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Characterization of Ground Penerating Radar (GPR) wave response in shallow subsurface for forensic investigation in controlled environment

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Abstract

Applied geophysics plays an important role in getting information beneath the ground surface. Ground penetrating radar (GPR) is one of the vital ground-based geophysical tool which gained considerable attention of law enforcement and other similar organizations dealing with criminal investigations worldwide particularly in developed countries. The current study discusses GPR application with a practical example to simulate the response from the excavated zone containing materials of criminological importance due to their resemblance to those buried items which are most frequently found in actual crime scenes. The main aim was to achieve the radar response expected in real scenario in order to facilitate the identification procedure in non-invasive way of the most commonly buried remains in crime scenes.

Keywords: Ground-penetrating radar (GPR), Applied criminology, Forensic investigation.

1. Introduction

There are different geoscientific tools used for site studies during search procedures which take into account numerous factors depending upon the nature of a certain case or geological conditions of site (Pringle et al. 2012; Ruffell et al. 2017).

Ground-penetrating radar (GPR) is one of the geophysical technique being used in various disciplines including archaeological, geo-engineering, environmental, and soil investigations. Recently, literature reports the use of GPR in criminology and other related studies where such type of non-destructive techniques helps in narrowing down the suspected sites to be excavated. Thus, GPR is a relatively quick tool that provides with a qualitative subsurface image and offer large penetration depth in suitable conditions i.e. dry sands and appropriate frequency. For example, in dry sands, it can detect a target buried about 50 m with low frequency antennas (Smith and Jol, 1995). However, GPR is not a good choice where the target is concealed underneath wet clays which limits its penetration depth to typically less than 1 m (Doolittle et al., 2002). Besides these limitations, GPR can provide the forensic experts with necessary information to achieve successful results, and thus considered one of the recently implemented method in criminological investigations (Mellet, 1992; Pringle et al., 2008; Ruffell and McKinley, 2005; Ruffell et al. 2009; Schultz et al., 2006; Schultz, 2007, 2008).

This work presents GPR experiments to demonstrate the effectiveness of this method in mapping and identifying the underground evidences of recent burials. For this purpose, the data was acquired soon after burial of the metallic pipe and water can which are common material found in real forensic cases, present large dielectric contrast and thereby; suitable items to simulate the gun's response and buried liquids (drugs).

2. Materials and methods

2.1. Experimental site

We selected a site (Fig. 1) at National Centre of Excellence in Geology, University of Peshawar to see the electromagnetic wave response over the excavated experimental scene of dimension 1×1 m. Two items namely, water-filled bottle and metallic object were placed in the middle of the excavated zone within 5 feet. Table 1 shows two experimental cases to analyze the influence of buried items over the ground probing radar wave. The selected items and the corresponding experimental scene are shown in Fig. 2. The water bottle in the experiment is common plastic tank which is usually used to store mineral water while metallic object is sink shaped target to mimic the real-world scenarios.

2.2. Ground-penetrating radar (GPR) survey

GPR is a geophysical method based on the propagation of electromagnetic waves which are defined by means of four Maxwell's Equations. There are four main components in a GPR system: a control unit, transmitting antenna, computer unit and a receiving antenna (Fig. 3). The transmitting antenna transmits the EM waves into subsurface where they interact with different geological layers of different dielectric properties. Thus, part of the energy is reflected and some part makes its way into deeper layers via transmission phenomenon. The receiver antenna records the reflected signal which is further processed and interpreted. The common-offset mode is usually used for GPR data acquisition to detect a buried target along a specific direction at fixed separation between the two antennas i.e. transmitter and receiver. Finally, an image of the underground called radargram is obtained in two-dimensional where the X-axis shows antenna distance covered on the ground along a profile, and the Y-axis indicates the two-way travel time in nanoseconds of the pulse.

Fig. 1. Experimental grids: large square indicates the total area under survey, whereas the small inner square shows the area for excavation of suspected scene.

Fig. 2. Two experimental scenarios, described in Table 1. Metallic object; water can (right to left)

Table 1. The buried items and description of crime scenes.

No	Buried Object	Description
1	Metallic Piece	Simulation of the response of a homicide weapon
2	Water can	Forbidden drugs, Underground Storage Tanks (USTs)

The GPR survey was carried out Mala/GPR CU-II system using a 500 MHz antenna due to its successful applications in similar studies (Schultz and Martin, 2011). The 500 MHz antenna provides with penetration depth within 5-6 m from the ground surface at a reasonable spatial resolution under optimal conditions as discussed by Daniels, 2004. The GPR data was collected in N-S direction over the buried targets. We used 500 MHz shielded antenna for both metallic and water filled objects using the common-offset mode. The survey direction of the GPR profiles is shown in Fig. 1, where the blue line with arrow specifies the start and end points of the GPR profile. The acquired data was processed by applying different routines such as background DC removal, amplitude correction and deconvolution etc. for suppressing an unwanted noise in the raw-data in order to produce subsurface resolving the buried features and/or targets of interest for easier and meaningful GPR data interpretation.

