2D Resistivity Technique in Exploring Soil Contamination Zones, Kwashe Area, Duhok, North of Iraq

Kaheen D. Bamerni 1 and Rashied J. Mohammad1,∗

1 Department of Applied Geosciences, College of Spatial Planning and Applied Science, University of Duhok, Duhok, Iraq

∗ Correspondence: kaheen.abdullah@uod.ac

Abstract
The impacts of leachate on the soil count as one of the main environmental issues, especially near waste dump areas. The Kwashe dumpsite is located in the Semel district, west of Duhok City. Different types of waste had accumulated from medical, construction, and household materials without any barrier or control of the contamination. Wastewater flows on the surface and percolates downward all over the area. Geophysical methods provide high-resolution data to investigate subsurface environmental conditions with no disturbance in the materials. In this study, the 2D resistivity technique by Ohm-Mapper device (G-858G) with a dipole-dipole arrangement was utilized along six resistivity profiles. The system uses one Transmitter to couple an active current signal to the ground and the voltage difference is recorded by one Receiver with separation distances of 2.5, 5.0, 10.0, and 15.0 m. The resistivity data from MagMapper software was transferred to Res2dinvx32 software to create an inversion model for the subsurface. The results showed two main parts: The upper part consists of soil material mixed with recent deposits and fill materials formed of alluvium deposits with resistivity values of 15-50 Ohm.m at a depth between 0.25-3.0 m. The bottom section represents leachate of bowl-shaped anomalies of very low resistivity values of less than 1.0 Ohm.m at various depths. The type of materials in the left and right edges of each of the models represent the main weak zone for leachate infiltration.

Keywords: Soil contamination; Ohm-Mapper; Dipole-dipole configuration; Inversion model; Kwashe dumpsite

1. Introduction
Industrial development and the growth of the urban population have resulted in an increase in the production rate of various types of waste. Contamination is a hazardous substance from man-made activities or natural sources (Bayowa et al., 2015; Islami et al., 2018; Livinus et al., 2020). Leachate is a pollutant formed during rainfall on the dumpsite area and takes contaminants downward. Currently, geophysical methods have been progressively popular in engineering and environmental studies. This technique provides useful subsurface information based on the contrast in physical properties (Uchegbulam and Ayolabi, 2014). The geoelectrical resistivity method is a non-invasive and cost-effective alternative for obtaining subsurface geological information. In these methods, an electrical current is passed through the ground and two potential electrodes record the resultant potential difference between them to measure the electrical impedance of the subsurface material. 2D

DOI: 10.46717/igj.56.1A.19ms-2023-1-31
resistivity techniques cover larger areas, have a quick speed of data measurement, and employ processing techniques (Hazreek et al., 2018). The electrical resistivity contrast between the conductive leachate zone and the surrounding materials is an additional benefit to the applicability of the method (Bayode et al., 2011).

Several authors have worked on the use of the electrical resistivity method in mapping leachate plumes in groundwater investigation (Adebayo et al., 2015; Ugwn et al., 2016; Akpan et al., 2018). The results of their studies showed that 2-D resistivity imaging is capable to detect zone of contamination as low resistivity zone. The integration of different geophysical methods attribute to find low and high resistive anomalies and the results showed contamination patches with low resistive values (Çınar et al., 2016; Popoola and Adenuga, 2019). To map subsurface soil pollution, the use of 2-D resistivity methods determined different geo-electric layers of various resistivity values obtained (Raji et al., 2018). The low resistivity value related to the indication of a leachate plume (Ofomola et al., 2016). Therefore, the selection of a waste storage site is important, especially in terms of geological formations. Over 20-year-old Kwashe household sorting plant collects wastes from the center of Duhok, Semel, and the villages encompassed by Fayde, Domiz, and Sharia with daily disposal of nearly 400 to 500 tons. The current problem is the factory only sort around 200 tons and the majority of waste is stored in open dumps (Fig.1) because there are no proper policies and regulations made by the municipality of Duhok. The area is continually polluted and the people living nearby are suffering from the bad scent and the leachate became like large streams flowing on the surface and extending hundreds of meters away from the dumpsite.

