

## MAGNETIC SURVEY IN TEL HERMAL ARCHAEOLOGICAL SITE SOUTHEAST BAGHDAD, IRAQ WITH APPLICATIONS OF GIS ANALYST TOOLS

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### ABSTRACT

A magnetic survey has been executed in the partially discovered archaeological site of Tel Hermal. It lies southeast of Baghdad and belongs to ancient Babylonian time (1500 – 2000 B.C). The area is covered by  $2 \times 2$  m net of magnetic measurements including 3367 readings. The goal of this work is to delineate the locations and extensions of buried archaeological structures. The statistical and geostatistical analyst tools involved in ArcGIS Software are utilized in this study. These include the histogram of data distribution, some statistical parameters and methods of interpolations. The study shows that the histogram is unimodal, which suggests a unique magnetic background in the site, and of a negative skewness with relatively high standard deviation which may be related to high noise level. The main noise sources are debris, electrical power lines, fences, and electromagnetic waves of communications. Accordingly, many magnetic anomalies of archaeological and non archaeological meaning have been identified on the residual map. Archaeological remains represented by wells and walls are recognized at a depth of 1.2 m at the northeast side of the study area.

### المسح المغناطيسي في موقع تل حرمل الأثاري مع الاستفادة من الادوات التحليلية لنظام GIS، جنوب شرق بغداد، العراق

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#### المستخلص

أجري مسح مغناطيسي في موقع تل حرمل الأثاري، الذي يعود الى العهد البابلي (1500 – 2000 سنة ق.م)، الواقع إلى الجنوب الشرقي من محافظة بغداد. وتضمن الموقع البالغة مساحته 13800 م<sup>2</sup> شبكة منتظمة من نقاط القياس بفاصله مقدارها 2 م × 2 م. ويهدف المسح تحديد تواجد وامتداد التراكيب الأثرية المغمورة والمعتقد تواجدها على عمق لا تتجاوز 3 م. ويعاني الموقع من خلفية ضوضاء عالية؛ تمثلت بمصادر الرئيسية بالانقراض المنتشرة بصورة عشوائية وأغلبها مواد حديدية ومواد فخارية، خطوط نقل الطاقة الكهربائية، الأسبجة الداخلية والخارجية المحيطة بالموقع إضافة إلى الموجات الكهرومغناطيسية للاتصالات. وقد تمت الاستفادة من الإمكانيات المتاحة ضمن نظام جي آي أس المتمثلة بأدوات الإحصاء الجيولوجي لغرض تحليل ومعالجة البيانات المغناطيسية وإعداد خرائط تساوي الشدة المغناطيسية للمجالين المتبقي (المحلي) والإقليمي، بالإضافة الى خريطة تبين مناطق اختلاف الانحدار الأفقي

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في الجهد المغناطيسي. وبين المدرج التكراري لتوزيع البيانات ان هناك خلفية مغناطيسية واحدة في الموقع وان التوزيع ذو ميل سالب مما يعني ان هناك عدد قليل من القراءات ذات القيم الواطئة نسبيا. كما وتعتبر قيمة الانحراف المعياري للبيانات عالية نسبيا (18) وذلك بسبب تأثيرها بمستوى الضوضاء العالي. وحددت على خريطة المجال المغناطيسي المتبقي بعض الأماكن التي تضم شواذا مغناطيسية ذات ساعات وأبعاد مختلفة والتي يعتقد أنها على الأغلب، تعود إلى مصادر قريبة من السطح وعديمة الفائدة من الناحية الأثرية، كما حددت بعض الأماكن التي تضم شواذا مغناطيسية من الممكن أن ترتبط بمصادر ببقايا أثرية مطمورة. وبينت نتائج الحفر اللاحقة في أحد هذه الأماكن وجود تراكيب أثرية تمثلت ببئر يتراوح قطره بحدود 1.1 م إضافة إلى جدار طيني مجاور له وعلى عمق 1.2 م.

## **INTRODUCTION**

Geophysical prospecting is required by archaeologists to guide the excavation program and to rescue a site destined to be partially destroyed. Magnetic method is usually used in archaeological exploration to detect features such as buried walls and structures, pottery, bricks, fire pits, buried pathways, tombs and numerous objects. The features are detected and mapped as a result of their being more magnetic than the surrounding material (Patella, 1991 in Urbini *et al.*, 2006). The technique gives the possibility of obtaining quick information on buried archaeological structures in already known sites.

Due to the cooperation between State Board of Antiquities and Heritage and GEOSURV, a magnetic survey has been carried out in a partially discovered area, the so called Tel Hermal Archaeological Site for archaeological investigations (Al-Bahadily *et al.*, 2009).

It is recorded that this historic site, which is a part of Eshnunna Kingdom, belongs to the ancient Babylonian time (1500 – 2000 B.C). During the period 1945 – 1962, Iraq archaeological group discovered an important part representing a temple and scientific library in this site. However, a relatively large part of the site is still undiscovered and the archaeologists believe that it may contain many archaeological structures covered by soil with a maximum depth of 3 m (Fig.1).

The goal of the magnetic survey is to detect the locations and extensions of the buried archaeological remains with the use of GIS Analysts Tools in processing. Tel Hermal site is located to the southeast of Baghdad, about 8 Km to the east of the Tigris River (Fig.1). The geographic coordinates of the site are: 33° 18' 35" N and 44° 27' 59" E.

