3D resistivity imaging survey to delineate Um El-Githoaa cavity in Hit area, Western Iraq

Jassim M. Thabit[1] , Ali M. Abd[2] , Firas H. AL-Menshed[3]

[1] Department of Geology, College of Science, Baghdad University, Baghdad, Iraq.

[2] Department of Applied Geology, College of Science, Anbar University, Ramadi, Iraq.

[3] The General Commission for Groundwater, Studies and Investigations Department, Baghdad, Iraq.

Abstract

The 3D resistivity imaging survey was carried out over Um El-Githoaa cavity in Hit area, western Iraq. Resistivity data were collected along four parallel traverses using Dipole-dipole array with electrode spacing of (2m) and (n) factor equal to 6. Inversion 3D models of standard least-squares method and robust constrain method for Um El-Githoaa cavity showed horizontal slices of the 3D resistivity distribution with depth. The first three slices, which represented the resistivity changes from ground surface to depth approximately equal to (3m), showed relatively higher resistivity reflecting the dry sediments of gypsum rocks, and some of these rocks visible on ground surface .The slices after (3m) depth showed the effect of the subsurface cavity by noticeable increasing in resistivity contrast (more than 800 ohm.m)with surround sediment, and the dimensions of the cavity equal approximately to the actual dimensions of this cavity. The comparison between the two methods of inversion appeared that the invers model produced by the robust constrain method has sharper and straighter boundaries, and the dimensions of the Um El-Githoaa cavity appeared closer to the actual dimension of this cavity (maximum diameter equal approximately to 19.3m, while the minimum equal to 15.8m and perpendicular to the first diameter). Therefore, the 3D resistivity imaging survey was delineated Um El-Githoaa cavity at depths ranges from (3 to 6 m). It is concluded that, the dense measurements along 2D lines in small area can be increasing the 3D imaging resolution.

Key words: 3D Resistivity imaging, Um El-Githoaa cavity, Dipole-dipole array.

Introduction

Electrical imaging involves measuring a series of constant separation traverses with the electrode spacing being increased with each successive traverse to achieve deep information. Apparent resistivities were inverted to true resistivities by a three-dimensional inversion algorithm [1] in order to obtain more accurate resistivity distribution of the subsurface.

The most common way to build a 3D data set is by applying number of 2D survey parallel lines, and these lines then combined into 3D data set for 3D inversion. The ideal three- dimension 3D imaging measurements are collected by using multi electrodes in a rectangular grid, and measuring the apparent resistivity along possible directions.

Alternative and most common strategies are measured the apparent resistivity in two perpendicular directions (X and Y) or along a single direction (X or Y). Practical field techniques were described by [2, 3, 4, 1, and 5].

There are few previous studies that used resistivity method for detecting cavities in Iraq, such as [6] used Wenner array to detect the cavities in Hmam Al Aleel, north Iraq. Resistivity map was drawn which appeared high positive anomalies, where that present of the cavities within gypsum rocks. [7] collected two sounding measuring stations, one over the known cave and the other at a distance of 80m west of the cave were carried out using Wenner and Schlumberger arrays. Also, twelve horizontal resistivity profiles, along which resistivity measurements were carried out using Wenner, Schlumberger and Pole-dipole (Bristow׳s method) array configurations. It is concluded that the best result was obtained from the Pole-dipole array configuration by using the graphical Bristow method. But we didn't found any study about using 3D imaging technique to detect subsurface cavities (even in recent spill). Besides, it is believed that there are no previous studies that used resistivity method for investigating subsurface cavities in Iraq, except the two studies as mention above.

The most 2D and 3D imaging surveys had been used for engineering and environment studies, and in the following, some previous studies are curried out of cavity target in the world [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21].

The Object of this study was to evaluate the usability of 3D imaging technique for detecting and delineating the subsurface cavities.