![Fig. 1. A- waste pile in the Kwashe dumpsite; B) leachate occurred on the surface within the dumpsite; C) the area of dumpsite with flowing waste stream all over the Kwashe area](image_url)

Kwashe dumpsite is in Semel district and lies about 25 km to the west of Duhok province, Kurdistan Region, Iraq. The area is surrounded on the northern side by the Bekhair anticline, Mal Hassan village to the west, and Kwashe village to the east. At the same time, it’s open to the flattened area with a slight dip towards the artificial reservoir lake of Mosul Dam towards the south. Stratigraphically, one rock unit is exposed on the surface in the studied site represented by the clastic sediments of the Upper Miocene Injana Formation (previously Upper Fars Formation). Tectonically,
the Kwashe section lies within the High Folded Zone of the Western Zagros Fold-Thrust Belt according to the tectonic divisions of Iraq (Fouad, 2015) (Fig. 2).

![Fig. 2. Location and geological map of the study area (Doski and Mcclay, 2022)](image)

In terms of geomorphology, the drainage system in the study area depends mainly on rainfall. As well as its type and shape mostly depend on the climate condition. According to Khalil and Hassam, (2018,) eight basins were identified in the study area, but only the Til-Zer basin showed a great impact on the transfer of liquid industrial pollutants. The basin descends from the southern slope of Bekhair anticline with an altitude of 1300 meters and flows into the Mosul Dam in the southern direction, as shown in Fig. 3. In terms of hydrological conditions, according to the general directorate of groundwater in Duhok, the level of water table in the Kwashe area is around 85-95 meters with relative seasonal variation.

The aim of this study is to investigate the area around the Kwashe household sorting plant, determine various zones of contamination vertically and horizontally based on resistivity values, and for the first time use the Ohm-Mapper system to conduct resistivity profiles. The results of this study will provide a 2-D inversion model of the subsurface area. This study will support previous articles related to the impacts of the waste within Duhok governorate and also, support the governmental sector and non-governmental organizations to find an appropriate plan to protect the environment from pollution.

2. Materials and Methods

The Ohm-Mapper system provides a survey grip map and the operator is capable of entering the desired survey location map, reviewing, editing the data during the survey and after processing. Different components of the system illustrated in (Fig.4).
2.1. Data Collection

Before collecting the data, the system was set-up for a walk-away test to get a good signal and determine the current level and gain level (Geometrics, 2001). The depth of investigation was limited to only 6 m, because the maximum depth depends on the separation between the two dipoles. The use of non-conductive rope from 2.5m, 5m, 10m, and 15 m to provide a constant distance between Transmitter and Receiver dipoles during surveying. The length of each resistivity profile depends on the area available differing from 50 meters to 100 meters (Fig. 4). The Ohm-Mapper system follows the dipole-dipole array, which is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in resistivity.

After the set-up of the device geometry of each profile entered through Ohm-Mapper console, including Receiver dipole and Transmitter dipole length which is constant to 5 m, then the rope separation entered and the type of survey chosen (simple survey mode), six resistivity profiles conducted as shown in Fig. 5, and coordination of each of the profiles shown in Table 1. The first Profile A-A' surveyed in which A present start point of the profile and A’ is end point. In order to do pseudo-section each profile was surveyed four times with different separations. First rope 2.5 m was used as forward from A to A’ then 5 m used as reverse direction from A’-A, then 10 m was used as forward and 15 m as reverse. Each resistivity profile consists of four lines and is saved in the console during fieldwork, the device produces a grid map of the area surveyed, and geometry of the survey presented where the operator can change the length of rope, and dipole cables of each of the Transmitter and Receiver. After collection, the raw data transferred to computer by Magmap software, where hundreds of measurements can be shown, the software plot Ohm-Mapper readings, resistivity map, and resistivity surface. Because the inversion model by Magmap was not clear and not suitable for interpretation, the data from magmap software (ASCII file) was conveyed to Res2dinv software.
Fig. 4. Ohm-Mapper G-585G equipment’s, a. Receiver dipole, b. Transmitter dipole, c. Console with 2 batteries of 24 Volt d. Cables of 2.5 meters connecting between Rx and Tx, e. Fiber optic communication wand with the depressor weight to maintain Rx while being towed, f. Rope with plugs, g. Loop, Console cable, and Clamp

Fig. 5. Google earth image illustrate six Resistivity Profiles conducted around Kwashe dumpsite with different direction to the waste stream.