Several magnetic studies have already been made in different archaeological sites in Iraq. For example, Hamo (1977) studied the Sippar and Abu-Skhair sites; Salumy *et al.* (1978) studied the Tel Kutha archaeological site, of the Sumerian period and, used a grid net of (2 m × 2 m) of measurements to detect walls lying below 0.8 – 3.6 m of soil; Ahmad (1979) studied Ctesiphon (Taq-Kisra); Al-Bahadily and Yousif (2012) carried out detailed magnetic survey in Taq-Kisra Site southeast of Baghdad using 2 m × 2 m net of magnetic stations totaling 5260 stations.

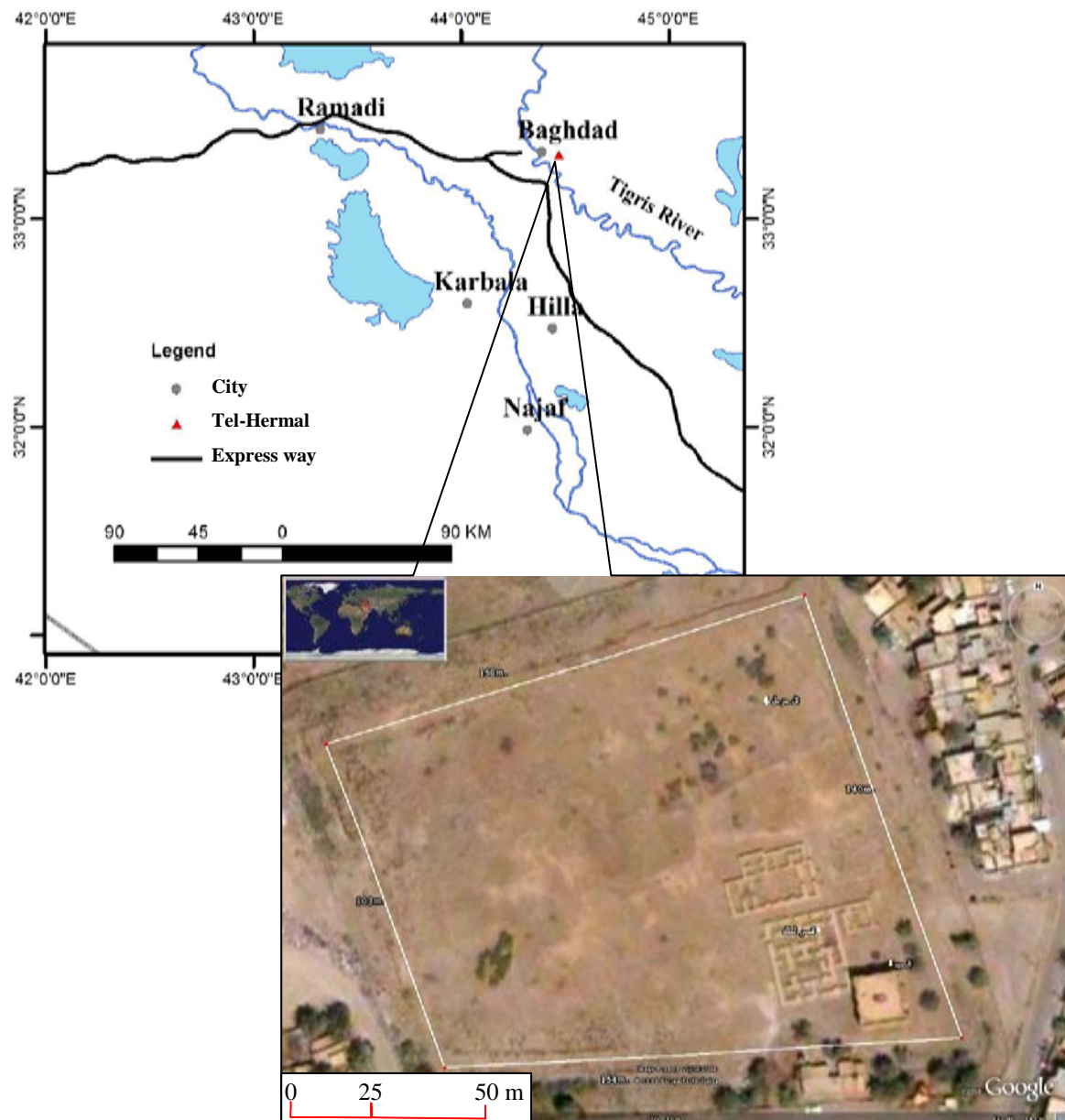


Fig.1: Location map of Tel Hermal archaeological site with satellite image of the study area (the image after Google Earth, 2002)

### MAGNETIC SURVEY

A regular grid ( $2\text{ m} \times 2\text{ m}$ ) of measuring stations is used at the present site, which has an area of about  $13800\text{ m}^2$ . Two proton magnetometers, type Geometrics G-816 with sensitivity of  $1\text{ nT}$ , are used. The first one is used for the acquisition of magnetic data, whereas the second is used as a base station. The total number of measurements is 3367 readings (Fig.2). Generally, the diurnal variation analogues (magnetogram) are relatively gentle and smooth, where no unwanted disturbances commonly known in literature such as spikes, stripes and zig-zag have been identified. However, very low peaks (not exceeding  $5\text{ nT}$  in value) have been noticed.

