



## **Geotechnical study for cavity detection in highways using Ground Penetrating Radar, Sulaimani City, Iraqi Kurdistan Region**

Bakhtiar Q. Aziz<sup>1</sup> and Halo A. Othman<sup>1</sup>

*1Sulaimani University, College of Science, Geology Department.*

*Email: bakhtiar.aziz@univsul.edu.iq*

<b>Article info</b>	<b>Abstract</b>
Original: 6 January 2016 Revised: 15 June 2017 Accepted: 19 July 2017 Published online: 20 September 2017	Construction and extension of a road over the mountainous area have undergone different problems. Several of cavities and voids were encountered during road construction especially when the road is passing through some geological formations containing limestone layers. The annual precipitation in the area under consideration approaches 750 mm. Consequently, numerous cavities of different sizes and depths developed. These cavities reduce support to the ground above when overloaded daily by a large number of heavy tracks and can cause localized collapse of the overlying rocks and deposits. Ground Penetrating Radar (GPR) has selected for detection the locations, extensions and depths of such cavities over a part of the Sulaimani – Said Sadek road passing through the limestone rocks. The GPR survey carried out over six traverses by using high resolution 200 MHZ antenna. 1642 m length covered by the survey. The result shows that GPR was very effectiveness in such high resistivity area, where the rocks are cropping out to the surface and no others geophysical methods have worked correctly. Several cavities were detected have a dimension ranging from 1 to 3 meters, and they located at depths ranging from 0.5 to 6 meters.
<b>Key Words:</b> GPR, Cavity, Geotechnical problems	

### **Introduction**

According to the data collected from the traffic office of Sulaimani City, one of the significant problems being the high number of car accidents on the outer road from the center of the city to most of the townships and districts. The accidents are due to more than thousands of collapses and subsidences recorded on these roads due to the underground cavities of various sizes as well as a karstic feature of the rocks. The average dimensions of most of them were measured; they are ranging from 0.5 to 3.5 meters and their depths from the ground surface is ranging from 0.20 to 0.60 meters. Most of them concentrated on some segments of this roads and had not or rarely seen on the rest parts.

In geological point of view, The concentration of these cavities and karst appears on those parts of these roads that are passing through limestone rocks of the different geological formations such as Kometan, Balambo, Sinjar, Pila Spi, and Qamchuga. These geological formations mostly characterized by the existence of a significant number of cavities and karst, figure (1); several researchers denote to the cavities and karstic features of these rocks such as (1, 2, 3 and 4). The high solubility of limestone rocks is mainly due to their carbonates nature and high annual weak acidic precipitation in the region may approach 750 mm. Limestone is mostly made up of the calcite mineral that composed of calcium carbonate ( $\text{CaCO}_3$ ). The Calcite is not so soluble to make the rocks dissolve very quickly. However, when a weak acid rainfall is available, it will react with the carbonate to form hydrogen carbonate  $\text{HCO}_3^-$  ions, which are very soluble in water, and lead to dissolve the limestone.

Among the geophysical techniques can be used to map the existence of cavity and void below the road, the authors selected Ground Penetrating Radar (GPR) system. The main aim is to test its capability in such disturbed and the noisy area where limestone talus scattered on the surface due to the cutting process so that others geophysical methods unable or inefficient to work.

GPR is now a well-accepted geophysical technique, the method uses radio waves to probe the ground which means any low loss dielectric material (5). Radar Signal Processing (RSP) involves using specialized filters to enhance and adjust the digitized reflections, as well as to remove noises contained in the set of recorded radar pulses (6). GPR can image high-resolution stratigraphy in the shallow subsurface sand, gravel, and peat with the best results obtained in clean (free of silt and clay), quartzite-rich, and nonclastic sediments (7).



Figure- 1: Shows one of the cavities appears on the surface due to the cutting process.

### Methodology and Field procedure

A 100 MHz antenna frequency is used to preserve both resolutions and adequate depth. The specific time window of about 400 ns was adjusted for all the radar sections to cover depths of about 15 meters. The transmitter and receiver antenna with 1m of separation between them are run very close to the surface of the ground for the sake of minimizing ambient noises as much as possible. A control unit used for controlling all parts and time generation of the radar wave pulses. The control unit sends the collected data to a monitor for a view the radar time sections and changing the setup of some field parameters of the device such as time window, antenna separation, signal searching and primary filters. The horizontal distance measured through a hip chain. The collected data processed for converting from the time domain to depth section by using the actual radar velocity around 11 cm/ns for the limestone.

