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# A combination of geophysical methods (GPR and ERT) to detect and trace the water leakage in sedimentary area

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## Abstract

Water leakage is one of the critical challenges in engineering and geological projects (dams, tunnels, and industrial and urban infrastructure projects). This study aimed to detect and trace the origins of water loss in a sulfur store in the South Pars gas field, Asaluyeh, Iran. To that end, combined geophysical methods using high-frequency electromagnetic waves and electrical resistivity methods involving Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) were employed to determine leakage points in the region. According to the site condition and available spaces, 15 penetrating radar profiles have been taken over the study area. 15 geoelectrical surveys with Pole-Dipole and Wenner-Schlumberger arrays were conducted along with GPR profiles. In this research, only anomalies detected by both methods consider as the origin of water leakage. The results indicated that the two detected anomalies in the radargrams (profiles 4 and 11) were in line with ERTs. Therefore, these points choose as a possible sources of water leaks. In the other profiles, no anomalies were observed, or the detected irregularities were partial, dispersed, observed at depths lower than the buried water pipes, or not detected by the ERT method. The excavation operation was conducted along with the selected points. The evidence revealed that the main pipe water had cracked in the chosen area. The leak rate was estimated to be more than two cubic meters per second. Therefore, the study exemplifies the efficacy and reliability of the combined use of GPR and ERT in detecting water leakage in sedimentary media.

**Keywords**: Electrical resistivity tomography, Ground penetrating radar, Sedimentary area, Water leakage detection.

## Introduction

Water seepage is one of the issues that has constantly challenged engineering and geological projects, for example, dams, tunnels, and industrial and urban infrastructure projects. Detecting and tracking the precise location of the water leakage is very important. Over the past few decades, some researchers have applied different geophysical techniques to detect water leakages, including acoustics, gas sampling, GPR, remote sensing and GIS, electrical resistivity tomography, pressure wave detectors, linear polarization resistance, etc., (e.g., Huang et al., 2005; Marunga et al., 2006; Faidrullah, 2007; Morais and de Almeida, 2007; Weifeng et al., 2011; Britton et al., 2013; Agapiou et al., 2014; Bièvre et al., 2017; Cheung and Lai, 2019; Ling et al., 2019; Moubayed et al., 2021).

In regions with an antiquated underground water pipe infrastructure, like Iran, water leakage has become the main problem. Besides, when the precise location of the pipeline network is unclear, the situation becomes more serious. Water loss from pipelines, fittings, fractures, and service reservoirs overflows, causes waste of precious natural resources and economic costs. Water leakages could also be attributed to water quality, soil, materials type, the technology used, the age of the system, operating pressure, and maintenance practices (Morais and de Almeida, 2007; Agapiou et al., 2014).

Changes in electrical properties are a function of rock, soil type, and moisture content. Ground-penetrating radar is a non-destructive geophysical technique. It utilizes high-frequency electromagnetic waves to obtain subsurface information. GPR has the potential to detect water seepage, especially in primarily drylands in which the soil-water mixture creates a high dielectric contrast (Nakhkash and Ardekani, 2004). GPR can provide more detailed images but has a limited penetration depth, especially in conductive unconsolidated sediments (Neal, 2004).

Modern methods of finding water leaks require the use of high-cost geophysical devices. Sometimes researchers use only electrical resistivity tomography (ERT) techniques to reduce costs. But there is always the possibility of error results using this method. Based on Loke (2001), and Liu et al. (2002), the electrical resistivity and high-frequency electromagnetic methods involving Electrical Resistivity Tomography and Ground Penetrating Radar are considered adequate for detecting water leakage.

Eshaghi et al., (2012) proposed integrating two or more geophysical methods to solve or alleviate unreliability or ambiguity in the interpretation of geophysical data. They chose a water aqueduct as a model and implemented Electrical Resistivity Tomography and Ground Penetrating Radar methods. The evidence indicated that the optimum result obtained from the combination of geophysical methods.