The site is characterized by relatively high noise level. The main noise sources are random scattered debris; some of which are due to ferromagnetic sources, on or near the

ground surface, electrical power lines, presence of bricks spread into the soil and the electromagnetic waves caused by communications. These noise sources render the useful signals identification more difficult. Intensive efforts have been exerted to clean the study area from this debris before and during the survey operations.

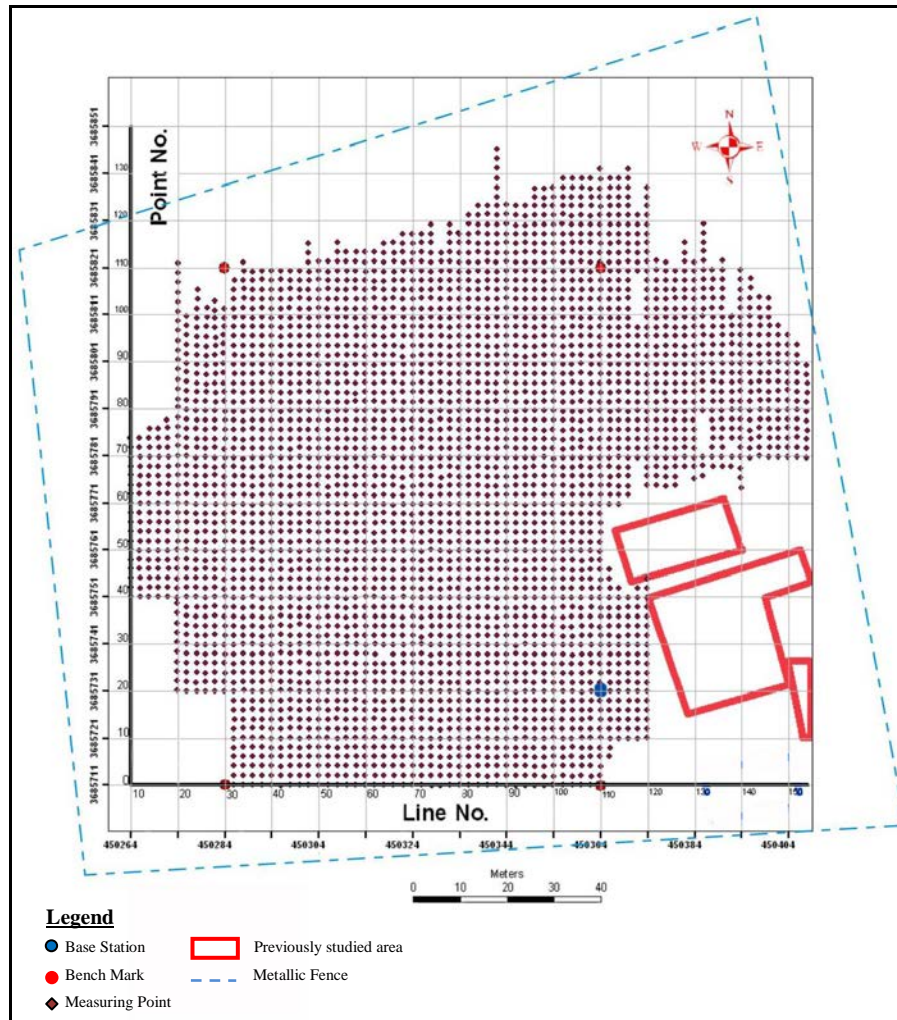


Fig.2: The distribution of the magnetic stations in Tel Hermal site. The discovered areas, the outer metallic fence and locations of base station and the bench marks are also delineated

## APPLICATIONS OF GIS ANALYST TOOLS

ArcGIS software includes some important tools that may be helpful in geophysical data processing and interpretation. Al-Bahadily *et al.* (2014) in a recent study have applied these tools on magnetic datasets of three archeological sites. They have concluded that;

The statistical parameters and the type of distribution of the magnetic data may give an important idea about the magnetic background and noise level, while the error within the magnetic anomalies may be caused by the interpolation method. It is concluded that the Kriging method is better in representing the anomalies than Inverse Distance Weight (IDW) method, where the former is affected by the data distribution and the spatial correlation of the variable (magnetic value), whereas the latter is affected by the distance only; therefore, it exaggerates the noise rather than diminishes it.



The above conclusions are considered for the processing and presentation of magnetic data of Tel Hermal site.

Figure (3) shows the histogram of the distribution of the magnetic data with some important statistical parameters. The histogram shows a negative skewness i.e. the data is not normally distributed. It indicates a relatively small number of readings with low magnetic values. In addition, the histogram is unimodal that suggests a unique magnetic background. It should be pointed out that the interpolation methods used to generate a surface give the best results when the data is normally distributed (ESRI, 2008). This means the evaluation error is relatively high in the site. However, normal QQ plot is useful in determining the values that lie out of the normal distribution, and then they may be removed or processed in order to reduce the estimated error. Normal QQ plot is created by plotting data values with the value of a standard normal where their cumulative distributions are equal (Fig.4). The standard deviation of the data is 18, which is related to the high noise level.

