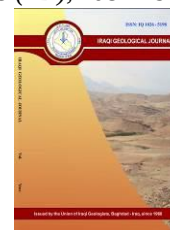




Iraqi Geological Journal

Journal homepage: <https://www.igj-iraq.org>



Employing Ground Penetrating Radar Technique to Investigate the Secondary Channel of the Ancient Euphrates River Valley (Kari Saada) in Najaf

Ammar J. Al-Khafaji^{1*}, Nabeel A. Al-Mazal², Amjed S. Al-Jaafary³, Hussain M. Hussain³, Hasan A. Jaafar⁴, and Abed Al-Kadhum J. Marzooq³

¹ Department of Petroleum Engineering, College of Engineering, University of Kerbala, Iraq

² College of Archaeology, University of Kufa, Iraq

³ Department of Applied Geology, College of Science, University of Kufa, Iraq

⁴ Department of Civil Engineering, College of Engineering, University of Kufa, Iraq

* **Correspondence:** ammars.j@uokerbala.edu.iq

Abstract

Received:

1 April 2025

Accepted:

27 September 2025

Published:

31 October 2025

In the field of archaeological investigation, geophysical methods serve as a non-destructive exploration method. In this study, the Ground Penetrating Radar was used to detect the second phase of the ancient Euphrates River Valley. The ground penetrating radar survey was conducted for two sites in Najaf Governorate. The first site at Kufa University, where the length of the ground penetrating radar profile reached 285 m, and the second location was in the Al-Tamem neighborhood at the Captivity Bridge, where the length of the ground penetrating radar profile was 350 m in the east–west direction. Two data processing programs have been used: RAMAC GroundVision and Reflex 2D Quick-test version. The results of the cross-section of the ancient Euphrates Valley indicated five stages. The first one, the Euphrates River lateral expansion, is 285 m; the depth of the river valley is 11 m and the width of the river valley is 195 m. The width of the deeper river valley is 60 m; two banks are present at the west side. In the second stage, its lateral expansion became 150 m, the depth of the river valley is 6 m, the width of the river valley is 63 m, and the width of the deeper river valley is 60 m at the west side. In this stage, the receding of the river, possible tectonic movement that changed the course of the Euphrates River. The third stage clarified that the river's lateral expansion was 25 m, the depth of the river valley is 4 m, and width of the river valley is 55 m. This stage represents a deposition period, the river be quit in this stage and decrease in the depth of the river. Here is an indication that the river has become a seasonal river. In the fourth stage, the remaining Euphrates, the depth of the river valley is 2.63 m, and the width of the river valley is 10 m because of the burials. The fifth stage represents the current final stage of reed vegetation, especially reed spread. The depth of the river valley is 2 m, and the width of the river valley is 10 m. As for the depth of the river in the second site, it reached a depth of 11 m. The results of the ground penetrating radar survey also indicated the presence of burial layers for the valley and shoulder of the river, the results also showed that there is a phase of the river flooding.

Keywords: GPR survey; Euphrates cross section; Archaeology; Paleochannel of River

1. Introduction

The Kari Saada River, alternatively termed the Khabor Trench, is hypothesized by researchers to represent a paleochannel of the Euphrates River. This ancient fluvial system is postulated to have extended from Hit to the Arabian Gulf, traversing the sacred governorates of Karbala and Najaf, as well

as central and southern Iraq, without intersecting the Tigris River, spanning approximately 1100 km (Jassim and Goff, 2006). The research team suggests that numerous unexcavated archaeological sites and settlements may lie along its banks. Among the archaeological sites located in the ancient Euphrates River Valley (Wilkinson, 2000; Matthews, 2003) such as Al-Ukaydir Fortress, Al-Aqsir Church, the Bani Muqatil Palace, and others.

Historical urban development often favored proximity to riverine environments. Notably, existing archaeological discoveries in the region predominantly cluster along the modern Euphrates waterway (Abdoulrazzaq et al., 2019). The Euphrates River, a principal hydrological feature of Iraq, drains through the Mesopotamian zone, including Al-Anbar and Karbala provinces (Al-Shammari, 2019). Over geological timescales, fluvial systems (Buday, 1980) such as the Kari Saada River valley dynamically adjust to environmental and tectonic changes (Aqrawi, 2001; Sissakian et al., 2023). The Mesopotamian Plain of the central part of Iraq is a large subsiding basin covered by thick Quaternary sediments of the Tigris and Euphrates Rivers with their tributaries and distributaries (Fouad and Sissakian, 2011).

Ground-penetrating radar (GPR), a high-resolution electromagnetic method, is extensively employed for shallow subsurface investigations of geological formations, infrastructure, and hydrological features (Daniels, 2000). As a relatively recent geophysical tool, GPR has gained prominence due to its capacity to delineate near-surface structures with proper resolution (Chen, 2001). The technique utilizes high-frequency electromagnetic pulses (10–1,000 MHz), with signal propagation governed by the subsurface's dielectric properties (Davis and Annan, 1989; Greal, 2006). By analyzing wave velocity and attenuation, GPR enables the determination of relative permittivity, a critical electrical property of geological materials at high frequencies (Hubbard et al., 1997).

Functioning as a non-destructive testing (NDT) method, GPR employs microwave-band electromagnetic propagation to detect reflections from subsurface heterogeneities. The system operates via a transmitter-receiver configuration that records reflections of electromagnetic impulses, facilitating precise imaging of buried structures (Daniels et al., 1998; Arcone et al., 1998). Common-offset reflection (COR) configurations are frequently deployed for bathymetric surveys, wherein antennas are towed along transects to map subsurface reflections spatially (Bapeer and Bakir, 2018). This approach permits simultaneous bathymetric and sub-bottom profiling, enabling rapid assessment of sediment thickness independent of prior topographic data (Lachhab et al., 2015). The resultant radargram contrast arises from variations in subsurface dielectric permittivity (Bakir and Thabit, 2016).