Table 1. The given table provides coordination of profiles with measured length

<table>
<thead>
<tr>
<th>Profiles</th>
<th>S/E profile</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Length(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-A’</td>
<td>Start A</td>
<td>36.97361</td>
<td>42.80956</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>End A’</td>
<td>36.97329</td>
<td>42.80916</td>
<td></td>
</tr>
<tr>
<td>B-B’</td>
<td>Start B</td>
<td>36.97310</td>
<td>42.80884</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>End B’</td>
<td>36.97334</td>
<td>42.80920</td>
<td></td>
</tr>
<tr>
<td>C-C’</td>
<td>Start C</td>
<td>36.97223</td>
<td>42.80759</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>End C’</td>
<td>36.97202</td>
<td>42.80836</td>
<td></td>
</tr>
<tr>
<td>D-D’</td>
<td>Start D</td>
<td>36.97246</td>
<td>42.80630</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>End D’</td>
<td>36.97202</td>
<td>42.80601</td>
<td></td>
</tr>
<tr>
<td>E-E’</td>
<td>Start E</td>
<td>36.97130</td>
<td>42.80740</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>End E’</td>
<td>36.97148</td>
<td>42.80667</td>
<td></td>
</tr>
<tr>
<td>F-F’</td>
<td>Start F</td>
<td>36.97046</td>
<td>42.80556</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>End F’</td>
<td>36.96968</td>
<td>42.80588</td>
<td></td>
</tr>
</tbody>
</table>
2.2. Inversion and Processing Procedure

After transferring the apparent resistivity data to the Res2dinv model, the data contained a large amount of bad data points with high RMS errors due to some technical issues related to the batteries. In high conductive ground, the attenuation of the signal is greater, hence the readings contained a lot of noise. However, noise is common with dipole-dipole array and can cause readings to have unusually low or high values. To overcome the issue, the Res2dInv program provides an option to remove bad data points (exterminate bad data points) as shown in Fig. 6. The apparent resistivity data are interpreted using a Least-Square inversion that produce a model with a reasonably smooth variation in the resistivity, particularly for very noisy data sets and provides finest results. Most of the resistivity raw data was processed until 10 iterations to achieve an approximate image of the subsurface materials. The depth of investigation in Ohm-Mapper survey is determined mainly by the total length of the array (L). When n-factor ≥ 3, then the investigation depth is equal to L/5, but if n is 2, the penetration drops to L/5.7, and for n=1 the penetration is only equal to L/7.2. During fieldwork rope 2.5m, 5 m, 10m and 15 meters has array geometry of 11.5, 14, 19, and 24 meters, respectively. Hence the depth of investigation is limited to around 6 meters.

![Fig. 6. Data set with bad points from Profile (A-A'), the bad data point is removed using (exterminate bad data point) option](image)

3. Results

The following resistivity profiles show the inversion model of the subsurface area, in which the number at the horizontal line indicates the length of the profile, and does not present the distance between electrodes and the vertical line is the depth. The colored scale of resistivity values ranged from very low resistivity to high resistivity values. The discussion will emphasize the interpretation and analysis of the geoelectrical resistivity model.

3.1. Profile A-A'

The inversion model shows variation in resistivity between the upper and lower parts of the section (Fig. 7), the first zone is the top soil, with resistivity values ranging from 14 to 44 Ohm.m with a thickness of around 3m restricted in the center part. It is a mixture of recent deposits mixed with rock fragments and debris of variable-size. In the bottom section, three bowl shaped anomalies of very low resistivity zones were found of less than 1.0 Ohm.m at a depth of around 4 to 6 meters. These are interpreted as contaminated leachate assumed to the high organic content in the waste and the increase in moisture content. The area of low resistivity in the southwestern side of the inversion model is a
mixture of granular materials composed of clayey silt, this weak zone aids in the percolation of the leachate to extend downward. The black line separates the leachate zone from the rest of the surrounding materials.

**Fig. 7.** The inverse model section A-A’ with Standard Least Square Inversion method

### 3.2. Profile B-B’

In the inverted model of profile B-B’ illustrated in Fig. 8, the model typically shows various zone of high and low resistive anomalies due to the nature of the area and climatic conditions. The first zone was identified as a layer of high resistivity values of around 30 Ohm.m at a depth ranging from 0.25 to 3.0 m restricted in the center part. This zone interpreted the top soil mixed with recent deposits and filling materials formed of alluvium of yellowish-brown clay and silt loam of variable-size, subangular to subrounded particles. The second zone represents the presence of clayey silt particularly restricted in the left and right sides of the section with low resistivity zone exist of less than 10 Ohm.m with depth ranges from 0.25 to 6 meters. The zone of contamination was found in the bottom section with resistivity values of less than 1.0 Ohm.m.