Kriging method is used to interpolate the total magnetic intensity (TMI) and residual data, while second degree Global polynomial regression is used to represent the regional (local regional) components of the total magnetic field, as will be shown in next paragraph.

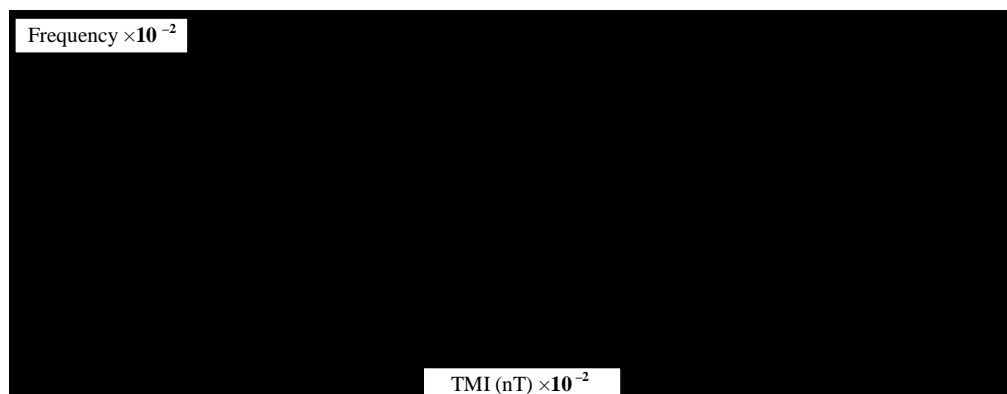


Fig.3: The histogram of data distribution. Total magnetic intensity and their frequencies after multiplying by  $10^{-2}$  are represented on the horizontal and vertical axes, respectively.

It shows negative skewness histogram with some important statistical parameters of the magnetic data of Tel Hermal

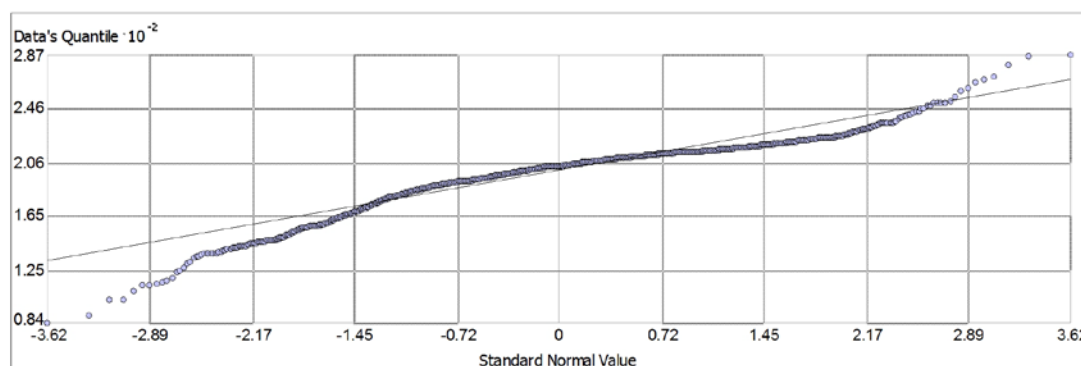


Fig.4: Normal QQ plot of the magnetic data shows the samples that lie out of normal distribution (straight line)

The rate of maximum change in z-value (magnetic intensity) from each cell of the interpolation surface is identified for determining the high gradient in the area. The high gradient may represent a magnetic contact between the archaeological remains and the host soil.

### **QUALITATIVE INTERPRETATIONS**

Some magnetic measurements related to noise can easily be recognized and isolated. They have been removed before the interpolation. TMI map is constructed, after applying the diurnal correction, using Kriging method as shown in figure (5). Accordingly, the residual and regional maps are derived from the TMI map as shown in figures (6 and 7), respectively. The minimum and maximum recorded values, of residual magnetic anomalies, are  $-51$  nT and  $32$  nT, respectively. This range includes two sources of magnetic anomalies; non-archaeological and archaeological sources.

The first source (non-archaeological) gives anomalies characterized by short wavelengths, high amplitudes, and dipolar. This source is related to debris which is covered by soil. Such debris may include steel cans, lumber, roofing steel, machinery parts, and other cultural artifacts such as remains of building materials of houses. A greater concentration of, such non-meaningful signals is noted in a small depression within the southwestern part of the prospected area, and delimited by the area A in the residual map (Fig.6). Relatively smaller areas, B, C, D and E have the same magnetic characteristics of anomalies as in area A and could be well recognized in this map. Moreover, many isolated anomalies noticed scattered, everywhere in the map, maybe related to the same sources as well.

The second source (archaeological) gives anomalies characterized by relatively low amplitudes, and long wavelengths such as areas G, H and I in figure (6) which are suggested to be anomalies related to archaeological sources. The most important one is anomaly in area G. This anomaly has positive and negative values of about  $+20$  nT and  $-10$  nT, and an elongation NNE – SSW direction with a length of about  $9$  m and a width of  $5.5$  m. More to the east of G, another important anomaly assigned as H could be noticed. It has an extension of  $5$  m, and has normal polarity, where the positive and negative parts have the values  $+12$  and  $-21$  nT, respectively. Area I represents another anomaly, which has an amplitude value of  $18$  nT. The axis of this anomaly runs in a NW – SE direction, and the maximum length and width are  $4.5$  m and  $6$  m, respectively.