GPR was used by Abueladas and Akawwi (2020) at the Ma'muriya (Baptism Site), located north of the Dead Sea on the west bank of the Jordan River. The survey successfully identified the location and depths of ancient architectural features, including walls, ruins, and subsurface hydraulic structures such as canals, pools, pipelines, and an extension of an ancient clay conduit at Elijah's Hill.

In Canada Akinpelu (2010) applied GPR in the Department of Geology, University of Toronto to examine the morphology of the Saint Mary's River channels, situated near the Canadian Pacific Railway, about 7 km northwest of Monarch in southern Alberta. Their results indicated that the Saint Mary's River channels exhibited a ribbon-shaped pattern. The study emphasized the potential of GPR in regional scale investigations to delineate channel dimensions and assess their relation to tectonic processes.

Furthermore, Gracia et al. (2000) conducted a Ground Penetrating Radar (GPR) survey inside the Cathedral of Valencia, Spain, as part of a historical and structural assessment. The research aimed to supplement old maps and archival records of the cathedral and to evaluate zones of moisture related deterioration. The Radar survey successfully identified crypts, ossuaries, burial chambers, and graves, as well as ancient walls remains preceding the cathedral final expansion (Gracia et al., 2000).

This study aims to characterize the cross-sectional dimensions (width and depth) of a river segment in Al-Najaf Al-Ashraf Province using the GPR technique. The method is particularly effective for

subsurface inspection in engineering projects and stratigraphic mapping in both terrestrial and freshwater environments, though signal attenuation occurs in saline conditions (Mellett, 1995).

In Iraq, the GPR technique has been used to investigate and detect the locations of archaeological features in the west of Karbala city in Tulul Al-Ukhaidir. The GPR results have accurately demonstrated the depth and extent of the buried ancient walls that are believed to belong to dwelling houses that were built near the fortress and the walls of the foundations of the palace previously.

Nahaba et al. (2019) used GPR method to investigate the subsurface archaeological features in the province of Babylon, ancient city (constituted mound zoona) archaeological site. They found that the study area consist of clay and sandy soil, they detected the buried archaeological remains of clay brick walls. Mohammed (2025) has been used the GPR survey to investigate the subsurface features. The results of these studies have accurately demonstrated the depth and locations of graves, cavities, weak zones, and water table underneath the foundations of Al-Abbase holy shrine and Gaidan Building, respectively, in Holy Karbala city, the GPR results of six profiles of the Ghaidan Building determine the lateral and vertical extensions of the weak zones in the soil underneath the foundations from the ground surface to 5.5 m depth.

Bapeer and Bakir (2018) applied GPR for measuring Lesser Zab River discharge in Taqtaq area, the results of this study are that the width of the Lesser Zab River is about 36.5 m, the average of river floor is about 4.75 m, and velocity is about 1.88 m/sec. Bakir and Thabit (2016) dedected the distraction of two zero-spaced iron pipes in GPR for engineering problems, the researchers indicated that there is a direct relationship between the amplitude and space distance, the positive peak amplitude of radar waves increases with the increase of the space distance between the buried pipes.

The current study aims to characterize the cross-sectional dimensions (width and depth) of a river segment in Al-Najaf Al-Ashraf Province using GPR technique. Naturally, Archaeological sites are usually locating at shallow depth and covering with sediments such as sand, silt or river deposits. The amount and quality of information for archaeological sites can increase by using GPR survey which has accuracy with high resolution at shallow and without causing any damage. In the Tall Abo Al-Za'ar hill is located in Babylon governorate, within the Mesopotamian Plain. The GPR applied sections shows that the archeological anomalies are randomly and was not possible to recognized the thickness due to the high moisture content of soil (Al-Shamkhy et al., 2022). The high frequency of antenna reflects high resolution. For any projects of archaeological, the depth investigation is very important to estimate the suitable frequency of antenna. The reflection anomalies are concentrated near the surface.

2. Location of the Study Area

Kari Saada area is located in the Kufa City, belong site 1 near Kufa University, and belongs site 2, Al-Tamem neighborhood at the Captivity Bridge. The study area has a rough topography (Fig.1).

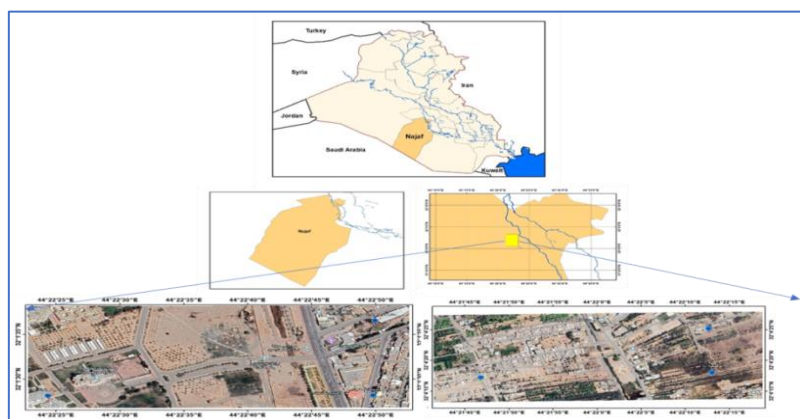


Fig.1. A Satellite image shows the study area of the two surveyed sites

3. Materials and Methods

In the location site of Kufa University, the GPR survey has been applied to determine the depth and the width of the cross-sectional Kari Saada channel. Fig. 2 illustrates that the transmitting antenna sends an interrupted sinusoidal impulse of the length of one and a half periods, and the receiver antenna receives the reflected signals (Cao et al., 2018). The antenna is chosen in the study area to be 250 MHz for a civil engineering investigation. The sampling frequency shall be set to approximately 10 times the antenna frequency. For this fact, the sampling frequency in the GPR survey in the study area was 2785. The number of samples shall be set to a value of near 500 for the best performance. The number of samples is 512.