**Fig. 8.** The inverse model of section B-B’ with Standard Least Square Inversion method

### 3.3. Profile C-C’

The electrical resistivity model (Fig. 9) distinguishes two zones with different electrical resistivity values. This profile is located perpendicular to the waste stream and parallel to the dump site. The inverse model reveals a range of values of resistivity ranging between 0.1 and 300 Ohm.m, with a majority of high values in the near-surface portions and a gradual decrease in values with increasing depth to around 6m. The zone of high resistivity values of around 300 Ohm.m at a depth between 0.25 and 3.0 m represents topsoil mixed with recent deposits and fill materials formed of alluvium of yellowish-brown clay and silt loam of variable-size, subangular to subrounded particles. The bottom section shows a low resistivity zone of less than 10 Ohm.m probably clayey silt materials act like a weak zone to infiltrate contamination to the subsurface, whereas the zone of contamination found at the left side of the section and in the bottom section with resistivity values of less than 1.0 Ohm.
3.4. Profile D-D’

Fig. 10 shows an inversion model with uniform and relatively high and low resistive anomalies. The section reflects a high resistivity zone at depth from 0.25 m to 4.0 m with apparent resistivity values ranging from 15 to 30 Ohm.m interpreted as topsoil mixed with recent deposits and fill materials formed of alluvium of yellowish-brown clay and silt loam of variable-size, subangular to subrounded particles. The low resistivity layer situated beneath the soil layer with values ranging from 1.0 to around 10.0 Ohm.m assumed as soil material probably clayey silt mixed with leachate. But the prominent feature in the model is the horizontal distribution of extremely low resistivity values of less than 1.0 Ohm.m, the possibility of a saturated zone full of leachate plumes. The model shows a lateral and vertical spread of the contaminants along the profiles starting at depths around 5 m and extending downward. At the endpoint of the profile, the D’ indicates that the contamination percolated downward due to the nature of the materials in the area aid in infiltration process. Also, humidity and moisture content within the study area are important factors for the spread of leachate. At the start point D leachate was found on the surface due to the effect of waste stream near the location of the survey.

3.5. Profile E-E’

The inversion model in Fig.11 shows variation in resistivity between the upper and lower parts. High resistive anomalies are found in the upper section at a shallow depth between 0.25 and 4 m interpreted topsoil mixed with rock fragments, this zone has relatively higher resistivity values of more than 8.0 Ohm.m. Low resistivity values ranged from 0.1 to around 5.0 Ohm-m with various depths observed underneath the topsoil. The second zone represents clay silt aids contamination to penetrate downward. In the left section of the model, contamination is at the surface, whereas the right section of the model shows the presence of clayey silt. The area with resistivity values of less than 1.0 Ohm.m related to the contamination zone (leachate).
3.6. Profile F-F’

The inversion model of this profile (Fig. 12) illustrates two main zones. The first zone is the surface soil and has a variation in resistivity values ranging from 20 to 50 Ohm.m, due to its composition, which contains different types of clastic sediments with a thickness of around 3 m at the middle part of the model section. This zone represents topsoil mixed with recent deposits and filling materials formed of alluvium of yellowish-brown clay and silt loam of variable-size, subangular to subrounded particles. The left and right edges of the model show resistivity values of less than 8.0 Ohm.m at a depth ranging from 0.25 to 5.88 m indicating the presence of clayey silt within the study area. At the bottom zone, two large anomalies of extremely low resistivity values were identified of less than 1.0 Ohm.m at depth of around 4 to 5.88 m. The zone of high conductivity represents the leachate-like bowl-shaped anomalies of blue and dark blue colors and has affected the surrounding subsurface materials.

4. Discussion

The area of the Kwashe dumpsite showed values of very low resistivity that supported the available chemical analysis from previous studies within the study area. The amount of leachate in each profile differed based on the geological condition within the study area and the presence of waste stream was another factor for contamination to be less or more (Fig. 13). The resistivity profile A-A’ was parallel to the profile B-B’, but in a different direction, both profiles were parallel to a waste pile. The waste water was shaped like small and large streams on the surface and percolated downward the valley, therefore, the length of the resistivity profiles was limited to only 50 and 40 m respectively.