Maryanto et al., 2016, conducted the geoelectric resistivity and GPR methods to investigate the subsurface structure and to delineate the underground leakage of hot water in Blawan geothermal field. They indicated that both methods are very sensitive to detect the presence of hot water.

The study area is a sulfur store that has suffered a loss and leakage of water from the underground water pipe. Any surface evidence like ground subsidence, changes in ground color, etc., was not observed in the area. The only evidence was the amount of water consumed in the study area was much higher than actual consumption. This problem indicated that there was water loss in an unknown location(s). Prior information on the water pipe network of the region did not also exist. In previous studies (Eshaghi et al., 2012; Maryanto et al., 2016), the amount of water below the ground was high, but in this research, water leakage had to be found from wet soil below ground level.

This research aims to use a combination of GPR and ERT methods to detect and trace possible locations of water seepage.

## Methodology

A combination of two geophysical methods, Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT), were applied to detect the locations of leakage in water pipelines.

### Ground-penetrating radar (GPR)

GPR is a safe and non-destructive geophysical approach that uses electromagnetic radiation to detect shallow subsurface structures in urban environments and protect subsurface settings' geological, environmental, and archaeological integrity (Daniels, 2004; Gamba and Lossani, 2000).

In this research, we used the MALÅ shielded 250MHz antenna for the investigation of anomalies. Based on the study area materials (sediments) and the ASTM D6342 standard, the proposed speed for electromagnetic waves was about 100 m/μs. Generally, the maximum penetration depth for 250 MHz devices in the sediment material was about 7 to 9 meters.

The obtained radargrams were processed by ReflexW software, and some filters such as background removal, F-k filter, Contrast, and Gain adjustment were also applied.

### Electrical Resistivity Tomography (ERT)

The electrical resistivity method is used in a wide range of geophysical investigations such as exploration for minerals, engineering investigation, geothermal studies, archaeological surveys, and geological mapping (Anomohanran, 2013; Alijani et al., 2020; Rezaei et al., 2022). ERT is one of the most commonly used methods for identifying zones of anomalous seepage or leakage (Bedrosian et al., 2012). A 2-D resistivity model is more precise to assess the subsurface where the resistivity changes in the vertical and horizontal directions.

Generally, an inversion of the measured apparent resistivity values is used to determine the subsurface resistivity in different layers or zones. Fresh groundwater and wet soils have low resistivity values.

The resistivity distribution model of data was prepared using Res2Dinv software (Loke and Barker, 1995).

An electrical resistivity survey can be conducted using different electrode arrays (Dipole-dipole, Pole-Dipole, Pole-Pole, Wenner, Schlumberger, etc.), depending on the research aim. In this study, to detect subsurface layer composition, the Wenner-Schlumberger and Pole-Dipole arrays were used.

### Pole-dipole array

The Pole-dipole array has relatively good horizontal coverage, but it has a significantly higher signal strength than the dipole-dipole array (Loke, 1999; Figure 1).

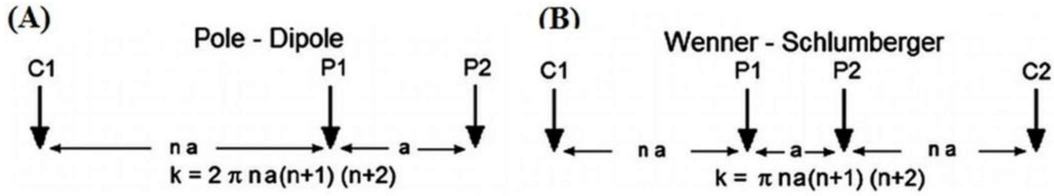


**Figure 1- A schematic illustration of arrays and their geometric factors, (A) Pole-dipole, and (B) Wenner-Schlumberger.**

**Wenner-Schlumberger array**

This array is a hybrid between the Schlumberger and Wenner arrays (Pazdirek and Blaha, 1996) (Figure 1). The Wenner-Schlumberger array is moderately sensitive to horizontal and vertical structures used in areas where both geological structures are expected (Loke, 1999).