A magnetic section in a N – S direction passing directly across the anomaly G is shown in figure (8). The profile shows many magnetic anomalies of different values and the most prominent of which is anomaly G with normal polarity and amplitude of the positive and negative parts of  $+25$  and  $-10$  nT. Another conspicuous one is anomaly G. It has an envelope of  $30$  nT with relatively broad positive part of  $20$  nT and narrow negative part of  $-10$  nT (Fig.6).

The local regional map of Tel Hermal site (Fig.7) shows a magnetic high, of amplitude up to  $20$  nT with horizontal gradient of about  $0.4$  nT/m, of isometric shape in the central part of the study area. It may be attributed to the relatively high thickness (the central part of the study area "hill" is elevated to about  $3 - 4$  m) multilayers related to successive periods which may have high magnetic susceptibility relative to the surroundings. The negative effect of the outer metallic fence on the magnetic field may also have an important role on the shape and magnitude of regional high. This effect can be seen easily on the TMI map which is reflected as a high gradients surrounding the study area (Fig.5).

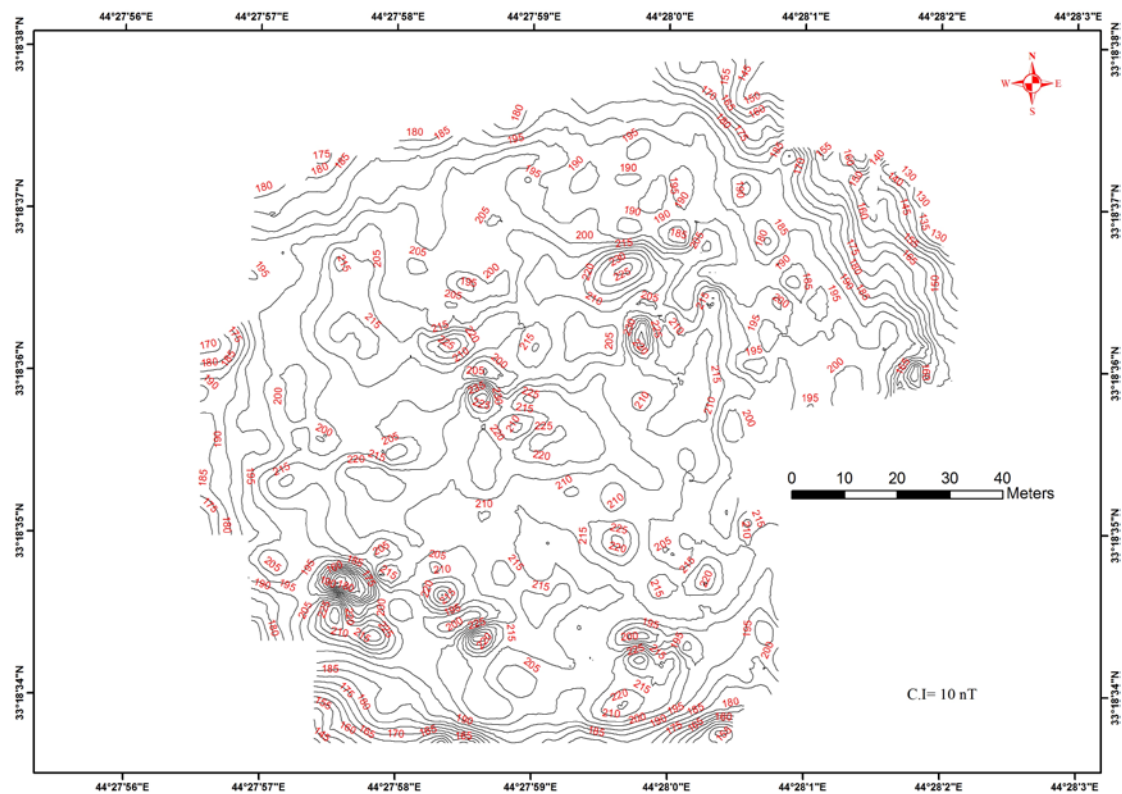


Fig.5: Total magnetic intensity map of Tel Hermal site. The effect of the outer metallic fence can be seen easily as high gradients surrounding the area