As the GPR unit moves along the survey line, pulses of energy are transmitted from the transmission antenna and reflected to the receiving antenna (the transmission and reception antennas can be the same). The receiving antenna sends the received signal to a recorder. The shielded 250 MHz is a general purpose antenna. It is used for medium penetration depth and medium resolution. It is commonly used for utility detection, underground archaeological and void detection.

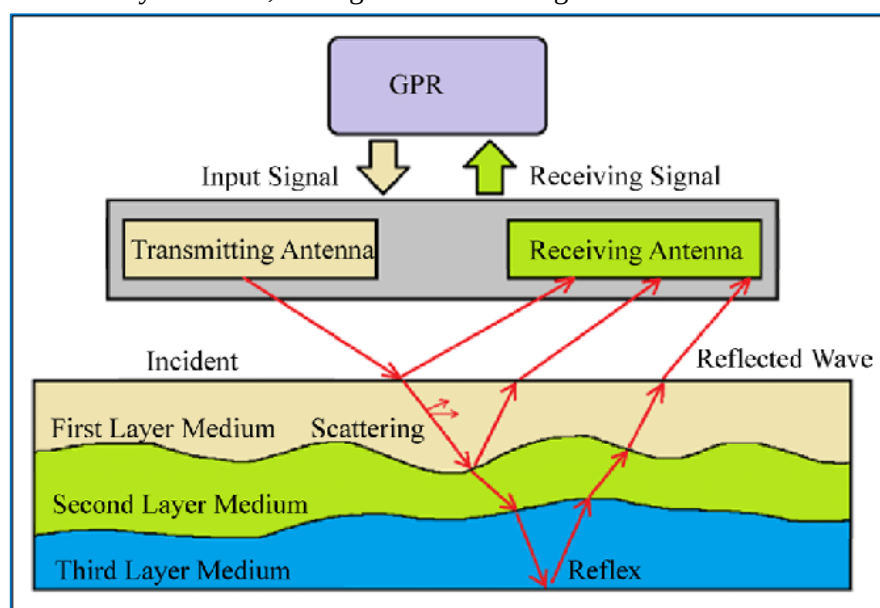


Fig. 2. GPR schematic, showing the principle of the GPR method (Cao et al., 2018)

4. Field Work

The field work is done through three stages. The first stage is exploratory; at this stage, satellite images, geological, and topographic maps, archaeological and historical information for the study site were prepared, in addition to preparing the GPR system to work on this strategic and important geological project. The second stage includes on-site detection, all the locational information was recorded, and sites were selected on the Kari Saada channel in the governorates of Najaf Al-Ashraf governorate. The third stage represents the geophysical survey that was conducted using the GPR method for the study site in Al-Najaf Al-Ashraf Governorate using the Swedish GPR device. Where the data for the GPR survey of the tracks was recorded by Antenna 250 MGH. A filter may be very useful for some applications and can be useless in others. Depending on the applications and the quality of the radar image, a range of different filters can be applied. The knowledge and experience of the user often determine the time it takes to produce a useful image. Generally the processing filters start with a DC filter and a Time Gain filter; after that, a Frequency filter or Background Removal filter is needed. The DC filter removes the DC component from the data, the Time-Gain filter applies a time-varying

gain to compensate for amplitude loss due to spreading and attenuation, and Band Pass filter is used to remove unwanted frequencies from the trace.

In some cases, the Running Average filter smooths the radargram. Subtract Mean Trace and Background Removal filter used to remove horizontal and nearly horizontal features in the radargram.

Track 1, was located in the Al-Najaf Al-Ashraf Governorate-within the boundaries of the university of Kufa, the track was extended 285 m long in the east–west direction, the starting point of the path is the middle island edge of the main street (Fig. 3), Kufa, the city center of Al-Najaf and the end of the path was inside the University of Kufa.

Track 2 is located at the bridge of the Al-Sabaya road in the Mayasan district. The track was 390 m long in the direction that extends from east to west. The starting point of the path is the edge of the main street and it reaches the end of the residential neighborhood (gardening).



Fig. 3. GPR survey to explore the Second Phase of the Old Euphrates River in Al-Najaf Al-Ashraf Governorate for track 1

5. Results and Discussion

GPR data processing was carried out using the RAMAC Ground vision Mala Company (Mala Geoscience Company, 2005) and Reflex 2D Quick-test version.

The primary aim of GPR sections interpretation in this study was to explore the lateral and vertical expansion of Kari Saada River Valley in Kufa city. Two tracks of GPR, 285 and 350 m long, were survived perpendicularly across the Valley of Kary Saada River, revealing the historical events of it, which represented the second phase of the ancient Euphrates River Valley.

A general recommendation in GPR data processing is to apply a series of filters to improve the quality and interpretability of the acquired signals. The DC filter eliminates the direct current (DC) component, which is calculated and removed individually for each trace. The time-gain filter introduces a time-varying gain to compensate for amplitude losses resulting from geometric spreading and material attenuation. The subtract mean trace filter reduces horizontal or nearly horizontal features in the radargram by subtracting a calculated mean trace from all traces. In addition, band-pass filters are applied to suppress unwanted frequency components, attenuating those below the lower cut-off and above the upper cut-off frequencies, collectively, these filtering techniques significantly enhance signal resolution in GPR surveys (Mala Geoscience Company, 2005)

The results and interpretation of the GPR data of this track can be explained as follows:

The center of the river which represents its greatest depth at a distance of 62 m from the start point (0.0), which represents the beginning of the path. The highest depth of the river valley was at a depth of 11 m. The lateral extension of the river was continuous beyond the distance of the 285 m towards the west, and in general, this extension was almost flat land free from topographic phenomena such as

variation in the height of the surface of the land and the the extension of this range was confined between the distances of 90 and 285 m and width of the band equals 195 m (Fig. 4). The depth of the river valley for this stage was 11 m and is located at distance of approximately 63 m, from the starting point of the path. The width of the valley was 60 m confined between the distances of 30 and 90 m (Figs. 4 and 5a). The water covered all this area and was up to two meters deep or less. The section also clarified that the cliff of the river was located at a depth of 6 and 4 m from the western and eastern sides, respectively. This means that there is a discrepancy in depth for the eastern and western banks of the river (Figs. 5 and 6). This case concludes that it is expected that the river in the section has a degree of torsion, so that the picture becomes clear that the erosion was on the western side of the river, while the sedimentation was on the eastern side (Figs. 5, 6, 8 and 9). This stage represents the river's flood (Fig. 7).