Site description

Karstification is a common phenomenon in different parts of Iraq. The Karst features are developed due to dissolving of limestone or gypsum. The main type is the sinkholes, which are developed indifferent shapes and dimensions. The main problem of karstification, which makes it one of the geological hazards, when the forms are developed under the ground. If they are not recognized and located, then they will certainly cause severe damages to any kind of engineering structure built over it. A good example is the rock-slabbing factory in Haqlaniyah [22].

In the southern part of Al-Jezira, along the left bank of the Euphrates River large caves are formed in gypsum beds of Fatha Formation and carbonate rock of Euphrates Formation. Few kilometers north of Hit a large cave (Um El-Githoaa cavity) is formed in the gypsum beds of the plateau that border Euphrates valley (Fig.1). The shape of the cavity is ovulate, maximum diameter is about 19.3m (286 ° direction), while the minimum is 15.8m (perpendicular to the first diameter). The area of the cave about 300 square meters. The cave is a dome in shape and its roof reaches 2m in height. The depth from the surface to the roof of the cavity is equal nearly to 3.8m and to the bottom 6m, and connected with the surface by two small entrances. It is rich in dripstone (stalactite, stalagmite and column) developed by water dripping from the cave coiling. The stalactite and stalagmite are thick and have the form of date palm stem from which the name of the cave is derived. The cave is more likely of Early Pleistocene age, developed at the same time as the height terrace level [23].

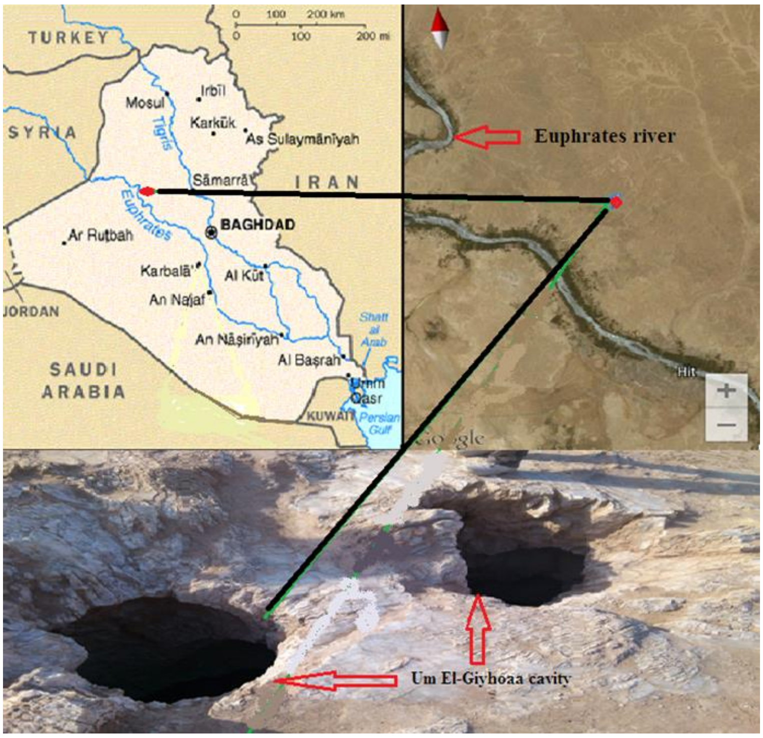

Figure (1) Photos show the location and slots of Um El-Githoaa cavity in Hit area.

Data acquisition

The 3D imaging survey was composed in a very small area. The data acquisition included of dense measurements along parallel 2D lines instead of dense perpendicular lines to increase the resolution of the subsurface 3D image, and achieve nearly true 3D coverage of the subsurface image. Then the parallel 2D lines were merged to form reasonably true or accurate 3D imaging .Numerous authors have been noted several suggestions to help migrate 2D imaging data to 3D acquisition [1, 3, 24, 25, and 26]. Four parallel survey lines (traverse-1, traverse-2, traverse-3, and traverse-4) were positioned to West-East direction above Um El-Githoaa cavity. These traverses are separated by (4m) distance, and each line has (44 m) length, as shown in (Fig.2).

