicular to that direction). Finally, measurement of the phase angle between the horizontal electrical and magnetic fields gives information about the vertical variation of resistivity. A homogeneous earth produces a (45˚) phase angle, while a two-layer earth produces phase angles greater than or less than (45˚). A conductors over an insulator produces a phase angle less than (45˚), while a more resistive surface layer produce a phase angle greater than (45˚) [25]. The third geophysical method which used in the present work is electrical resistivity method, applying horizontal technique for determining variations in the subsurface at a more or less fixed depth of investigation, using wenner array with space (a=50m). All the resistivity measurements have been carried out using the instrument of ABEM Terrameter SAS 300B, Sweden apparatus, that enables measuring the potential current ratio which then multiplying by the geometric factor of the array used to get finally the apparent resistivity values in (ohm.m) of any measured stations in the field. To clear the location and delineation of the subsurface anomalies, three of the previously discussed methods are capable of performing measurements of three different physical properties in order to indicate weather the picked anomalies are related with firstly, cavities and / or buried channels and secondly if these features are empty (i.e filled by air) or filled with water solution.

Field work procedure

Both EM 34-3 method using coil separation of (20m) with vertical dipole mode (VDM) and EM16R method with transmitting station of British Rugby (GBR) using a frequency of (16KHZ) which was found to be appropriate in the investigated area had been carried out along thirty one traverses with (10m) separation.

Readings were taken at (10m) intervals along these traverses covering an area of (100 × 300m) while the wenner resistivity array was performed only along the location of the picked anomalies for confirmation (traverses AA¯ & BB¯).

Data presentation, Results and Discussion:-

After elaborating the data from the field , the measurements were appeared and presented in two different modes. The first mode appeared as electromagnetic and resistivity profiling which gives useful information about the lateral conductivity and resistivity variations with a certain depth of penetration , so the plotted conductivity and resistivity graphs have been used to display the associated resistivity variations of some important subsurface features. The revealed graphs in fig. (4a, b, c, d, e, f, g & h) will be described in some detail later. Fig(4), on the other hand , present two sets of traverses (AA¯ & BB¯) in which each set represent four different profiles belong these different methods. It contains the apparent conductivity (mmhos/m), EM apparent resistivity in (ohm.m), EM resistivity phase angle and finally wenner apparent resistivity profiling, fig. (4a, b, c, d, e, f, g & h) respectively. All these values are versus the distance along traverses (AA¯ & BB¯). According to the observation and analysis, anomalous zones are marked and observed. Such anomalies can be interpreted as it is formed by karst cavity occurance. Well, the principle of interpretation and then correlation depends mainly on their anomaly character – minima or maxima – of the electrical conductivity, maxima or minima of both EM resistivity and apparent resistivity (i.e vice – versa). Whilst the anomaly character of the first set, (fig.4AA¯) that involves apparent conductivity, EM resistivity and apparent resistivity observed as minima, maxima and maxima respectively. Such character indicate mainly a presence of karst cavity filled air (i.e empty cave), the anomaly character of the second set (fig.4BB¯), observed as maxima, minima and minima for different anomaly respectively. Such character indicates also presence of karst cavity but filled with solution water. The phase shift between the horizontal component of the electric field vector can also be measured with radiohm equipment. Normally, in homogeneous conditions , electric and magnetic (45˚) phase shift between them, that is when the depth of the top layer is more than one skin depth. But if a second layer, in non-homogeneous conditions is of higher resistivity, the phase shift will decrease, and will increase over a more conductive second layer. However, and for further indication can also be given from the phase angle profiles fig.(4e&f) in which its anomaly character as trough (less than 45˚) is mainly related with low conductive zone or resistive one, whereas its character as positive, is mainly occured and related with a presence of high conductivity zone (more than 45˚), so good coincidence between them is obtained. The second mode appeared as contour maps. Well, it should be noted that, the most useful approach in the cavity or channel investigation, is to locate the high and / or low gradient of either resistivity or conductivity within a certain depth of penetration, i.e the lateral variation in apparent resistivity and / or apparent conductivity due to the presence of such subsurface features. So, to get a clear picture about the location, trend and delineation of such zone, a grid of traverses should be constructed with respect to the suspected subsurface features. All stations measurements with the same apparent conductivity or apparent resistivity values are jointed by contour lines and the final form of these contour lines is called a contour map. Two maps have been constructed representing the observed electromagnetic conductivity with (20m) coil separation and observed VLF – Radiohm electromagnetic resistivity, show in fig. (5&6) respectively. Having fig. (5&6), shows contour map of EM conductivity and VLF – Radiohm EM represented by well defined low and high conductivity, high and low resistivity anomaly, trending E-W and NW-SE respectively. Obviously, the behavior of these major anomaly zone clearly indicate the occurrence of concealed elongating subsurface features with its axis direction, (i.e the pattern shape of these anomalies indicate an extension of concealed bodies mainly as buried channels), anomaly (I) of E-W direction reflected empty channel. It should be noted that, a considerable interchange between the decrease and increase in the peak value of both anomalies is occured and observed as well, i.e anomaly (I) of (E-W) trend may reflect empty channel at depth ranges between (18 – 22m), by using Geonics standard curves [26], is interpreted by locating the interchange