The processing of the field data is carried out by using several filters for obtaining a high-resolution radar section as DC, time zero adjustment, amplitude correction, and time gain.

The field procedure for a sampling of data is carried out on six traverses at 15/12/2015, the length of each traverse is ranging from 205 to 360 meters and the distance between them is about 3 meters. Consequently, the total length of the traverses is equal to 1642 meters. The whole area covered by the survey is around 3284 m<sup>2</sup>, it is located at the intersection point of the latitude 35<sup>0</sup> 26' 43" and longitude 45<sup>0</sup> 41' 33" as shown in Figures (2) and (3).

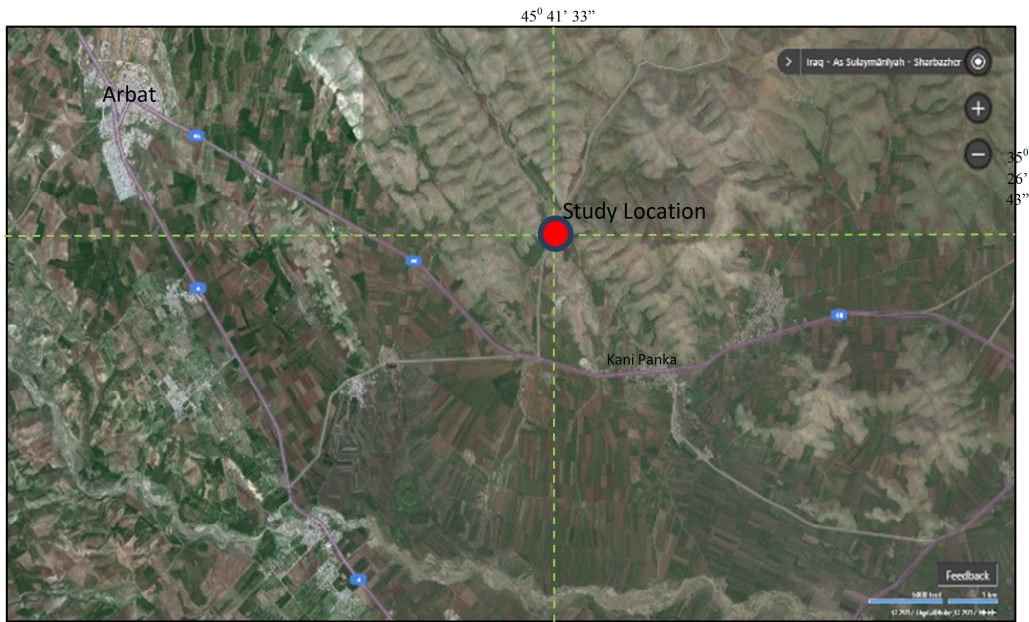


Figure-2: Satellite image shows the location of the investigated site.

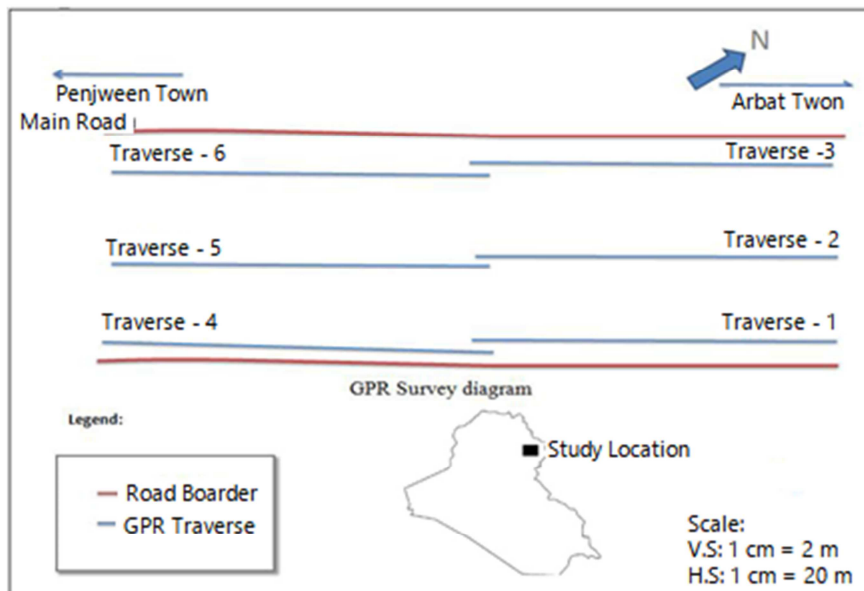


Figure-3: Shows the main road with 2D resistivity traverses.