## Geological setting of the Study Area

The Zagros fold and thrust belt is the main part of the Zagros orogenic belt in SW Iran. This orogenic belt is the result of complex deformation processes between the Arabian and Iran plate. Due to the main features of Iran's oil and gas reservoirs are located in this belt, and many of the faults of this region have not reached the surface, researchers are interested in studying this area. For example, Sherkati et al., (2006); Lacombe et al. (2011); Khalili and Mirzakurdeh, (2019); Khalili and Dilek, (2021). The study area with latitude 52˚35'45"- 52˚36'10" E and longitude 27˚31'27"- 27˚31'43" N is located in the southwestern part of the Fars geological province. This region is located in the economic zone of Asaluyeh, South Pars gas field, Bushehr province, Iran (Figure 2).

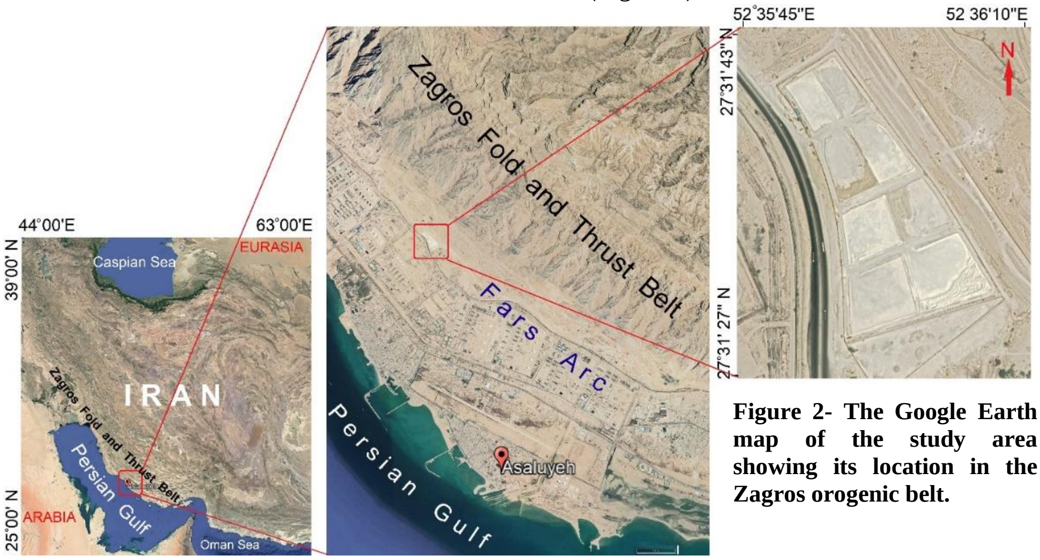


**Figure 2- The Google Earth map of the study area showing its location in the Zagros orogenic belt.**

From a geological point of view, the region is located in a sedimentary-structural zone of the Zagros and part of the Ahvaz-Bandar Abbas tectonics zone (Zamani et al., 2011).

The main structural feature of this region is the Asaluyeh anticline (Figure 3). The generalized lithology of the South Pars field is dominated by sediments (dolomites, shallow marine limestones, shales, and evaporates) (Rahimpour Bonab et al., 2010; Figure 3).