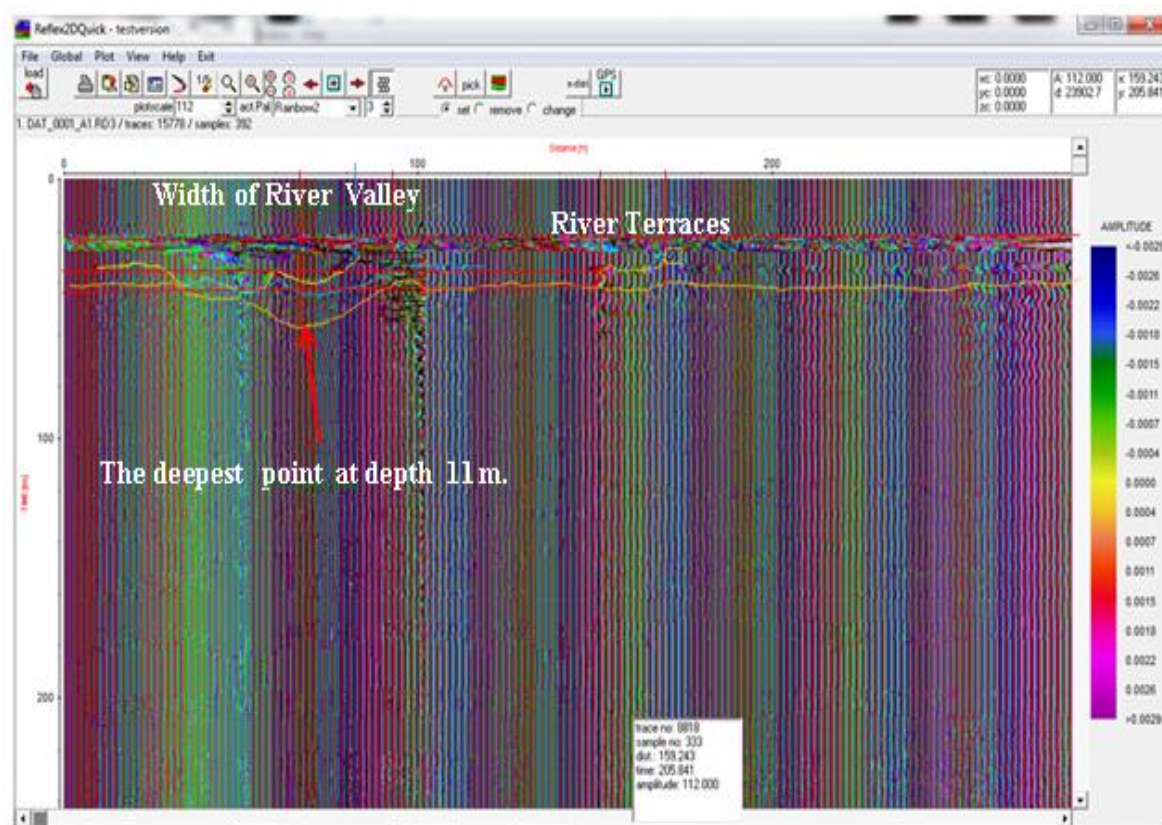


Fig. 4. The second phase of the Euphrates River in site of Kufa University in Al-Najaf Al-Ashraf Province for the track

1. The river retreated due to the lack of the amount of water drainage. It may be the period of lack of rain or any climatic or geological changes, especially the structural ones. The georadar section showed the western bank of the river appeared at a distance of 87 and 150 m from the center of the river valley and at a depth of 3 m. However, the eastern bank occurred at a distance of 30 and 33 m from the center of the river, at a depth of 4 m.
2. The ground movement that led to the block shifting from the river cliff on the western side occurs at a distance between 167 and 173 m, with a width of 6 m. This upward movement was vertical towards the earth's surface. A rise in this narrow range is evidence of this movement. The same is true for the distance between 115 and 150 m and the width of 35 m. It is possible that a lake existed as a result of the ground movement.