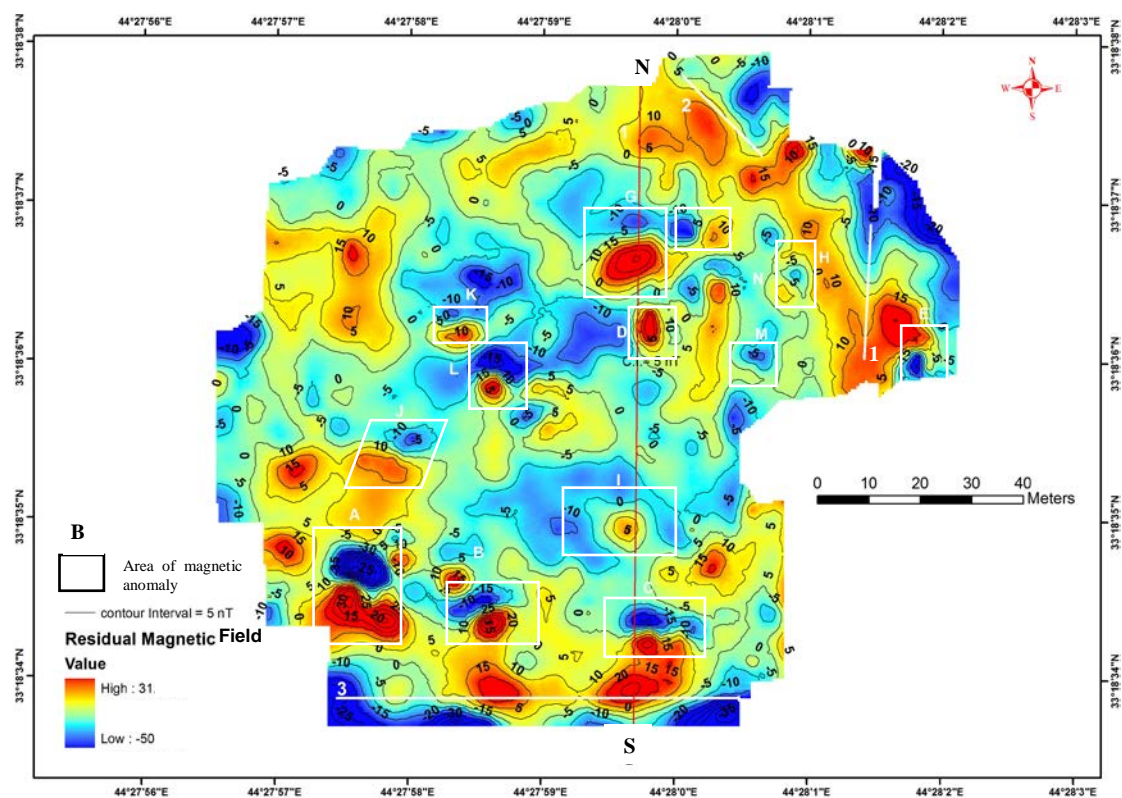


Fig.6: Magnetic map of residual field of Tel Hermal site

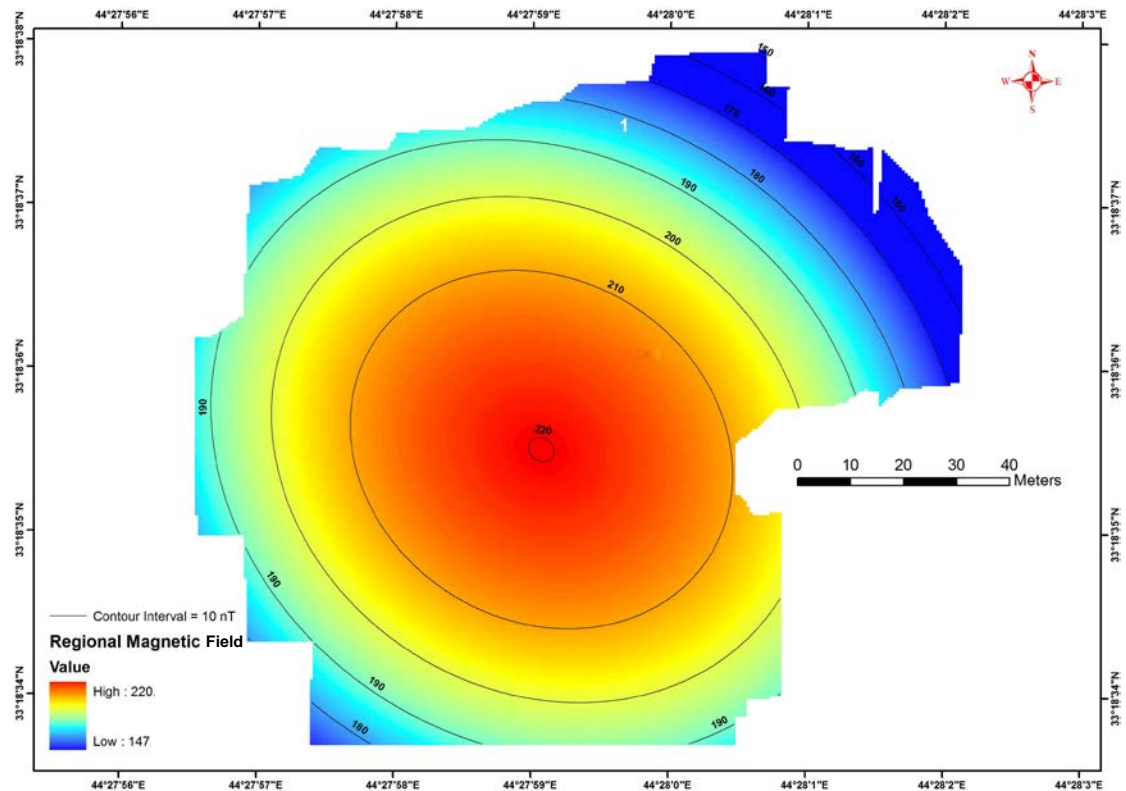


Fig.7: Magnetic map of local regional field of Tel Hermal site

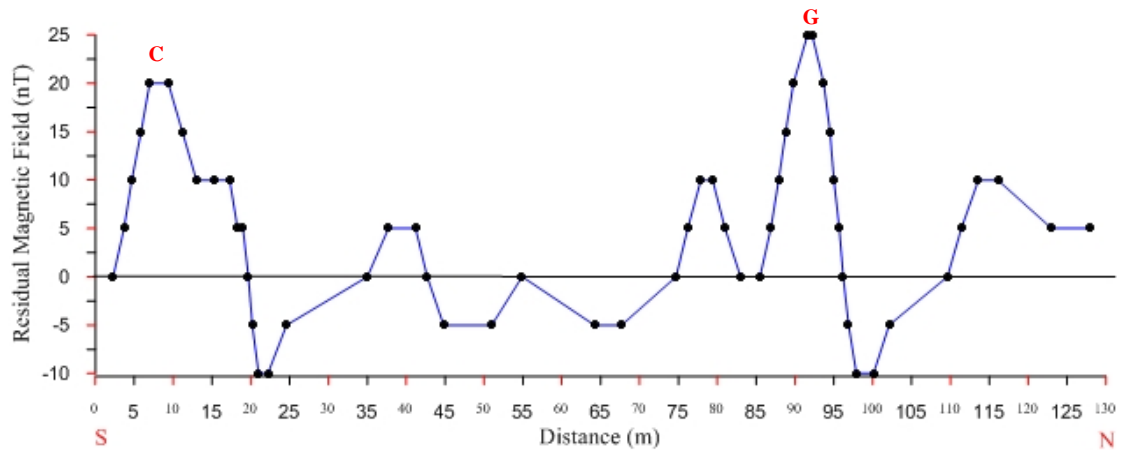


Fig.8: Magnetic section in N – S direction running from anomaly C in the south to G in the north (for location refer to Fig.5)

Horizontal gradient or slope map (Fig.9) is useful to delineate the edges of the buried structures which appear as a red color. Slope map is important to improve the magnetic responses of the magnetic structures, especially, that of elongated shapes.



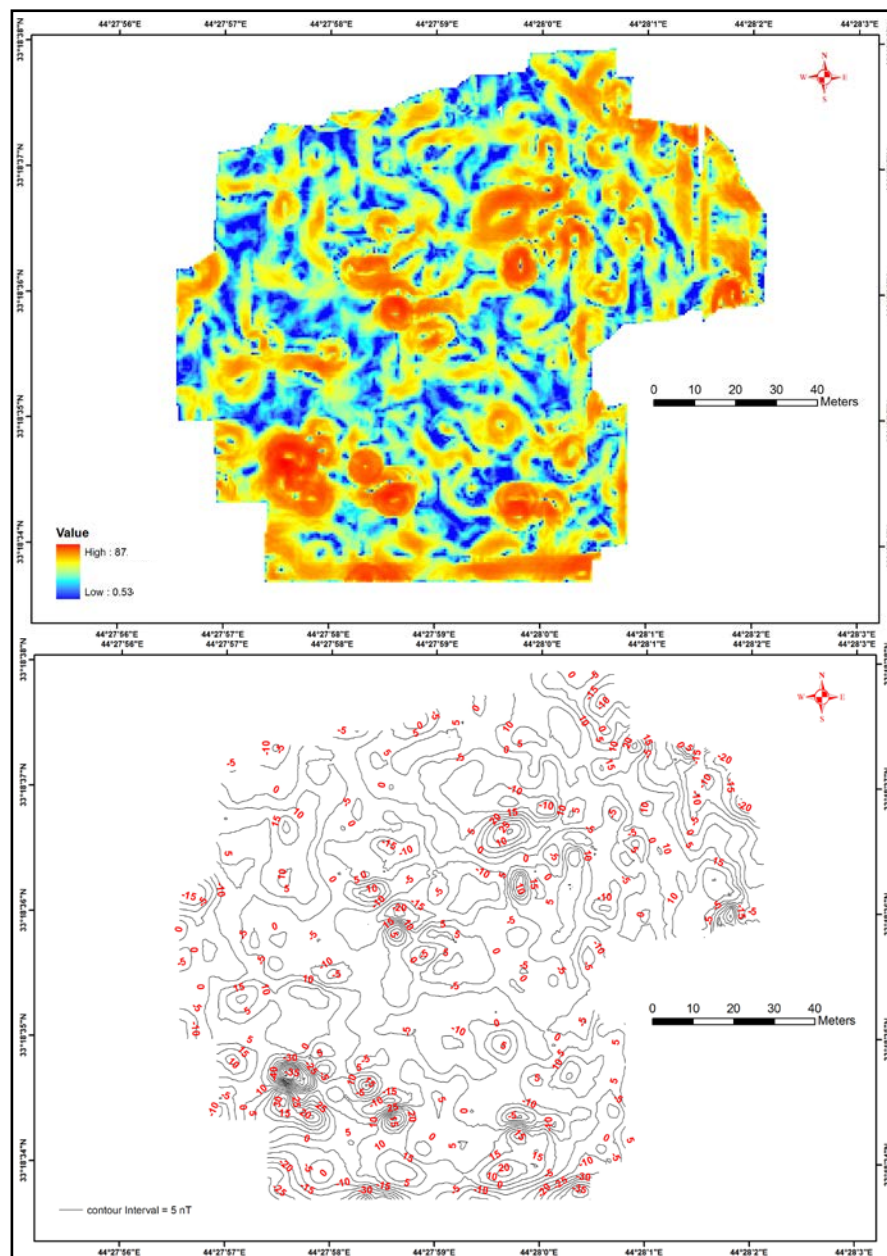


Fig.9: Slope of residual map of Tel Hermal site (upper) shows the high gradient areas and the residual contour map (lower) for comparison

## RESULTS AND DISCUSSION

The area G in the residual magnetic map has been chosen for checking up the causative source. A trench at the central part of the anomaly, with dimensions (3 m length  $\times$  1 m width  $\times$  1.2 m depth), trending NW – SE has been excavated. An archaeological structures represented by well and wall have been identified at a depth of 1.2 m (Fig.10). The well is made up of burned bricks, and has a diameter of 1.1 m, while the wall is built up of clay materials.