### Ground Penetrating Radar data

#### *A-processing:*

These are usually applied directly to the raw data (often automatically) without the need for additional subsurface information and apply to most collection modes. Typically, they take the form of trace editing, filtering or data correction and introduce minimal operator bias into the data. In practice, most, if not all, of these steps are required before a basic interpretation can make. If the sections are to view in a three-dimensional (3D) context (e.g., with time slicing), then an element of manual control is vital to retain both data quality and consistency between each section. In the current study, the main data processing's are carried out by RAD explorer.

Explorer software, applying the necessary filters as DC, times zero adjustment, amplitude correction and time gain. They selected depending on the appearance of a distinct section and anomalies could be seen. Then, each radar section is converted to a depth section by using a suitable radar velocity for the limestone rocks equal to 11 cm/ns.

#### *b- Interpretation:*

It is expected that Ground Penetrating Radar survey shows a good response because the site is located on high resistive limestone rocks. Consequently, many anomalies in the form of hyperbolic shapes have been detected on the radargrams, Figs. (4, 5, 6, 7, 8 and 9). Most probably they might represent the reflections from the top surfaces of cavities as shown in the radar sections. The resolution of the hyperbolic shapes on

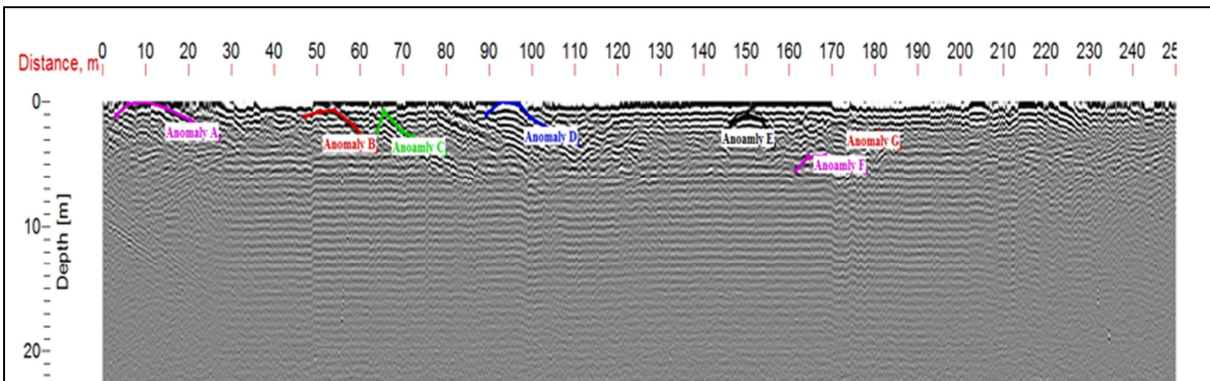


Figure 3: Radar section in traverse one, 100MHZ

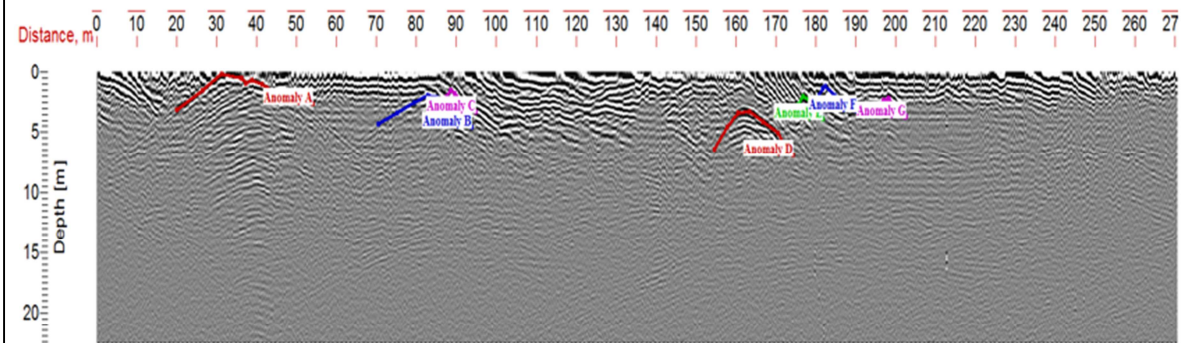


Figure 4: Radar section in traverse two, 100MHZ

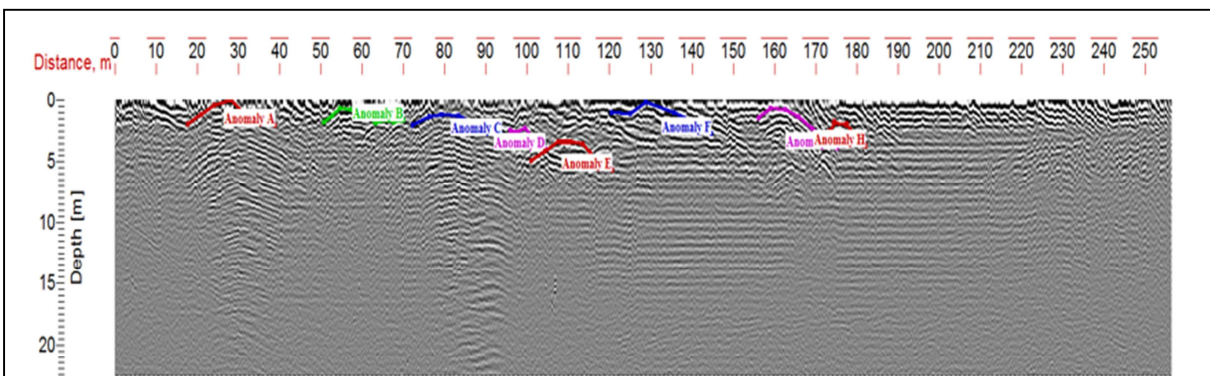


Figure 5: Radar section in traverse three, 100MHZ

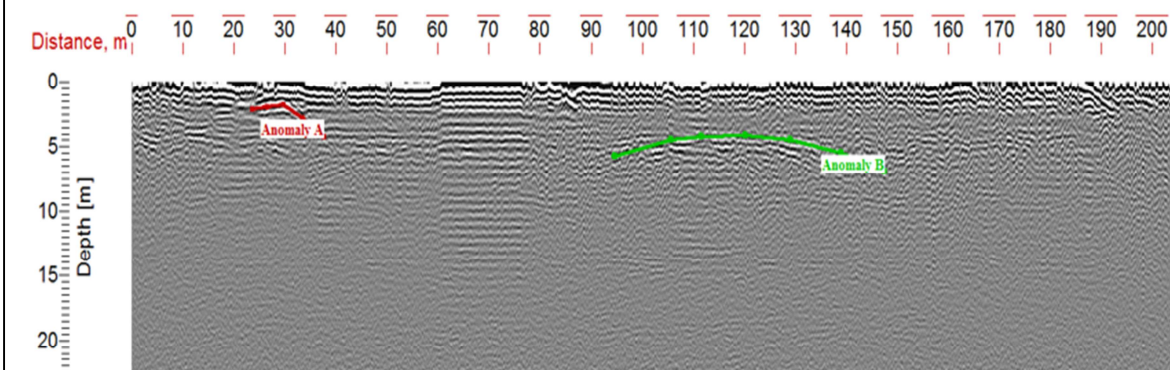


Figure 6: Radar section in traverse four, 100MHZ

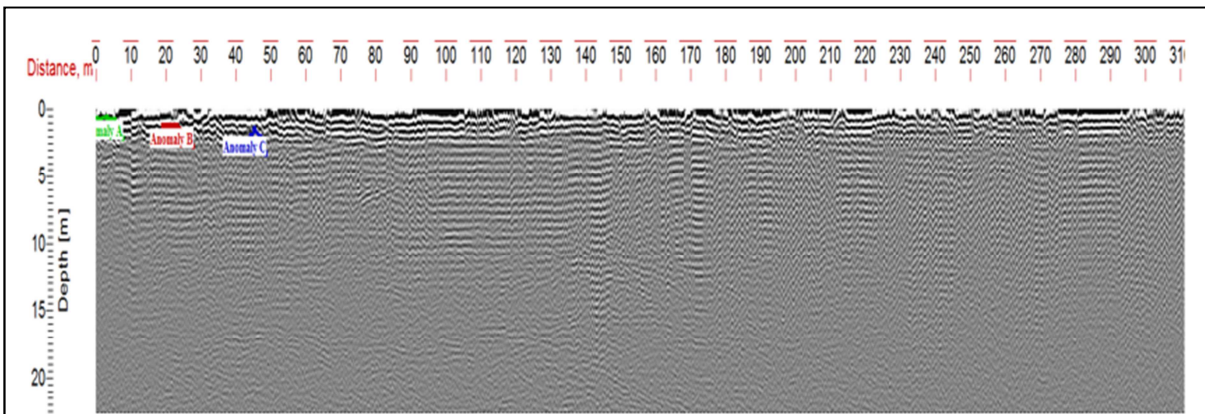


Figure 7: Radar section in traverse five, 100MHZ

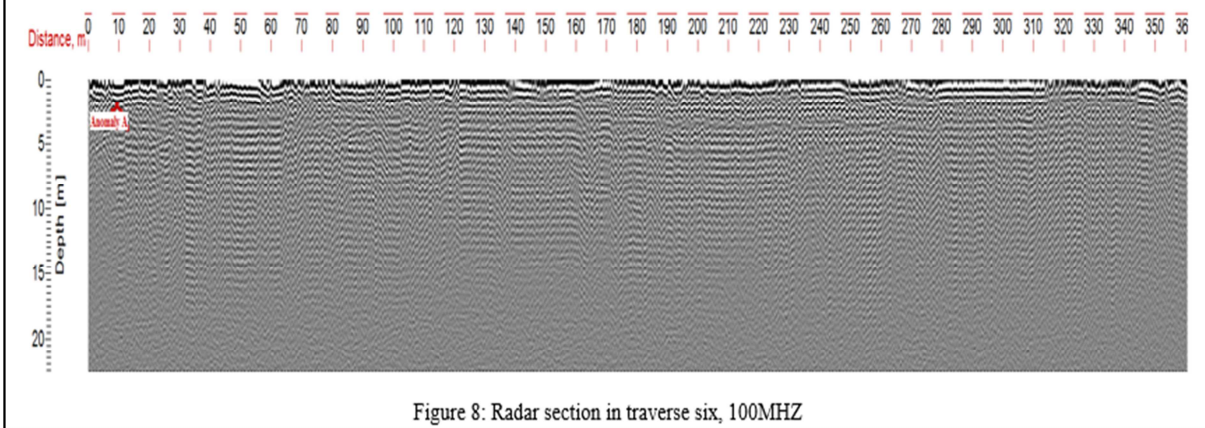


Figure 8: Radar section in traverse six, 100MHZ

the radar sections depends on the electric conductivity contrast between the existence materials inside the cavity and the surrounding limestone rocks. The results show high resolution in some locations and fair in others, this refers to the air-filled of some cavities and clay-filled or weathered product-filled with others cavities. Table (1) shows the anomalies detected in the survey, the distance from the beginning of the traverses and their depths are determined.

Table 1: Show the horizontal distances and the depths of the detected anomalies by meters.

Traverses	1		2		3	
Anomalies	Distance	Depth	Distance	Depth	Distance	Depth
A	10	0.5	31	0.5	27	<b>0.5</b>
B	54	1	82	1.5	56	<b>1</b>