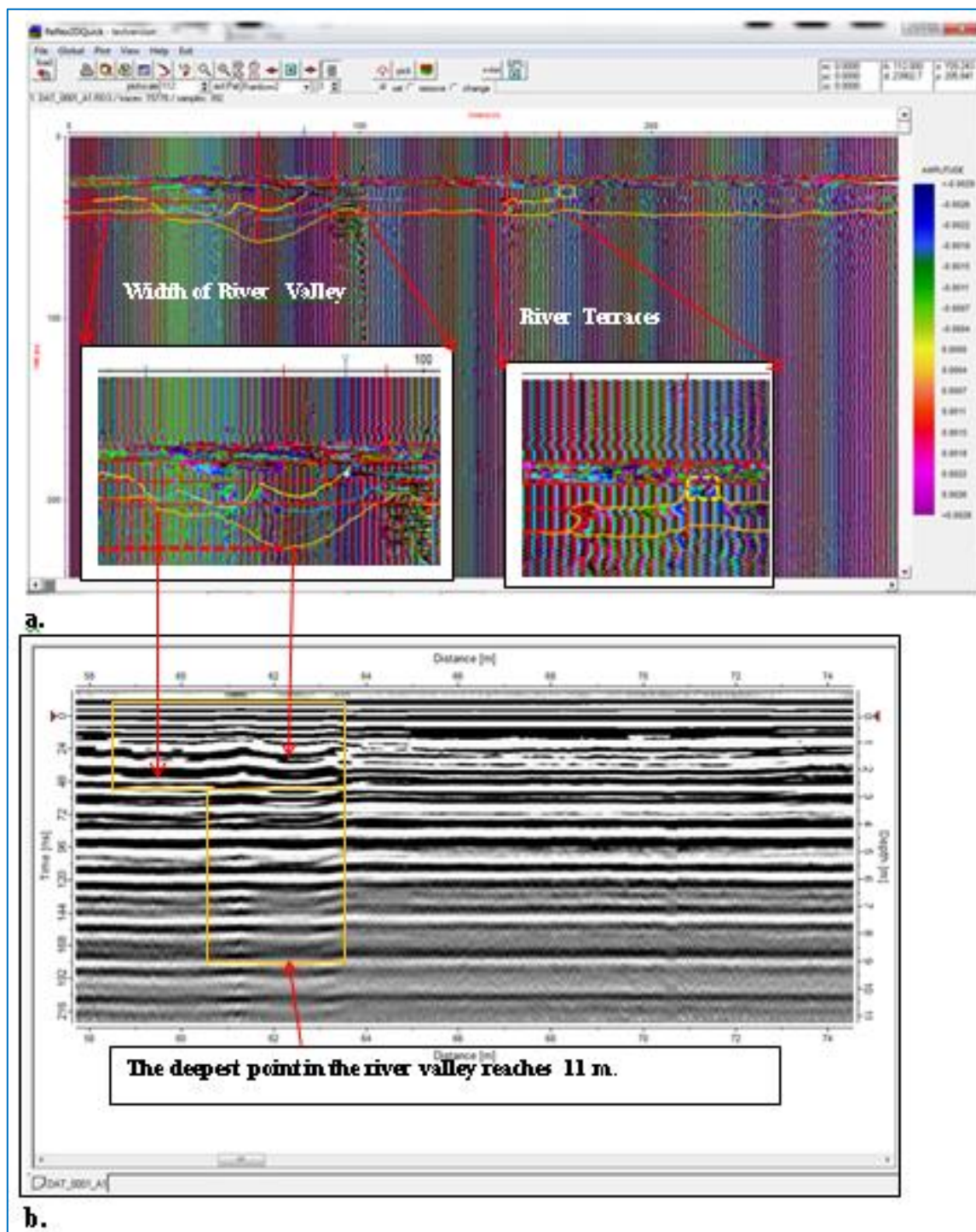


Fig. 5. The second phase of the Euphrates River in the site of Kufa University in Al-Najaf Al-Ashraf Province for track 1, a. Reflex 2D Quick, b. RAMAC Ground vision

3. The depth of the eastern and western banks of the river was 2.63 m at a distance of 27 m, representing the deepest point in the river valley. The depth reached approximately 5 m at a distance of 90 m from the study site ground surface. The thickness was 4 m on the eastern side. These observations reflect the sedimentation stage associated with river course change and river valley retreat.

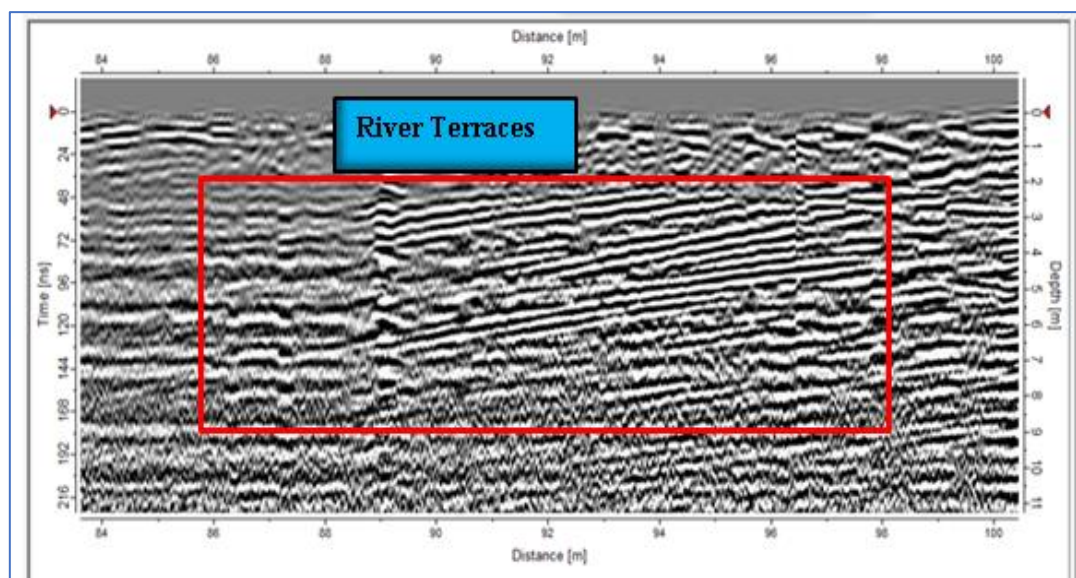


Fig. 6. River terraces in the west bank in the second phase of Euphrates River in site of Kufa University in Al-Najaf Al-Ashraf Province for track 1