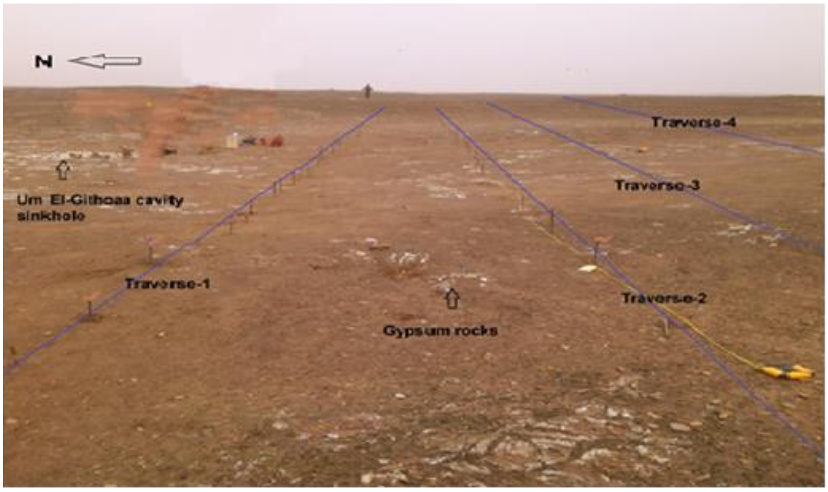

Figure (2) 2D Dipole-dipole traverses above Um El-Githoaa cavity.

The Terrameter SAS 4000 instrument was used for measuring apparent resistivity along four parallel traverses in the field. The 2D survey was carried out by Dipole-dipole array with (n) factor equal to 6, and electrode spacing (a) equal to(2m) .Because this array provided the best imaging of subsurface cavity than those of the Pole dipole and Wenner-Schlumberger arrays [27]. The number of apparent resistivity measurements along each traverse is equal to 171, and then the total measurements along four lines are equal 684, which are distributed in an area equals to (12×44m).

Data processing

As an attempt to make a 3D view of the subsurface Um El-Githoaa cavity, so that the data files of four 2D traverses (1, 2, 3 and 4) had set in one data file that can be read with RES3DINV program which is in tend to use for inversion.

RES3DINV program [28] is a computer program that will automatically determine a 3D resistivity model of the subsurface, using the data obtained from a 3D electrical imaging survey [29 and30]. One advantage of this program is that the damping factor and flatness filters can be adjusted to suit different types of data.

The 2D imaging data of the four lines were collected by using RES2DINV program in one data file that can be read by RES3DINV program, and iteratively calculates a resistivity model, trying to minimize the difference between the observed apparent resistivity values and calculated from the model. The maximum number of iteration was set to 10. The inversion process is resulted a satisfactory 3D model. The inversion results generate a three-dimensional volume and displays user to selected horizontal slices. The 3D anomalous zones are easily displayed by selecting iso-resistivity surfaces. The natural logarithm of the resistivity values was used in order to highlight the resistivity variations.

If the data set is very noisy, a relatively larger damping factor (for example 0.3) is used. If the data set is less noisy, use a smaller initial damping factor (for example 0.1), as mentioned in [5]. Here because of noisier data near surface, a higher initial damping factor was used to be (0.15), and higher minimum damping factor to be (0.02). Additionally a higher damping factor was used for the first layer to be (2.5).The inversion subroutine will generally reduce the damping factor after each iteration. However, a minimum limit for the damping factor must be set to stabilize the inversion process. The minimum value should usually set to about one-fifth the value of the initial damping factor.

Another important sub option is (Vertical / Horizontal flatness filter) ratio weight of 1. If the main anomalies in apparent resistivity pseudo section are elongated horizontally, it must choose a smaller weight than vertical filter [5]. So, the flatness filter was used weight of 0.5.