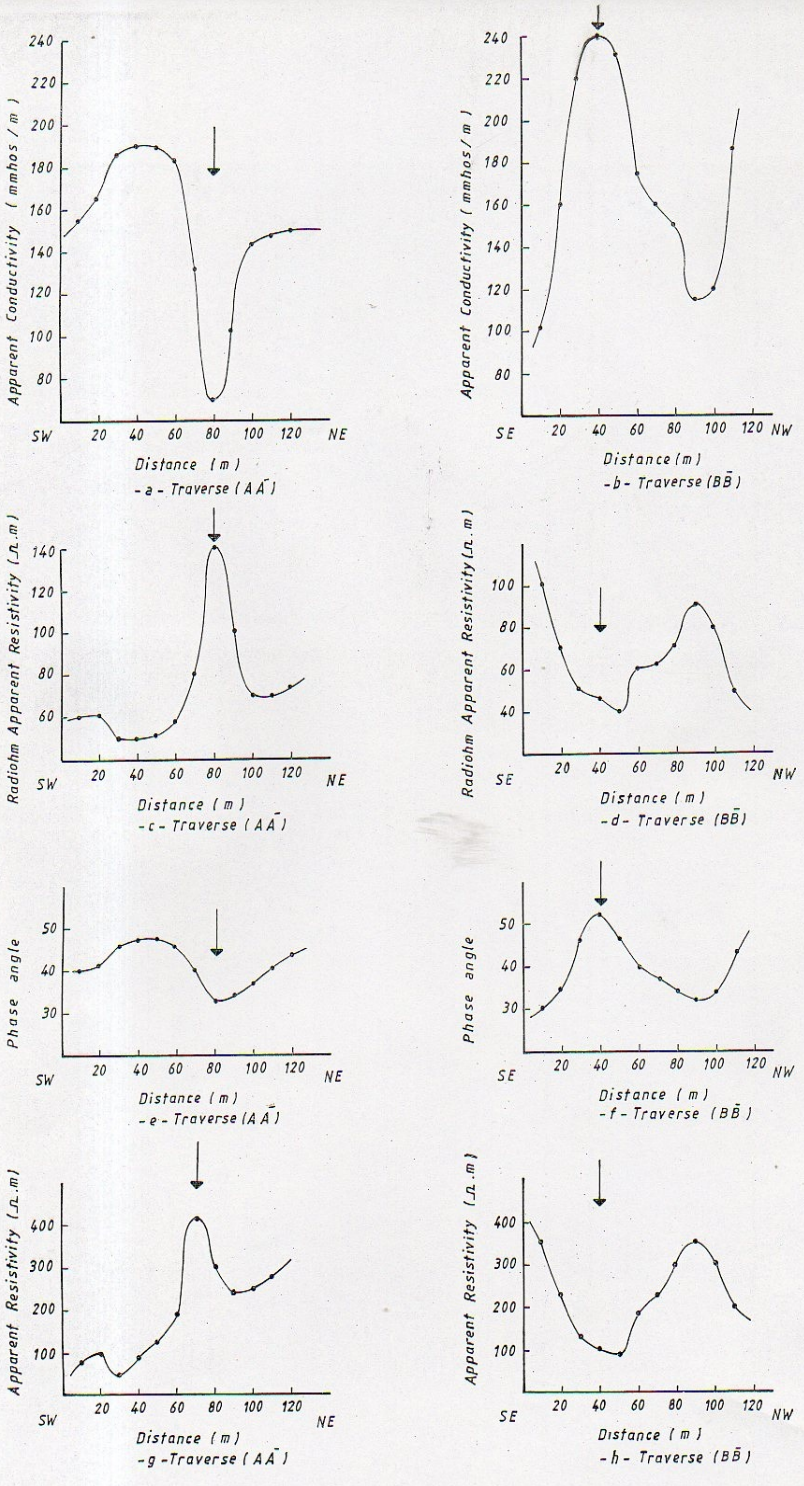

Fig.(4).

a & b - Observed conductivity values (σ_a) for coil separation (20 m) along traverses (AA¯ & BB¯) respectively.

c&d - Observed radiohm resistivity values (ρ_a) along traverses (AA¯ &BB¯) respectively.

e&f - Observed phase angle values along traverses (AA¯ & BB¯) respectively.

g&h - Wenner resistivity profiling along traverses (AA¯ &BB¯) respectively (a = 50 m).

phenomena as high resistivity value (140 ohm.m) and low conductivity (80mmhos / m), whereas the anomaly (II) of NW- SE direction at depth ranges between (19 -21m), by using Geonics standard curves [26], is expected to reflect channel of saturated water (filled with water), interpreted by locating the interchange phenomena as low resistivity value as (40 ohm.m) and high conductivity as (240 mmhos/m).