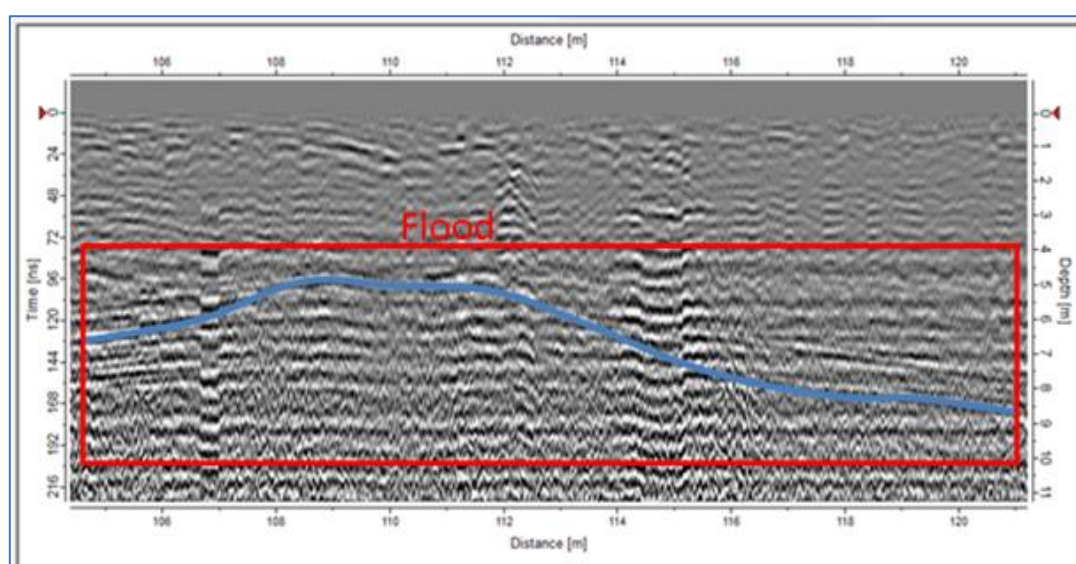


Fig. 7. The stage of flood sedimentation in the river flood stage in the west bank in the second phase of the Euphrates River in the site of Kufa University in Al-Najaf Al-Ashraf Province for track 1

4. The river valley symbolizes the deep area between 30 and 80 m. The width is 50 m, and the depth is up to three metres. It is totally buried, as is the range beneath the existing arch inside the institution, which spans 48 to 58 m. A 10-meter breadth remains under the iron bridge in front of the institution. The speed and amount of water drained into the river at this stage decreased, resulting in sedimentation on the convex bank of the river to the east. This stage reflects the valley's burial caused by human intervention. The remnants of the river and the thickening of forest cover a distance of 30 to 50 m, which is 20 m broad, spread across the river's shoulders and a freshly buried section.

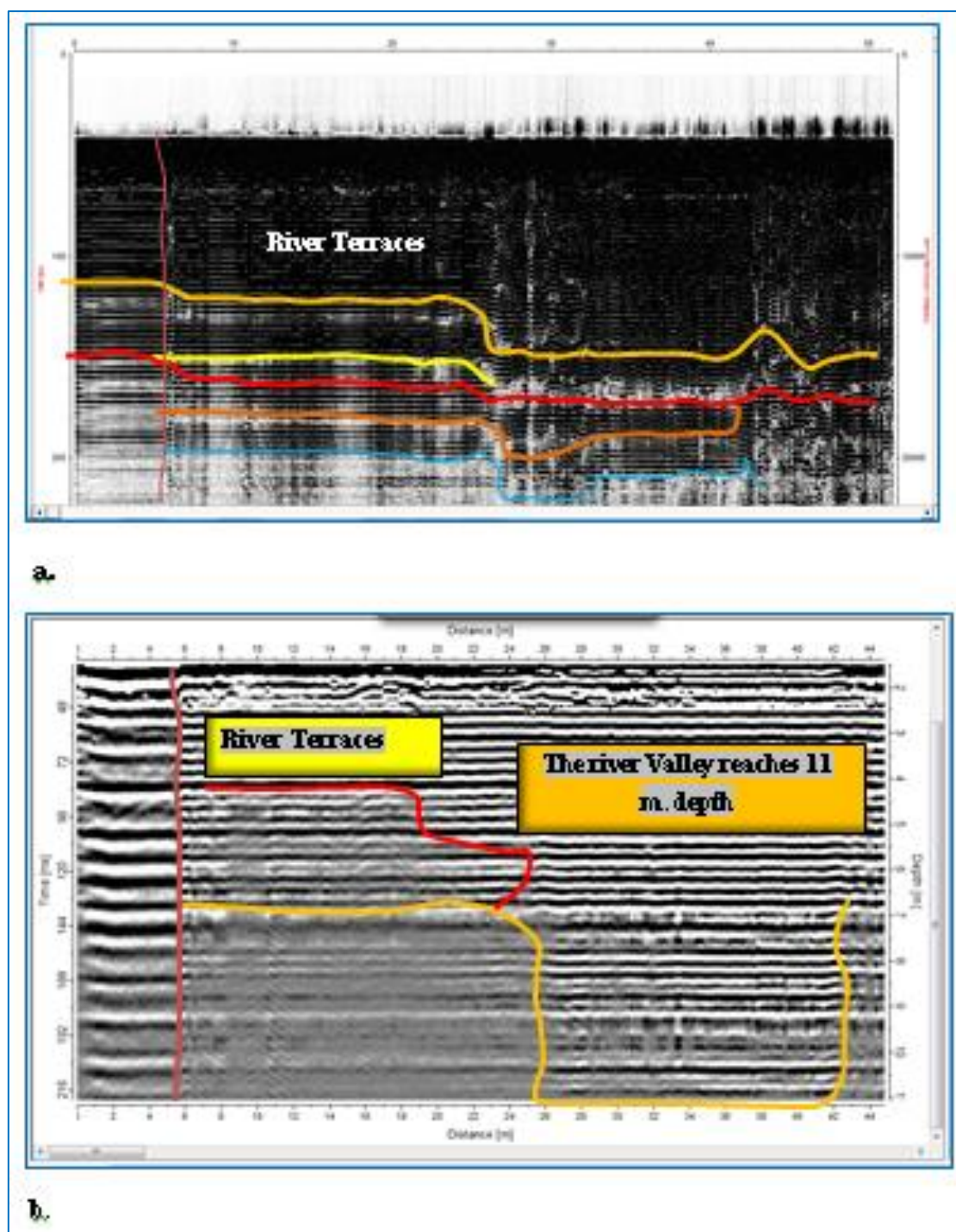


Fig. 8. The river terraces and the river valleys in the site of the bridge of the Al-Sabaya road in the Mayasan district for track 2, a. Reflex 2D Quick, b. RAMAC Ground vision

5. The trench is a remnant of an ancient course or phase of the Euphrates River that extends from Hit to the Arabian Gulf, passing through the holy governorates of Karbala and Najaf, so as to reach the central and southern regions without meeting the Tigris River, with a length of approximately 1100 km.
6. Many undiscovered archaeological sites and cities may have been scattered on the banks of this river, since the nature of the establishment of cities in the past was on the banks of riverbeds.