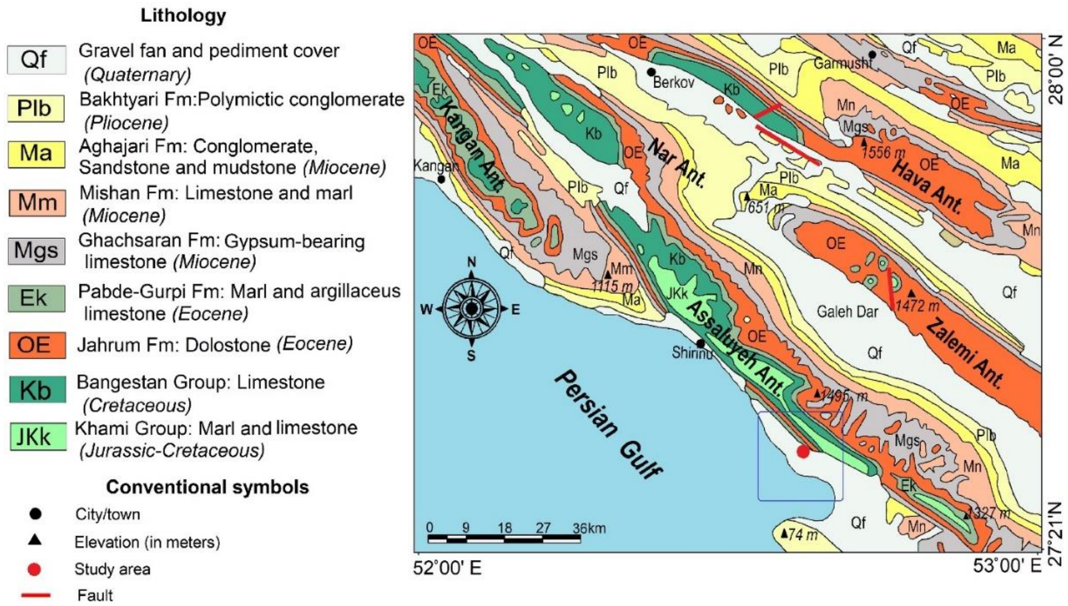

**Figure 3- The geological map of the study area and the surrounding (part of the Fars geological province, Zagros Fold, and Thrust Belt) (Simplified from Fakhari, 1994) shows the major tectonic structures and stratigraphic formations in the region, the blue box illustrates the South Pars gas field.**

Structurally, there are no significant surface faults in this area, and this region has a low hazard level for the future occurrence of an earthquake (Zamani et al., 2012; Khalili and Zamani, 2016).

There is no permanent river in the study area, and its surface water resources are limited to a few short-term but destructive floods. Most of the land in this region is covered with permeable rocks or geological formations into which many celestial precipitations and floodwaters penetrate and form minor, limited underground aquifers (Parvin Nia and Ahmadi, 2016). The alluvial sediments of the region are primarily due to the erosion of Fars Group formations, especially the Gachsaran Formation. Among them, large amounts of gypsum and salt particles can be seen (Parvin Nia and Ahmadi, 2016). The South Pars Gas Complex Company in Asaluyeh comprises five independent gas refineries, of which sulfur is one of the valuable.

## Results and Discussion

The study area is a sulfur store that has suffered from loss and leakage of water from the underground water pipe. In this research, two main techniques, including GPR and 2D resistivity (ERT), were used to investigate probable seepage points and fractures along the water pipelines.

In previous studies (Eshaghi et al., 2012; Maryanto et al., 2016), the amount of water below the ground was high, but in this research, water leakage had to be found from wet soil below ground level.

At first, according to the site condition and available spaces, 15 penetrating radar profiles have been taken over the study area (a total length of 1903 m; Figure 4). Then, to achieve more accurate results, geoelectrical surveys, with electrodes spaced one or/and 2 meters apart, were measured only with GPR profiles indicating the anomaly (Figure 5).

As mentioned earlier, the information regarding the exact plan of the network location of the water pipe of the study area was not available. The only hint was that the pipeline is positioned about 1.5–2 m below the ground surface. Therefore, in this research, observed anomalies at a depth of fewer than 2 m can be related to the water leakages and moisture.

The obtained 15 radargrams of the GPR method show that some GPR profiles (2, 3,12,13, and 14) have no anomalies. Therefore, only along with profiles 1, 4, 5, 6, 7, 8, 9, 10,11, and 15, geoelectrical surveys were conducted (Figure4; 15 ERTP).

In this research, due to limited space, of all the profiles of GPR and ERT (Figure4), only the radargrams and inverse model resistivity sections of whose anomalies were detected by both methods are shown. The radargrams of profiles 4 and 11, whose anomalies locate at shallow depths, and these anomalies were also seen by the ERT method, are shown. In the other profiles (1, 6, 7, 8, 10, and 15), the detected irregularities were partial, dispersed, observed at depths lower than the buried water pipes, or did not detect by the ERT method.