C	65	1	89	1	80	<b>1.5</b>
D	95	0.5	161	3	100	<b>2</b>
E	150	1	176	2	110	<b>3</b>
F	166	5	183	1.5	130	<b>0.5</b>
G	180	2	197	2	160	<b>1</b>
H	-	-	-	-	175	<b>1.5</b>
Traverses	4		5		6	
Anomalies	Distance	Depth	Distance	Depth	Distance	Depth
A	30	2	2	0.5	10	<b>2</b>
B	120	4.5	21	1	-	-
C	-	-	46	1	-	-

In both air-filled and material-filled cavities, there is a large difference of electrical permittivity contrast, this makes the target recognized easily. The cavities produce a hyperbolic shape of different sizes and in different depths due to the continuous reflection of waves from the ceiling parts.

Some of the hyperbolas are generated by the surface objects and recording on the sections or reflecting from an adjacent wall, car, and persons that should be differentiated from the underground anomalies properly. In some case it may not produce the hyperbolic shape, it creates a strong reflection than any other weak reflector. Anomalies at shallow depths can be observed much clearly than the deeper ones because the radar signals are attenuating directly with the depth. The short time window that is setting up leading to the loss of the anomalies at depth. The shallow anomalies appear more significantly, they have a significant effect on the surveyed road. In the current study, the majority of detected anomalies are represented cavities of different sizes within the limestone rocks.