The third important parameter is selecting Robust Inversion. From this the smoothness constrains can be selected. It must be either (the standard least-squares method) or (robust constrain method). The conventional least-squares method will attempt to minimize the square of difference between the measured and calculated apparent resistivity values. The robust data constrain option will attempt to minimize the absolute difference (or the first power) between the measured and calculated apparent resistivity values [31].

Interpretation

The model obtained from the inversion by standard least-square method of the data set is shown in (Fig.3). It can be seen from this figure, a very good 3D distribution of true resistivity in x and y direction with depth. Horizontal slices (1m interval between slices was chosen) were extracted in order to display the vertical extent of the high resistivity zone or anomaly (red color). It is observed that the high resistivity anomaly (more than 800 ohm.m) at depths ranges from (3 to 6 m), as shown in (Fig. 3). This anomaly is related to the subsurface Um El-Githoaa cavity. It can be seen from this figure, a very good 3D distribution of true resistivity in X and Y directions with depth. First , second ,and third slices represent the resistivity changes from ground surface to depth equal to (3m) , show relatively higher resistivity reflecting the dry sediments of gypsum rocks, and some of these rocks visible on ground surface. The slices after (3m) show the effect of the subsurface cavity, which is started to appear by noticeable increasing in resistivity contrast with surround sediment. At the fifth slices, the dimensions of the room cavity have accepted values compared with the actual dimensions of this cavity.

Most field data sets probably lie between the two extremes of a smoothly varying resistivity and discrete geological bodies with sharp boundaries. So, it might be a good idea to invert the 3D data twice. Once with the standard Least-square method (Fig. 3) and again with the robust constrain method (Fig. 4). This will give two extremes in the range of possible models that can be obtained for the same data set.

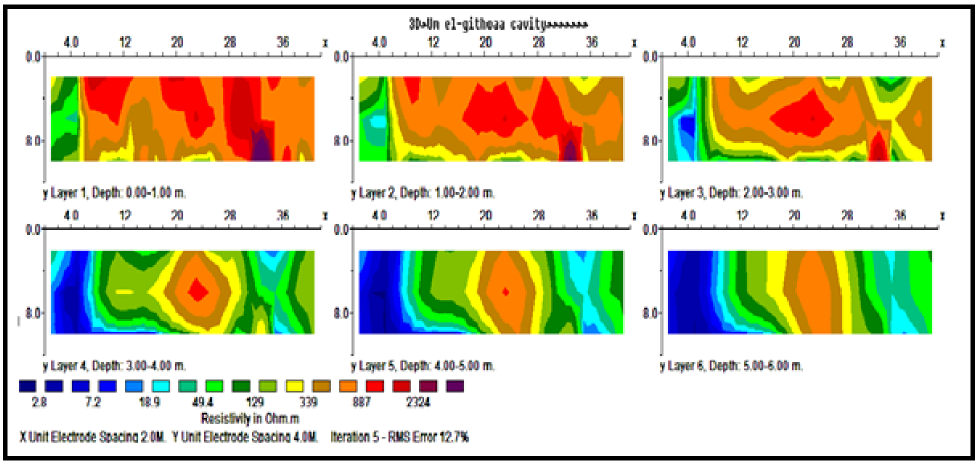

Figure (3) Inversion model for Um El-Githoaa cavity shows horizontal slices of the 3D resistivity distribution with depth. The highest resistivity anomaly more than (800 Ωm) is related to subsurface cavity using standard Least-square method.