7. The area through which the river passes is not focused on the archaeological research studies because the apparent archaeological cities that were found are located on the waterway of the Euphrates River, such as Al-Ukhaider area, Al-Aksair Church, and Kaser Bany Mokatel. The Kari Saada River, alternatively termed the Khabor Trench, is hypothesized by researchers to represent a paleochannel of the Euphrates River in Kufa city. Therefore, it was chosen in this study.

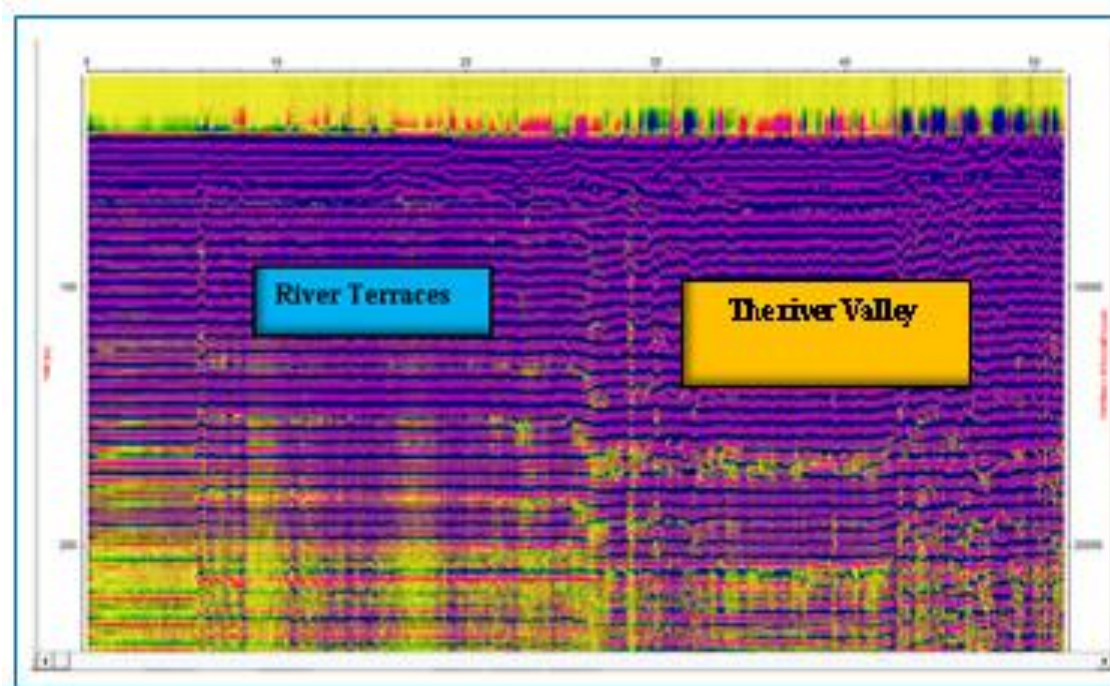


Fig. 9. River terraces in the west bank in site of at the bridge of the Al-Sabaya road in the Mayasan district in Al-Najaf Al-Ashraf Province for track 2

Bapeer and Bakir (2018) used GPR in their research; they found that the width of the Lesser Zab River in the Taqtaq area was 41 m. The highest depth was 3.4 m, and the Lesser Zab River valley was covered by the current water, but in the Kari Saada area in Kufa City, they used the GPR method too. In both studies, GPR technology was used to determine the depth variation and topographical shape of the valley.

The results of the georadar sections showed six geological stages. The width of the ancient Euphrates River was 195 m, the highest depth was 11 m, and most of the valley is buried and covered by river sediments. That means the GPR method is a very suitable geophysical technique to investigate buried features such as the properties of ancient river valleys.

6. Conclusions

- Naturally, Archaeological sites are usually located at shallow depth and covered with sediments such as sand, silt, or river deposits. The amount and quality of information for archaeological sites can be increased by using a GPR survey, which has accuracy with high resolution at shallow and without causing any damage.
- For the first time, the GPR method was used to explore the ancient valley of the Euphrates River in the Al-Najaf Al-Ashraf governorate. The findings of this investigation are:
- The GPR method is a very suitable geophysical technique to investigate buried features such as the ancient river valleys.

- The Kari Saada River channel in Kufa city represents the remnant of the ancient Euphrates River Valley, Phase II. The ancient Euphrates River is likely to have altered course to its current location due to tectonic activity and the rise of the western plateau during geological time.

Acknowledgments

The authors highly appreciate the President of the University of Kufa, Professor Dr. Mohsen Al-Zalmi, and our heartfelt thanks to all researchers in the Remote Sensitization Center at the University of Kufa.