Conclusion

Basically, the application of the electromagnetic and electrical resistivity methods is based on the existence of different electric properties of the object under investigation and the surrounding rocks. The electric in-homogeneities cause disturbances within the distribution of the electromagnetic field and the equi-potential surfaces results from passing electric field when a conducting or resistance body lies between the transmitter and receiver and the potential electrodes respectively. Generally, all geophysical methods have limitations and appearing some ambiguity in the interpretation of their data in the absence of any geophysical control, thus, the use of electromagnetic and electric is so useful and important in assisting each other for target inspection. According to the map analysis, two elongated anomalous zones trending E-W and NW-SE are marked and observed in which their behaviors can be interpreted as a presence of delineated buried features. The profiles analysis, on the other hand, show an interchange anomaly character between the conductivity and resistivity anomalies indicate mainly the characteristic type of such karst cavity. It is observed that the first anomaly represents an air buried channel whereas the second one represents buried channel filled with water solution.

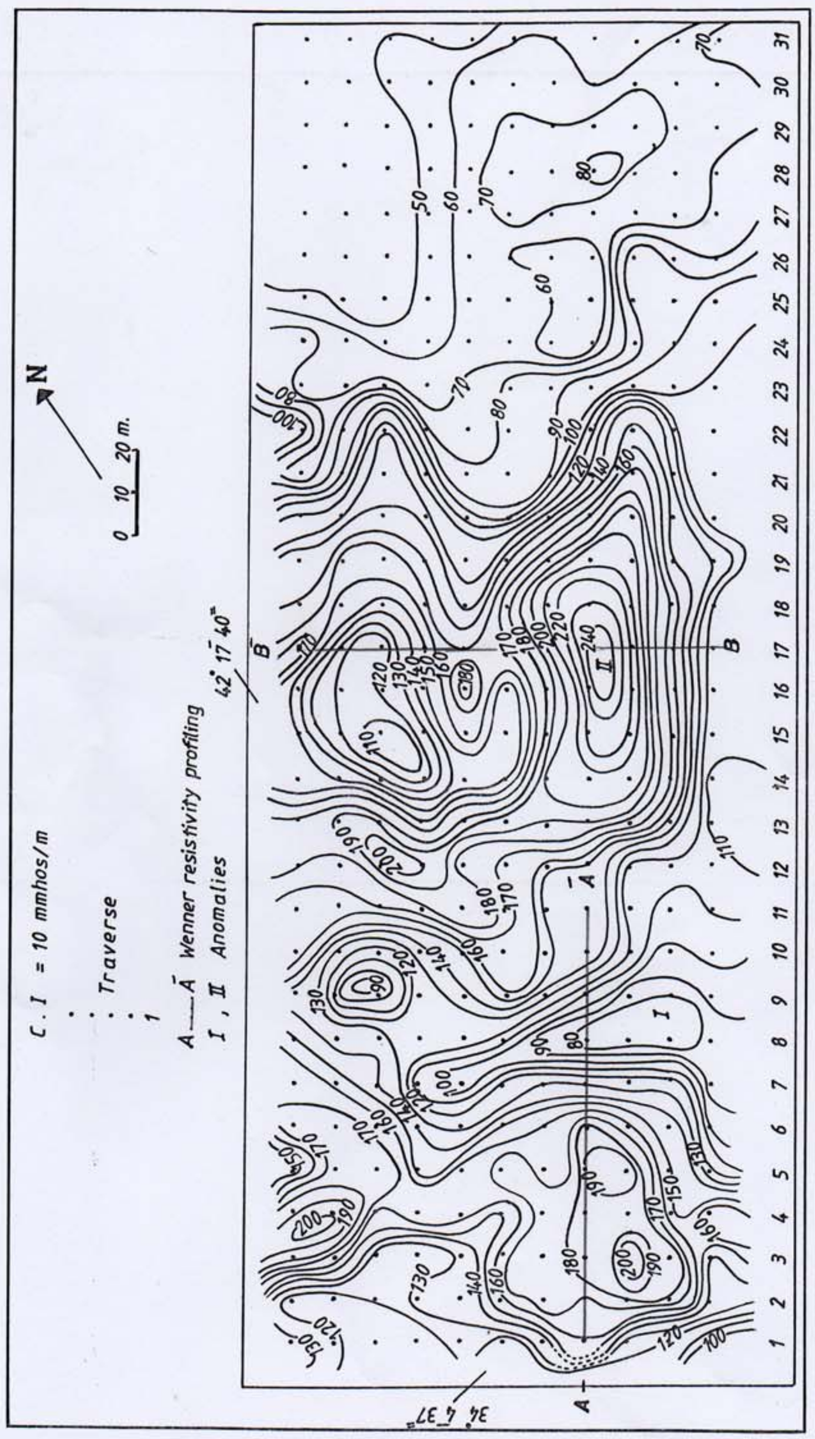

Fig (5): Observed EM apparent conductivity contour map of the study area. (Coil separation 20m.)

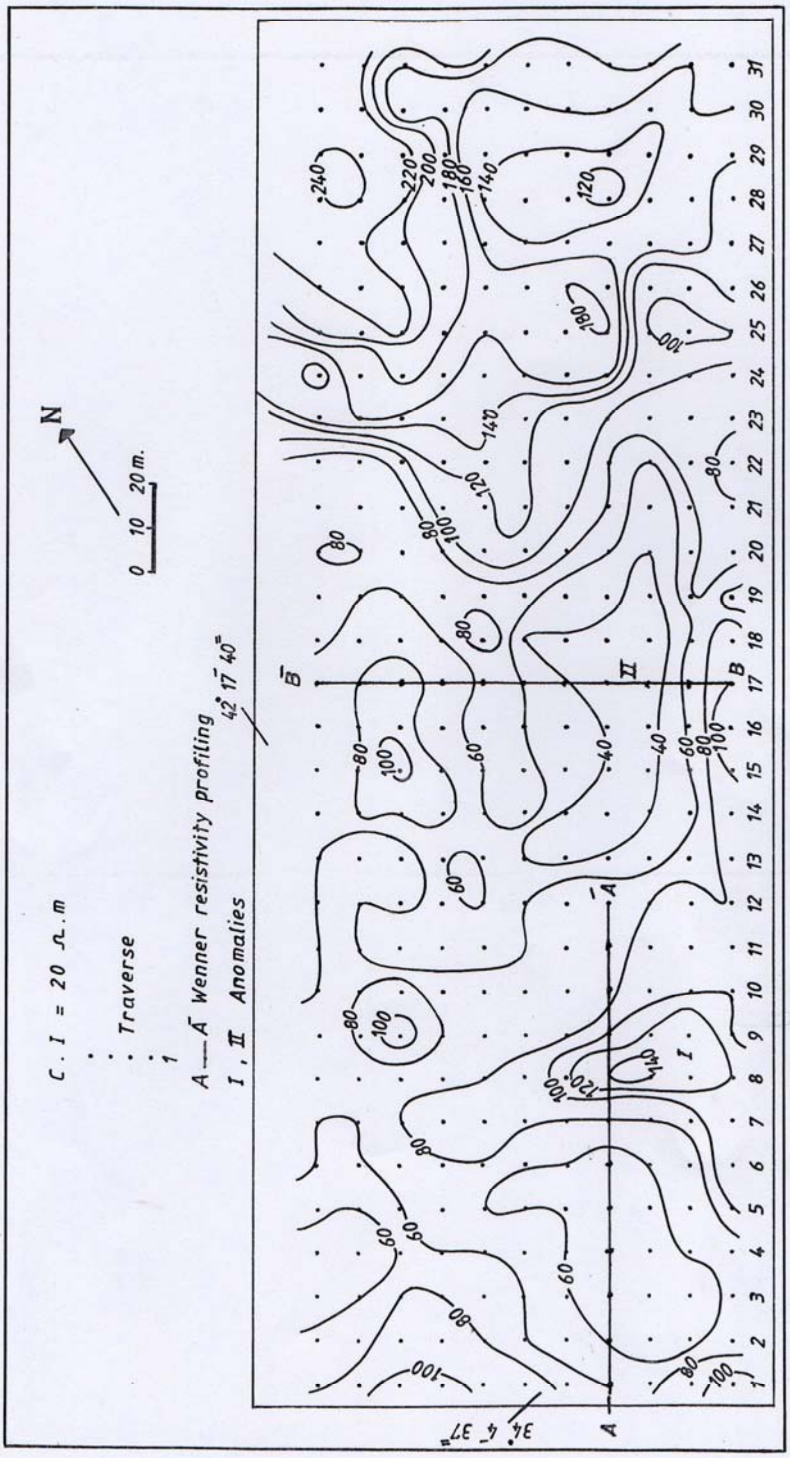

Fig (6): Observed VLF- Radiohm EM resistivity contour map of the study area.

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