The inverse model produced by the standard least-squares method has a gradational boundary for the cavity (Fig.3). While, the invers model produced by the robust constrain method (Fig. 4) has sharper and straighter boundaries. The inverse model is the true image that used for interpretation. The RMS error indicates how well the calculated pseudosection is fit to the measured pseudosection, so it is preferable to reduce it as much as possible. But in some cases this is not true, especially if there is a high amount of geological noises, and the noise is usually more common with electrodes arrays such as Pole-dipole and Dipole –dipole arrays that have a very large geometric factor, and thus very small reading between potential electrodes (Loke,2012). The RMS error is fairly high of these models, which may be as a result of near surface inhomogeneity of Gypsum rocks, and some of these rocks visible on ground surface. From the inverse models in (Fig. 3) and (Fig.4), the dimensions of the cavity appeared approximately equal to the actual dimension of this cavity. The comparison between two methods appeared that the invers model produced by the robust constrain method (Fig. 4) has sharper and straighter boundaries, and the dimensions of the cavity appeared closer to the actual dimensions of this cavity (maximum diameter equal nearly to 19.3m, while the minimum is 15.8m and perpendicular to the first diameter).

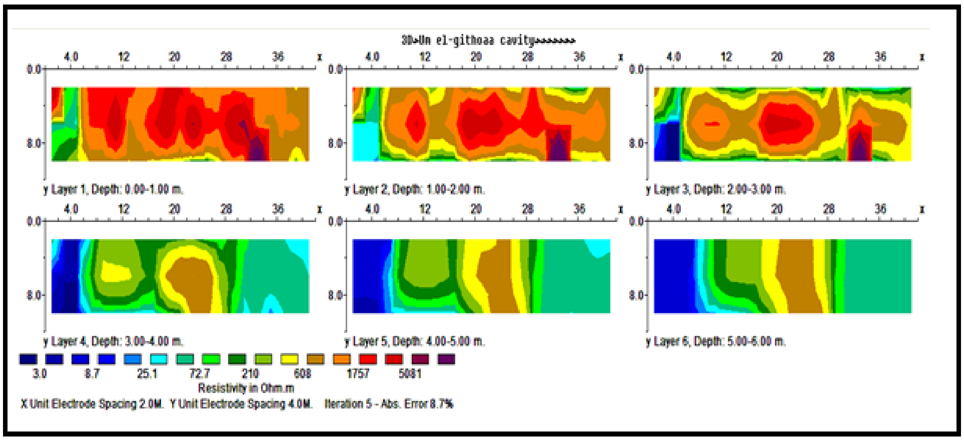

Figure (4) Inversion model for Um El-Githoaa cavity shows horizontal slices of the 3D resistivity distribution with depth. The highest resistivity anomaly more than (800 Ωm) is related to subsurface cavity using robust constrain method.

Displaying results in the form of slices makes the user capable of choosing the best slice that gives the best presentation to the problem under interest, for example we chose the slices that represent depth after (3m) the best to show the position of shallow Um El-Githoaa cavity.

Thus, even if the true 3D imaging survey carried out without any perpendicular lines in X and Y directions, the measurements can give nearly real 3D imaging survey, as far as if there are dense measuring points along 2D lines in small area. This may be increasing the 3D imaging resolution, when take into consideration the size of subsurface anomaly in comparison with electrode spacing (a) of Dipole-dipole array.

Conclusions

Inversion models of Um El-Githoaa cavity show horizontal slices of the 3D resistivity distribution with depth. Therefore, it can be seen a very good 3D distribution of true resistivity changes in X and Y directions with depth. The inverse model produced by the standard least-squares method has a gradational boundary for the cavity (Fig.3). While, the invers model produced by the robust constrain method (Fig. 4) has sharper and straighter boundaries. First , second ,and third slices represented the resistivity changes from ground surface to depth equal (3m) .These slices showed relatively higher resistivity reflecting the dry sediments of gypsum rocks, and some of these rocks visible on ground surface .The slices after depth equal to (3m) appeared the effect of the subsurface cavity by noticeable increasing in resistivity contrast with surround sediment(up than 800 ohm.m) , as shown in the inverse models (Fig. 3) and (Fig.4) of standard least-square method and robust constrain method, respectively. The dimensions of the cavity which achieved from the two methods equal approximately to the actual dimensions of this cavity. The comparison between two methods appeared that the invers model produced by the robust constrain method (Fig. 4) has sharper and straighter boundaries, and the dimensions of the Um El-Githoaa cavity appeared nearer to the actual dimensions of this cavity (maximum diameter is about 19.3m, while the minimum equal to 15.8m and perpendicular to the first diameter).