**Traverse 1:** It has a length equal to 250m; several anomalies are detected clearly on this traverse. All of them detected at shallow depths except anomalies F and G. The anomaly A located at the distance of 10m and depth equal to 0.5m. The anomaly B located at a distance of 54m and depth equal to 1m. At the distance equal to 65m the anomaly C is detected at a depth of 1m. The anomaly D appears at the depth of 0.5 and a distance of 95 m. The deepest anomaly F, on this traverse, is located at a depth of 5m and a distance of 166 m, figure (4).

**Traverse 2:** It has a length equal to 270 m. The anomaly A located at the distance of 33 m and depth equal to 0.5m. The anomaly B located at a distance of 83 and depth equal to 2 m. At the distance equal to 88 m the anomaly C is detected at a depth of 2 m. The anomaly D appears at the depth of 4.5 and a distance of 160 m. The anomalies E, F, and G on this traverse are located at a depth of 2 m and distances of 175, 182, and 198 m respectively, figure (5).

**Traverse 3:** It has a length equal to 257 m. The anomaly A located at the distance of 27 m and depth equal to 0.5m. The anomaly B located at a distance of 56 and depth equal to 1m. The anomaly C appeared at distance 80 m and a depth equal to 2 m. The anomaly D appears at the depth of 3 and a distance of 96 m. The deepest anomaly E, on this traverse, is located at a depth of 4.5 m and a distance of 110 m. The anomalies F, G, and H are located at depths of 0.5, 1, and 2.5 m and distances of 130, 160, and 175 m respectively, figure (6).

**Traverse 4:** It has a length equal to 205 m, two anomalies are detected clearly on this traverse. The anomaly A located at the distance of 29 m and depth equal to 2.5m. The anomaly B is broad hyperbole; it located at a distance of 105 m and depth equal to 5 m, figure (7).

**Traverse 5:** It has a length equal to 300 m, three small anomalies are detected at the beginning of the traverse. The anomaly A located at the distance of 2 m and depth equal to 1 m. The anomaly B located at a distance of 20 m and depth equal to 2 m. At the distance equal to 47 m the anomaly C is detected at a depth of 2.5 m, figure (8).

**Traverse 6:** It has a length equal to 360 m, A single small anomaly detected at the beginning of the traverse. The anomaly A located at the distance of 10 m and depth equal to 2.5 m, figure (9).

## Conclusions:

Ground Penetrating Radar proved that it worked very well over the dry high resistive limestone rocks exposed to the surface. The absence of the soil covers over these rocks gives the radar pulses considerable strength, and as results, very high-resolution radargrams have been recorded. Symmetrical hyperbolas of high resolution as well as of different sizes detected from depths ranging between 0.5 meters to 5 meters. The cavities detected through this study have volumes ranging from  $0.425 \text{ m}^3$  to  $8.5 \text{ m}^3$ . The study also

concluded that caves have volumes less than  $0.425 \text{ m}^3$  could not be detected within this range of depths by GPR while a lot of them observed during the excavation of the road. The study determined the locations, sizes, and depths of 28 cavities, most of them located in the north part of the area beneath traverses 1, 2 and 3. The study also proved that 100 MHz antenna of GPR is very suitable for such type of study and preserving both resolution and depths.

### References:

- [1] Aziz, B.K., "*Two dimension resistivity imaging tomography for hydrogeological study in Bazian-West Sulaimani City*". NE Iraq, Ph.D. thesis unpublished, University of Sulaimani, (2005).
- [2] Aziz, B.K., and Ali P.M., "*Karst cavity detection in carbonate rocks by integration of high-resolution geophysical methods*". Speleohungary100 conference. Budapest, Hungary. pp.7-9 May (2010).
- [3] Bakir, H., B., "*Ground Penetrating Radar and electrical resistivity studies for Hmamoke Dam site, NW Koya city*". Kurdistan region, Iraq, College of Engineering, University of Koya, pp. 143. (2008).
- [4] Stivanovic, Z., Iurkiewicz, A., and Aleksandra, M. "*New insights into karst and caves of northeastern Zagros and northern Iraq*". ACTA CARSOLOGICA Vol. 38. No.1, pp. 83-96, POSTOJNA (2009).
- [5] Jol, H., M., 2009, "*Ground Penetrating Radar: Theory and Applications*", Elsevier Science, 1st edition, pp. 524. (2009).
- [6] Goodman, D., and Piro, S., "*GPR Remote sensing in archaeology*", Springer, V9, pp. 233. (2013).
- [7] Smith, G., D., and Jol, H., M., "Ground penetrating radar: antenna frequencies and maximum probable depths of penetration in Quaternary sediments, Journal of Applied Geophysics Vol. 33, pp. 93-100. (1995).