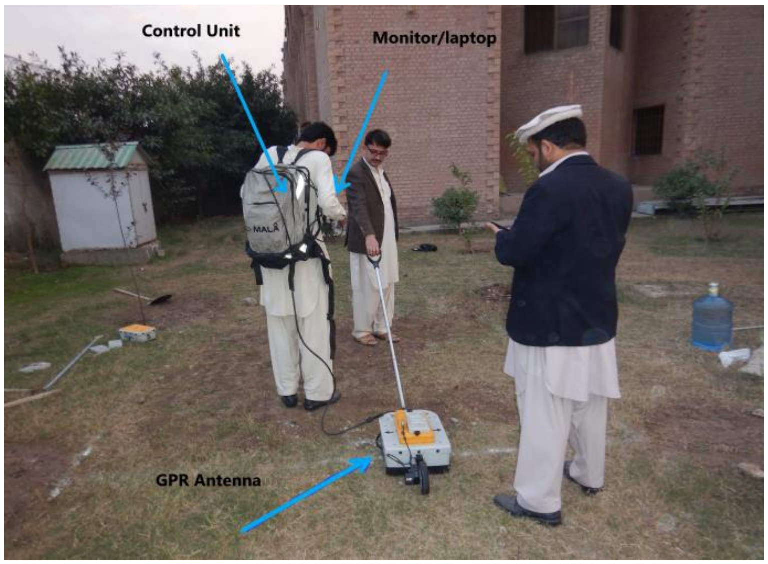

Fig. 3. GPR system showing the four main components: Two Antennas, control unit, and monitor. Data acquisition using 500 MHz shielded antenna in N-S direction

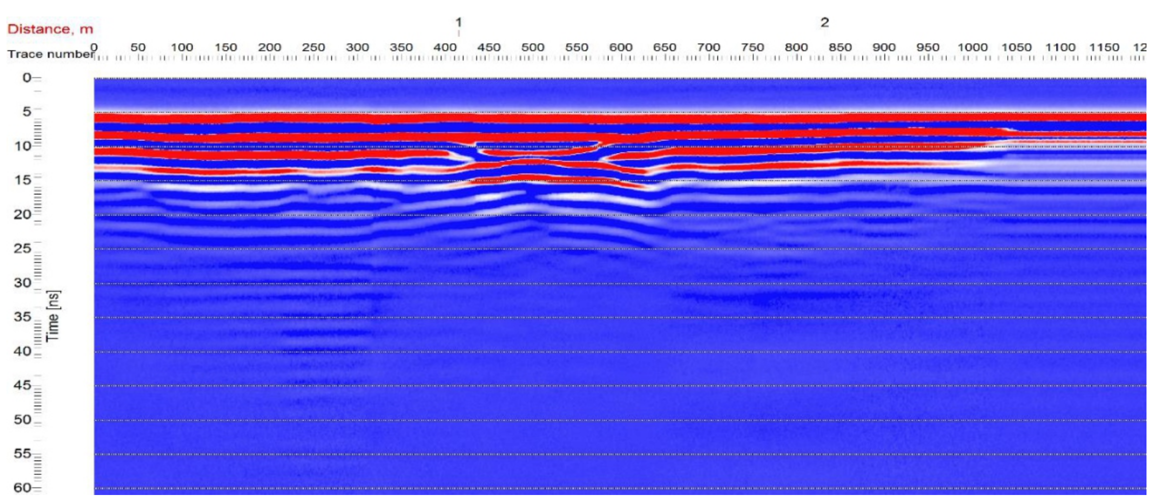

Fig. 4. Shows the uninterpreted GPR profile with the 500 MHz antenna over buried metallic object