3D resistivity imaging technique was delineated the high resistivity anomaly (up than 800 ohm.m) at depths ranges from (3 to 6 m), this anomaly is related to the subsurface Um El-Githoaa cavity .Therefore, the 3D imaging technique is the best to view underground cavities, because it appears the results in 3 dimensions, so it can define the problem in clearer image than the other techniques such as 2D imaging and 1D traditional electrode arrays techniques.

It is concluded that, if the true 3D imaging survey was collected without any perpendicular 2D lines, it could be an acceptable choice to achieve nearly real 3D survey, as far as the dense measurements along 2D lines in small area can be increasing the 3D imaging resolution, when take into consideration the size of subsurface anomaly in comparison with electrode spacing (a) of Dipole dipole array.

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المسح التصويري الثلاثي ألأبعاد لتحديد فجوه أم الجذوع في منطقة هيت ،غرب العراق

جاسم محمد ثابت[1] ، علي مشعل عبد[2] ، فراس حميد المنشد[3]

[1]قسم علوم الأرض ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق

[2]قسم الجيولوجيا التطبيقية، كلية العلوم، جامعة الأنبار، الرمادي ، العراق

[3]الهيئة العامة للمياه الجوفية ، قسم الدراسات والبحوث ، بغداد ، العراق

الملخص

تم أجراء المسح الثلاثي ألأبعاد فوق فجوه أم الجذوع الواقعة في منطقة هيت غرب العراق.وكان الهدف هو تقييم هذا النوع من المسح في تحديد الفجوات التحت سطحية.وتم أخذ القياسات للمقاومة النوعية بأمتداد أربعة مسارات متوازية، وبأستعمال ترتيب ثنائي القطبين (Dipole-dipole array). وقبل تنفيذ العمل الحقلي تم تحديد المسافة القطبية (a) والعامل (n) وكانت تساوي 2متر و6 على التوالي . وتم رسم الموديلين المعكوسين ثلاثيي ألأبعاد لفجوة أم الجذوع بطريقة (Standard least-squares) وطريقة (Robust constrain). أظهرت الشرائح ألأفقية لهما تغير قيم المقاومة مع العمق ،وأن الشرائح الثلاثة ألأولى تمثل تغير قيم المقاومة الى عمق 3 متر تقريبا، وتعكس أرتفاعا نسبيا في المقاومة والتي تعود الى الرواسب الجافة للحجر الجبسي والذي تظهر أجزاء منه على سطح ألأرض.الشرائح بعد عمق 3 متر تظهر تأثير فجوة أم الجذوع ،وذلك بزيادة فرق المقاومة لها(أعلى من 800 أوم.متر)مع الرواسب المحيطة . وأبعاد الفجوة المحدد من هذه الشرائح مساويا تقريبا الى ألأبعاد الحقيقية لها والمحدده من المشاهد الحقلية.عند المقارنة بين طريقتي التفسير أعلاه تبين أن الموديل المعكوس لطريقة (Robust constrain) قد أظهر حدود حادة واكثر أستقامة االى الفجوة ،وألأبعاد الى الفجوة أقرب الى ألأبعاد الحقيقية.لذلك فأن المسح الثلاثي ألأبعاد قد حدد فحوة أم الجذوع على عمق يتراوح بين (3-6) متر.وتم ألأستنتاج أن القياسات الكثيفة بأمتدادات المسارات الثنائية البعدين (2D Imaging) في المسوحات الصغيرة يمكن أن تزيد القدرة التحليلية للمسح الثلاثي ألأبعاد.

الكلمات الدالة: التصوير ثلاثي الإبعاد, كهف آم جذوع, نشر قطبين– قطبين.