**Figure 4- illustrates the location of stations (circles), the GPR profiles (GPRP; red lines), and the ERT profiles (ERTP) along with the GPR profiles (the blue hatching lines).**

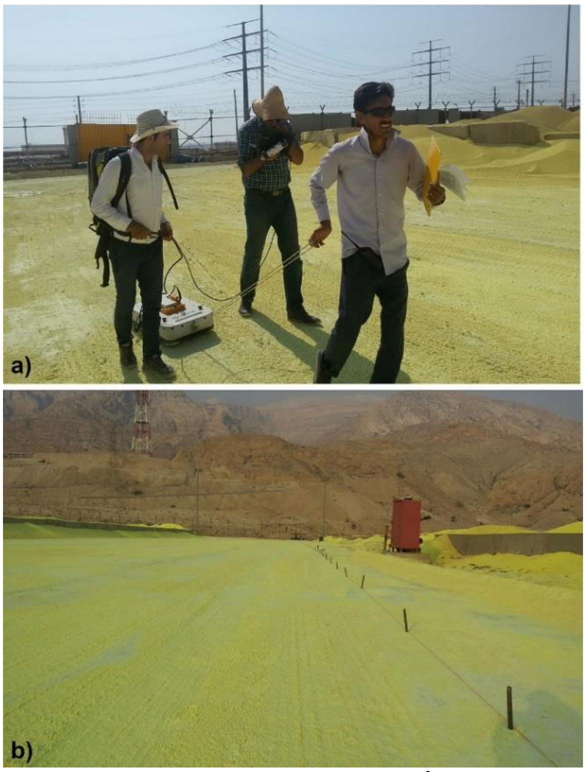


**Figure 5- a) Ground Penetrating Radar (GPR) surveys with the MALÅ shielded 250MHz antenna; b) geoelectrical surveys with electrodes spaced one or/and 2 meters apart.**

## Profile 4

In the radargram of profile 4, four anomalies at shallow depths were identified (Figure 6).
As Figure 6 shown, to achieve more accurate results, along with profile 4, four geoelectrical surveys with Pole-Dipole array were conducted (ERTPs 2, 3, 4, and 5). Of four obtained inverse models, the second geoelectrical measurements (ERTP 3; Figure 4) with an electrode spacing of 2 m, three electrical resistance anomalies indicated (Figure7).

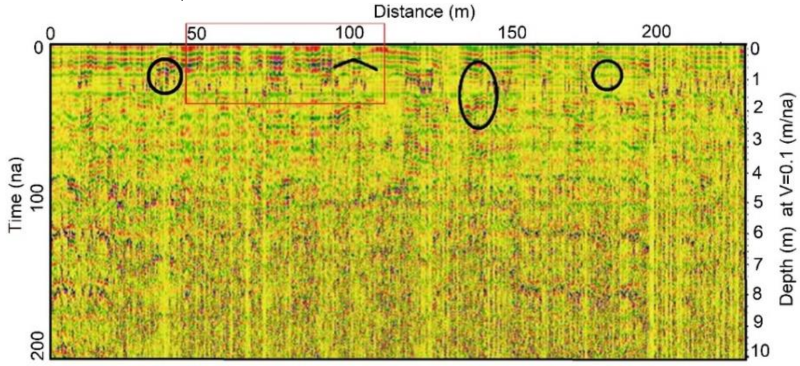


**Figure 6- the radargram of profile 4 (Figure4) was obtained with a 250 MHz antenna. The locations of possible anomalies are shown with the curve and closed curves; the red rectangle indicates the ERTP 3 location (Figure7).**