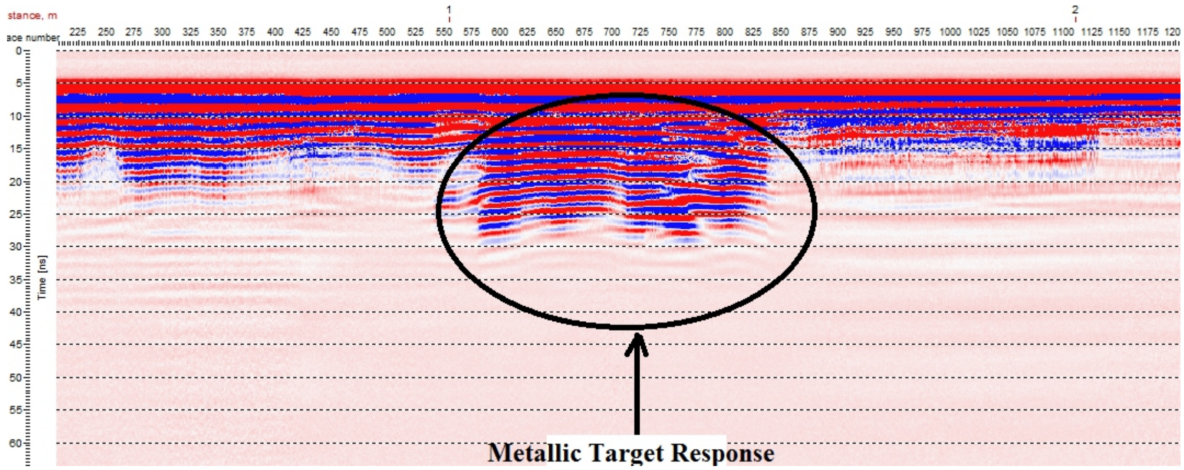

Fig. 5. Shows the interpreted GPR profile with the 500 MHz antenna over buried metallic object

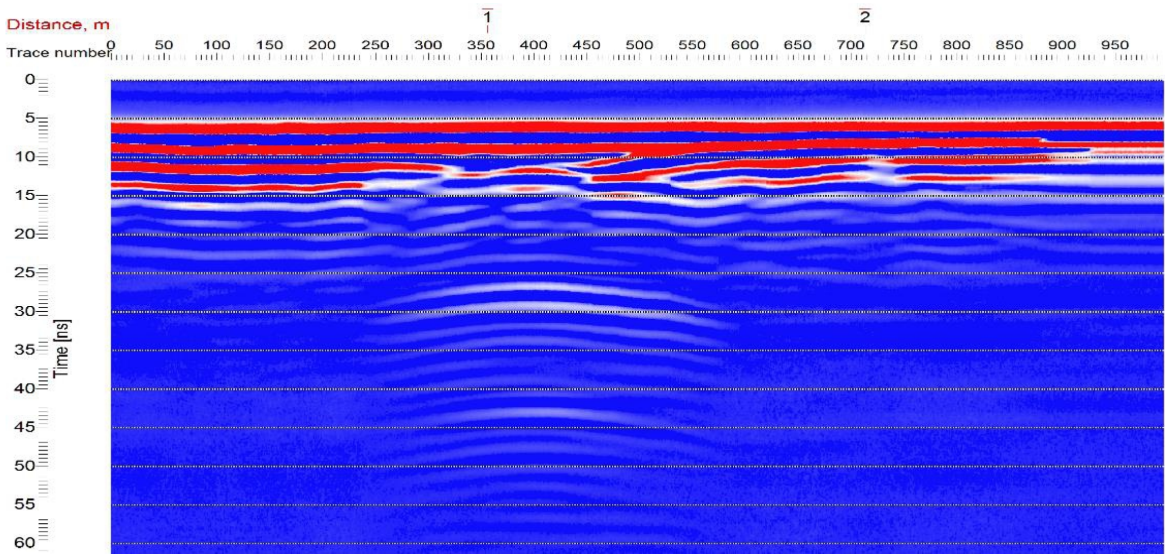

Fig. 6. Shows the uninterpreted GPR profile with the 500 MHz antenna over buried water-filled bottle

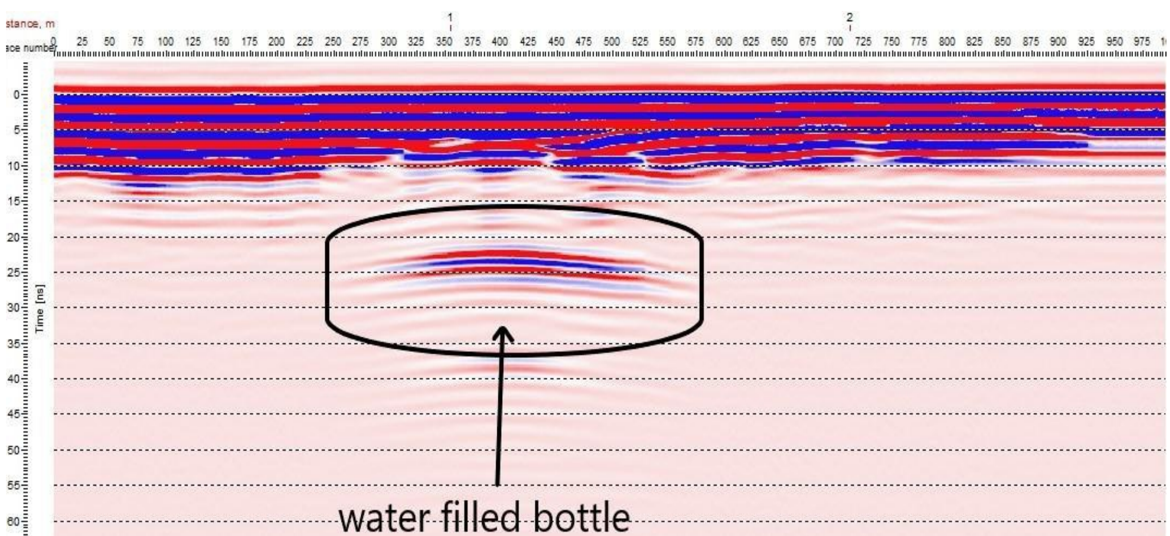

Fig. 7. Shows the interpreted GPR profile with the 500 MHz antenna over buried water-filled bottle