Many previous excavations were made over anomalies with different amplitudes delineated at the residual map as areas J, K, and L. These anomalies could be attributed to some magnetic materials (debris) that used during burying.

In figure (6) the magnetic effect of the external metallic fence on the magnetic measurements is recognizable on the northeastern part as a nose shaped anomaly and as a high magnetic gradient (lines 1, 2, respectively). In addition, another gradient due to the magnetic effect of remains of relatively newly built bricks wall at the southern edge of the study area, which is partially covered by soil (line 3). The topographic depressions give magnetic anomalies with different magnitudes due to accumulation of non archaeological magnetic objects, assigned as areas M, N and O in the figure.

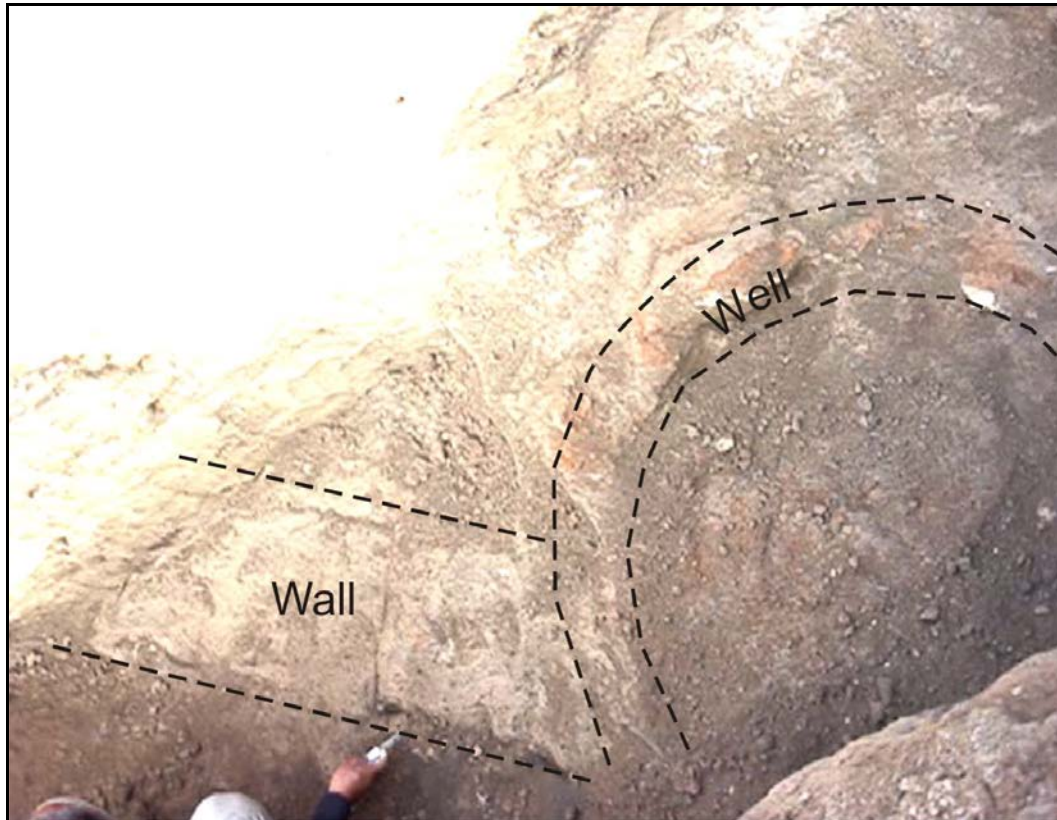


Fig.10: Archaeological features represented by well and wall identified during excavation in area G shown in Fig. (6)

## CONCLUSIONS

The magnetic survey in Tel Hermal Archaeological Site has provided important information to the archaeological research in this site. The following conclusions are obtained.

- The distribution of the magnetic data is of unimodal, non-symmetrical and negative skewness which suggests a unique magnetic background and small number of measuring stations with low magnetic values. The relatively high standard of deviation of (18) coincides with the high noise level.
- The site is characterized by relatively high background noise level. The main noise sources are debris (some of which are ferromagnetic) covered by soil, electrical power lines, abundance of bricks in the soil and electromagnetic waves caused by communications. Therefore, many magnetic anomalies without archaeological meaning are assigned in the residual magnetic map of the site.

- The highlighted anomaly in area G has a full archaeological feedback represented by well and wall proved by excavation followed this work. Two areas (H and I) are suggested to be as archaeological source for future excavations.
- The structures brought to light by the excavation are mostly made of burned bricks and clayey materials hosted by soil.

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