References

- Abdoulazzaq, Z.T., Thabit J.M., Al-Khafaji A.J., 2019. Identification of archaeological sites threatened with obliteration using space-borne and ground penetrating radars data in the site of Tulul Al-Ukhaidir, Iraq. *Applied Geomatics*, 11, 401-412. DOI: 10.1007/s12518-019-00272-9
- Abueladas, A. Akawwi, E., 2020. Ground penetrating radar inspection of subsurface historical structures at the baptism 9El- Maghtas) site, Jordan. *Geoscientific Instrumentation Methods and Data Systems*, 9, 491-497. DOI:org/10.5194/gi-9-491-2020
- Akinpelu, O. C., 2010. Ground Penetrating Radar Imaging Ancient Clastic Deposits: A Tool for Three-Dimensional Outcrop Studies. Ph. D. Thesis, Geology Department, University of Toronto. (unpublished).
- Al-Shammari, M. M. A., 2019. Delineation of Suitable Sites for Water Harvesting and Artificial Groundwater Recharge in Down Stream of Ubaydh Watershed, West of Karbala, Iraq. Ph.D. Thesis, College of Science, University of Baghdad. (unpublished).
- Al-Shamkhy, A. A., Abd-Al-Hasan N., 2022. Investigation and mapping Abo Al-Za'ar Archaeology Hill Using GPR Technique. *Iraqi Geological Journal*, 55, (1F), 47-58. doi.org/10.46717/igj.55.1F.4Ms-2022-06-19
- Aqrabi, A.A.M., 2001. Stratigraphy Signatures of climatic changes during the Holocene evaluation of Tigris-Euphrates delta, Lower Mesopotamia. *Global and planetary change*. 28, (1-4), 267-283. DOI:10.1016/S0921-8181(00)00078-3
- Arcone, S.A., Lawson, D.E., Delaney, A.J., Strasser, J.C., Straser, J.D., 1998. Ground penetrating radar reflection profiling of groundwater and bedrock in an area of discontinuous permafrost, *Geophysics*, 63, 1573-1584. DOI:10.1190/1.1444454
- Bakir, H. B., Thabit, J. M., 2016. Distinction of Two Zero-Spaced Iron Pipes in GPR radargram for engineering problems. *Iraqi Journal of Science*, 57(3A), 1775-1782.
- Bapeer, G., B., Bakir, H., B., 2018. Applying ground penetrating radar current meter devices for measuring Lesser Zab River discharge in Taqtaq Area, Iraq. *International Conference on Engineering Technology and their Applications (Institute of Electrical and Electronics Engineers)*, 151-154. DOI: 10.1109/IICETA.2018.8458091
- Buday, T., 1980. The regional geology of Iraq, Volume, Stratigraphy and paleogeography. Dar Al-Kutub , Mosul.
- Cao, R., Yang, Y., Wang, Y., Sun, X., 2018. Accuracy of a ground-coupled antenna based non-contact method for detecting the integrity of lining contours. *International Journal of Distributed Sensor Networks*. 14,11,1-13. DOI: 10.1177/1550147718814468
- Chen, J., 2001. Bayesian Approaches for Subsurface Characterization Using Hydrogeological and Geophysical Data. Ph.d. Thesis, Engineering. Civil and Environmental Engineering. University of California, Berkeley. (unpublished).
- Daniels, J.J., 2000. Ground penetrating radar fundamentals. Prepared as an appendix to a report to the U.S. EPA, Region V. DOI:10.4133/1.2921864
- Daniels, J.J., Brower, J., Baumgartner, F., 1998. High resolution GPR at Brookhaven National Laboratory to delineate complex Subsurface targets: *Journal of Environmental and Engineering Geophysics*, 3 (1), 1-5. DOI:10.4133/JEEG3.1.1.
- Davis, J.L., Annan, A.P., 1989. Ground penetrating radar for high-resolution mapping of soil and rock stratigraphy. *Geophysical prospecting*. 37, 531-551. doi.org/10.1111/j.1365-2478.1989.tb02221.x
- Fouad, S. F. A., Sissakian, V. K., 2011. Tectonic and structural evaluation of the Mesopotamia Plain. *Iraqi Bulletin of Geology and Mining Special Issue*, 4, 33-46.

- Gracia, P., Antonio, C. J., Pujades, L. G., Jaume, C., Oriol, C., Francesc, G., Raul, O., 2000. GPR survey confirm the location of ancient structures under the Valencian Cathedral (Spain). *Journal of Applied Geophysics*, 43, 2, 167-174. DOI:10.1016/S0926-9851(99)00056-7
- Greal, M., 2006. Resolution of ground penetrating radar reflections at differing frequencies, *Archaeological Prospection*, 13, 142-146. DOI: 10.1002/arp.283
- Hubbard, S., Rubin, Y., Majer, E.M., 1997. Ground penetrating radar assisted saturation and permeability estimation in bimodal systems. *Water resources research*, 33, 5, 971-990. DOI:10.1029/96WR03979
- Jassim, S.Z., Goff, J.C., 2006. *Geology of Iraq*. Published by Dolin, Prague and Moravian Museum, Brno.
- Lachhab, A., Booterbaugh, A., Beren, M., 2015. Bathymetry and sediment accumulation of Walker Lake, PA using two GPR antennas in a new integrated method. *Journal of Environmental & Engineering Geophysics*, 20, 3, 245-255. DOI: 10.2113/JEEG20.3.245
- Mala Geoscience Company, 2005. *Applied GPR Technology, Theory Practice*. www.malags.com
- Matthews, R. 2003. *The Archaeology of Mesopotamia: Theories and Approaches*. London: Routledge. DOI:10.5334/pia.214
- Mellett, J.S., 1995. Ground Penetrating Radar applications in engineering, environmental management, and geology. *Journal of Applied Geophysics*, 33, 1-3, 157-166. DOI:10.1016/0926-9851(95)90038-1
- Mohammed, A. J., 2025. Using GPR method to detect weak zones in the soil underneath the foundation of Ghaidan building, Holy Karbala City, Iraq. *Journal of Science*, 66, 1, 16, 196-208. DOI:10.24996/ijs.2025.66.1.16
- Nahaba, M. S., Thabit J. M., Mohammed A. J., 2019. Using of ground penetrating radar (GPR) for investigate the subsurface archaeological features of Babylon, the ancient city (Mound zoona). *Iraqi Journal of Science*, 60, 1, 103-114.
- Sissakian, V. K., Al-Ansari, N., Abdullah, L. H., Laue, J., 2023. Neotectonic Indications from the Western and Southern Deserts of Iraq. *International Journal of Geosciences*, 14, 5, 427-436.
- Wilkinson, T. J., 2000. Regional approaches to Mesopotamian archaeology: The Contribution of Archaeological Surveys. *Journal of Archaeological Research*, 8, 3, 219-267. DOI: 10.1023/A:1009487620969