3. Results and discussion

We conducted a geophysical experiment in controlled environment to demonstrate the GPR capability in forensic scene investigations by utilizing 500 MHz antenna. Two most commonly found objects in real crime scene were selected to explain the effectiveness of geophysical technology for the location of buried material of criminological importance. We have shown two examples to highlight the importance of non-destructive remote sensing tool in detection of the illegal buried remains. The experimental scenes present the interesting reflections generated from the metal piece and a bottle filled with water that mimic the real crime cases. It can be seen from the Fig. 4 that data collected over metallic object or water can, in raw form contains no useful and interpretable information which may reflect on the target of our interest due to contaminating noises produced by external sources (wires, metal bodies etc). However, filtering the GPR data following the processing steps as described in previous section, the processed radargram indicated the boundaries of the trench (1.03-1.37 m) as well as it made possible to identify and locate the metallic target at 1.20 m along x-axis. Fig. 5 clearly shows strong reflections due to large dielectric contrast between the buried metallic object and the surrounding backfill. Similar reflection pattern was observed when metallic handguns were scanned to test the applicability of GPR technique regarding search of firearms (Murphy and Cheetham, 2008). Also, water filled can was used to simulate the response of buried drugs in liquid form and underground storage tanks (USTs) on radargram. It can be seen from Fig. 5 that buried water bottle has produced a coherent pattern of strong reflections which attest the potentiality of GPR in detecting such type of illegal substances. The 500 MHz antenna provided greater details in case of metallic detection as compared to the water filled bottle. It allowed us to demarcate the boundaries/size of the experimental excavated site in addition to identification of the target itself.

The effectiveness of GPR in identifying buried objects of interest, such as pipes and landmines among others has been demonstrated earlier (Holden, et. al., 2002, Ayala-Cabrera et. al., 2011, Toksoz et. al., 2016, Gharamuhammad and Nourozi, 2018). Besidesobjects of metallic nature, buried bodies and remains are also a source of investigation for GPR techniques (Mollina et. al., 2016). Diamanti and Gianakis (2016) attempted to identify a way of GPR data usage for finding victims buried in rock fall or building collapse debris. In a similar study, Widodo et. al., (2016) utilized GPR for the identification of buried human remains in Cikutra graveyard, they found the method effective in finding buried human bodies. The results of the above mentioned studies demonstrate the applications of GPR technique in search and rescue missions and crime scene investigations.

The non-invasive nature of the method helps in avoiding the destruction of evidence on crime scenes, on the other hand it is less destructive to the environment. An important application of GPR in environmental management with respect to our study is the identification of underground storage tanks (USTs) (Mellet, 1995, Parish, 2004). USTs abandoned or functional are a major source of groundwater contamination. It is important to locate the tanks accurately, before any remedial measures are taken, to avoid leakage due to puncturing or damage. Further, any attempts of sampling or remedial measures may result in accidents if the precise location of the tanks are not known (Mellet, 1995).

4. Conclusions

The large dielectric contrast produced by the selected items (water can and metallic object) and data collection in perpendicular orientation enabled us to delineate the dimension of the excavated zone and locate the targets underneath ground. By observing the processed imagery acquired over both metallic and water can in subsurface, we infer that GPR has the capability to collect important information for underground crime scene investigation. The designed experiments in a controlled environment proved that GPR has the potential to assist in identification of buried remains in less time and cost as compared to intrusive and time-consuming traditional methods. It is first kind of ground-based remote sensing application in forensic investigation in Pakistan, thereby; current work opens a constructive discussion about the use of non-invasive methods for academic teaching and research in applied criminology. The current study implications also suggest the importance of low cost and time effective geophysical surveys to assist local practitioners working in environmental protection agencies in addressing groundwater contamination, wildlife crime and other related issues.

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Authors Contribution

M.Younis Khan, proposed the main concept and involved in write up. Khaista Rehman assisted in interpretation of the radar data. Syed Ali Turab was involved in field data acquisition and interpretation regarding geological content of the work. Wajid Ali and Khalid Latif contributed to provision of relevant literature, technical review before submission and proof read of the manuscript. Shahid Iqbal was involved in data collection and interpretation.

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