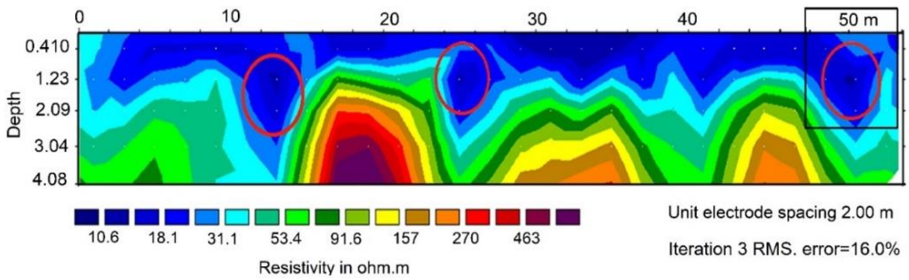


**Figure7- Shows the inverse model resistivity section of ERTP 3 (Figure4) with an electrode spacing of 2 m (Pole-Dipole array); anomalies illustrate with the red ovals; the black rectangle indicates the abnormality detected by the GPR method too.**

By comparing the results of both methods (GPR and ERT), it was revealed that at a distance of 100 meters from the beginning of station 4 (Figure 4), both ways recognized an anomaly. Therefore, there is a possibility that leakage exists in this area.

**Profile 11**

Four anomalies at shallow depths in the radargram of profile 11 were identified (Figure 8).

Besides, three geoelectrical surveys (ERTPs 12, 13, and 14) with the Wenner-Schlumberger array were conducted (Figure 4).

The resistivity inversion section of the ERTP 12 (Figure4) with an electrode spacing of 2 m shows a surface anomaly at 48 m from the beginning of station 3 (Figure 9), consistent with the irregularities identified by the GPR method. This point was proposed as a possible leakage point, as well.

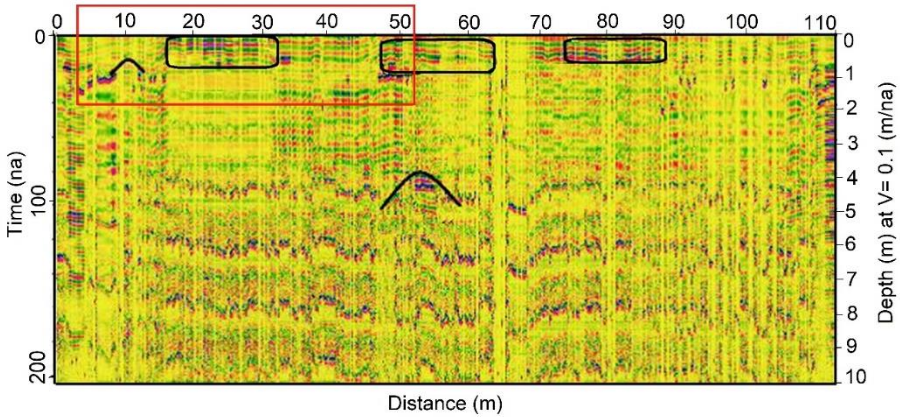


**Figure 8- the radargram of profile 11 (Figure4) was obtained with a 250 MHz antenna. The locations of possible anomalies were shown with curves and closed curves; the red rectangle indicates the ERTP 12 location (Figure9).**

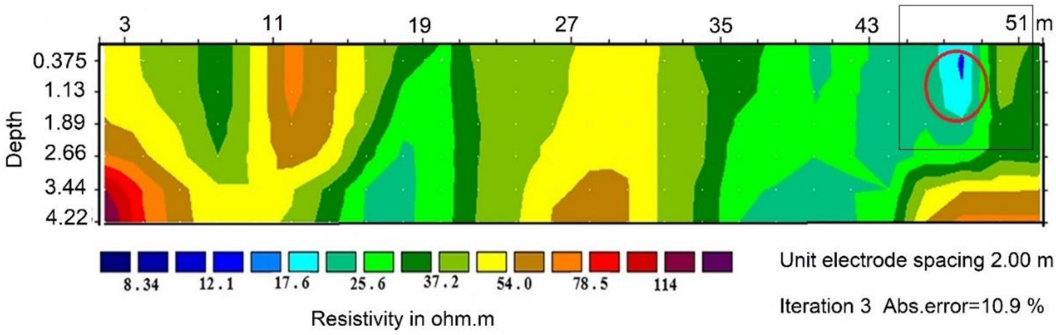


**Figure 9- the inverse model resistivity section of the second geoelectrical measurement (ERTP 12) along with profile 11 (Figure4) with an electrode spacing of 2 m (Wenner-Schlumberger array); anomaly illustrates with the red circle; the black rectangle indicates the abnormality detected by the GPR method too.**