The inversion model profiles A-A’ and B-B’, with almost similar lengths, provide two main zones of low and high resistivity. In the first profile in the northeastern direction, the model shows soil materials, whereas in the southwestern direction the area shows the presence of clayey silt and affected by the contamination from the waste stream. This layer acts as a weak zone since the silt is preamble
and aid in infiltration process and leads to leachate percolating into the subsurface. At the bottom section, around 4-6 m, two large bowl-shaped anomalies were found with resistivity values of less than 1.0 Ohm.m, chemical analysis according to Hassan and Umer, (2022) supports geophysical data in which the electrical conductivity showed very high conductivity of 6.37 ds/m more than acceptable range (0.6-1.2 ds/m). Also, soluble salts from sodium and potassium had higher values. The first profile in comparison to profile B-B’ showed a similar section in terms of resistivity values. The southwestern side of the model showed similar material like first profile; thus, the leachate was found near the surface. In the mid-section high resistive materials laid above the saturated zone of leachate at the bottom section, in the north eastern side a small patch of leachate found due to the flowing stream within the study area. Clay layers probably separate the topsoil from the leachate zone indicating as yellow color in the resistivity bar.

![Image](image_url)

**Fig. 13.** The effect of wastewater on the inversion model in two different seasons.

Resistivity Profiles C-C’ and D-D’, the two resistivity profiles situated by hundred meters away from the dumpsite, the start line of both profiles was perpendicular to the wastewater flowing on the surface. In the first profile, the inversion model showed a large variation in resistivity values ranging between 1 and 300 Ohm.m along the survey. In the western side of the model, low resistivity values appeared of less than 1.0 Ohm.m at a depth between 0.25 and 5.88 m, whereas in the center part the resistivity values ranged between 100 and 300 Ohm.m probably sand and gravel followed by clay layer of resistivity around 9.0 Ohm.m. The zone of contamination was found at the bottom section, where on the western side the leachate penetrated the area and extended downward leads the contamination to have bowl-shaped anomalies of very low resistivity of less than 1.0 Ohm.m at various depths. Profile D-D’ presented the same feature, in the left side of the model the presence of leachate with very low resistivity indicated the start point of soil pollution and gathered in the bottom section, on the right side the presence of clayey silt spread in the contamination to be surround the topsoil and its thickness ranged between 0.25 and 4.0 m. Hence, it is very clear the effect of the waste stream on the soil materials, and humidity within the area helped in the leachate distribution.

In the final comparison between profiles E-E’ and F-F’, the first profile intersected the waste stream on the northwestern side of the profile with a length of 100 m laid above agricultural land. Therefore the start point of the profile showed very low resistivity values of less than 1.0 Ohm.m, the area consists of clayey silt hence the leachate distributed all over the model especially in the lower section of the model, in the south-eastern side the profile showed materials of low resistivity values around 4.0 Ohm.m this can be interpreted clayey silt but not contaminated because the area was above the waste stream. The center part contains topsoil with low resistivity because the leachate affected the
soil. However, profile F-F’ conducted parallel to the waste stream, inversion model showed very low resistivity in the left and right side of the model assumed as clayey silt, the type of material leads the leachate to flow downward and accumulate in the lower section of the model. The zone of high resistivity above 10 Ohm.m appeared in the middle section at a depth between 0.25 and 4m.

5. Conclusions

This research demonstrates the importance of geophysical methods, particularly 2D electrical methods, in the study of environmental problems. The Ohm-Mapper device is a professional, high-quality data mapping tool for measuring the resistivity of subsurface formations. The system provides a continuous apparent resistance profile with an effective velocity process. The technique helps to explore subsurface areas and characterize contaminant zones as an inversion subsurface model. The following can be identified: the inversion model consists of two main zones. The topsoil was found at the center part of all the six profiles with variable resistivity values, the leachate zone determined at the bottom section with very low resistivity values of less than 1.0 m, the area mostly clastic sediments of clayey silt. Most of the contaminants appeared on the right and left sides of most profiles while in the center part of all six profiles high resistivity values of more than 10 Ohm.m to about 200 Ohm.m were found. This study recommends the integration of geophysical measurements with Geo-Radar methods for better quality and quantity. Also, the government and policy makers re-construct the Kwashe landfill with skilled personnel people to control the leachate plume that seeps downward. Household sorting plant factories should operate 24 hours a day to process most of the waste. The people living in Kwashe village need to move to a safer environment area from the polluted air and smell of the dumpsite.

References