As mentioned earlier, fresh groundwater and wet soils have low resistivity values. Therefore, by comparing two possible leakage points, the second point (Figure 9) that had both low resistance value (less than 10 ohms) and shallow depth (less than 2 m) was selected as the first proposed place prone to water leakage.

In the following, the excavation operation was conducted along with the selected point (Figure 10). This point was excavated to a depth of 2.5 m by a mechanical excavator (Figure 10a, b).

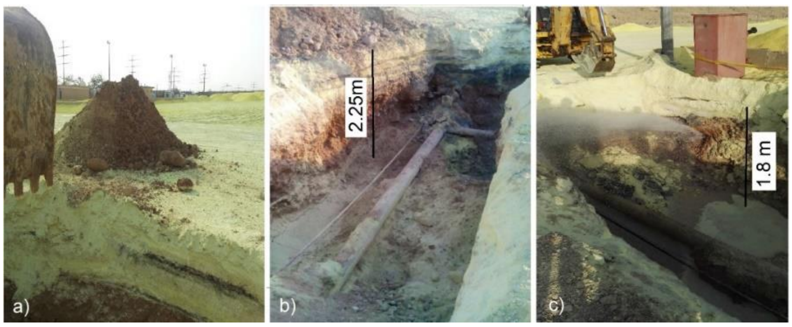


**Figure 10-a, b) the excavation operation at a distance of 48 m from station 3; c) the water leakage through a crack in the broken pipe.**

Table 1 indicates the characteristic of the observed layers (from surface to underground) at the excavation site in the leakage point.

**Table 1- Characteristic of the layers at the excavation site.**

| Layer | Depth (cm) | Composition |
|---|---|---|
| 1 | 0-30 | Sulfur |
| 2 | 30-40 | Asphalt |
| 3 | 40-60 | Sulfur |
| 4 | 60-70 | Asphalt |
| 5 | 70-120 | dry Sand |
| 6 | 120-200 | wet sand & gravel |
| 7 | 200-250 | dry sand & gravel |

It became clear that the main water pipe was cracked (Figure 10c). The leak rate was estimated to be more than two cubic meters per second. Although, the leak rate naturally increases after soil around a broken pipe is excavated.

The obtained result from the excavation operation indicates that combining GPR and ERT methods is a valuable and reliable way to detect water seepage at shallow depths and in areas where other strategies and modern devices are not available.

The pipes used for network construction were made from fiberglass or Glass-Reinforced Plastic (GRP) in the study area. Despite the many advantages of using fiberglass pipes, the fundamental defect of these pipes is deformation (or crack) due to high pressure (e.g., the pressure caused by the load-carrying trucks).

## Conclusions

Combined geophysical methods involving ground-penetrating radar (GPR) and electrical resistivity tomography (ERT) were employed to detect leakage points in the study area. The obtained results revealed that in profiles 4 and 11, the detected anomalies by the GPR were in line with those seen by ERT. Therefore, they were proposed as possible leakage points. In the other profiles (e.g., 2, 3,12,13, and 14), no anomalies were observed or, the detected irregularities were partial, dispersed, observed at depths lower than the buried water pipes, or did not detect by the ERT method (e.g.,1, 6, 7, 8, 10, and 15). The excavation operation was conducted along with one of the selected water leakage points (detected anomaly point at profile 11). The evidence revealed the main pipe water was cracked at the chosen topic. Therefore, it can be concluded that the combination of GPR and ERT methods is a valuable and reliable way to detect water seepage at shallow depth in the projects.

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