Geo-Environmental Characterizations in Heavy Metal and Oil Contaminated Soil Using Soil Electrical Resistivity

Chik, Z., Murad, O.F., Islam, T.
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia(UKM), Malaysia.

**INTRODUCTION**

Soil contamination by heavy metals has been a serious problem for the environment for many years all over the world. One of the vital contributors to this pollution is the waste management sectors of a country. In many landfills subsurface soils were significantly polluted by Arsenic (As), Lead (Pb), Iron (Fe), Copper (Cu), Aluminium (Al) and persistent organic pollutants such as Organochlorine pesticides, especially Dichlorodiphenyl-trichloroethane family (DDTS), Hexachloro-cyclohexane isomers (HCHS) and Polychlorinated biphenyls (PCBS) [13]. Due to Industrial Revolution emission of Pb have been increased significantly by different activities such as combustion of coal, use of leaded gasoline, disposal of leaded waste, use of Pb in constructions and paints[10]. These metals also reduce the agricultural production capacity of soil. This study involves the determination of harmful heavy metals using electrical resistivity of soil which is a non destructive and comparatively less time consuming method.

**Fig. 1:** Current flow distribution in homogeneous type of soil.

1. Importance of using soil electrical resistivity for determining contamination:
   
   From last 200 years of industrialization, soil contamination became a vulnerable issue in almost all over the world. Researchers, scientists, decision makers and general people are already well aware about water and air
pollution of environment as these pollutions have direct effect on environment. But the impact of soil pollution is not a well studied issue compared to other pollutions compared to general people. Heavy metal contamination of soil is of major concern from an ecological point of view. Metals such as Cd, As, Zn, Cu, and Hg, consequently resulting in metal contamination of agricultural products and pose a potential risk to human health [1]. In an investigation it has been found that direct or indirect consumption of soya bean can be harmful for human when the soil of soya bean crop field is contaminated with heavy metals [15]. So it is very important to locate the soil contamination of different areas. It is also necessary to find the origin of those contaminants so that sustainable environment can be monitored. Already many researches has been performed for measuring the amount of contamination in soil. In those methods for measuring soil contamination, sample has to be collected from every layer. In other words most of them are destructive in nature. Also those procedures are consumes lot of time. But electrical resistivity is more suitable procedure as it is effective for dense station spacing and spatial aliasing. It can provide higher precision with fast and larger dataset interpretation facility [14]. For this reasons using the electrical resistivity of soil, it will be possible to analyze heavy metal contamination of soil in a non-destructive, less time consuming and convenient procedure.

2. Present condition of heavy metal contamination in Malaysia:

In many landfills of Malaysia, such as Seri Petaling, Panchang Bedena, Ampar Tenang landfills soil contamination has been measured using many processes. In Ampar Tenang landfill, soil samples were obtained at different depth, starting from 2m to until 35m to investigate the migration of different contaminants into deeper layer. The maximum concentration of arsenic was 64.4 mg/kg and mercury was 11.5 mg/kg. In many states of Malaysia, As and Pb exceeded the safe limit values of 5.90 mg/kg and 31.00 mg/kg respectively based on provincial sediment quality guidelines for metals and the interim sediment quality values [18]. Though heavy metals contamination were below the Dutch Intervention Standard for Soil Remediation, necessary steps should be taken to identify the amount of contamination in the landfills [1].

![Landfills in Malaysia](image)

**Fig. 2:** Landfills in Malaysia.

3. Previous studies on soil contamination using electrical resistivity of soil:

Geophysical methods such as MASW, SASW have been applied to investigate soil for a considerable period. The electrical properties of a light non-aqueous phase liquid (LNAPL) was successfully investigated using 2D surface resistivity, ground penetrating radar (GPR), and electromagnetic methods (EM) [2]. But using of electrical resistivity of soil in soil investigation is comparatively new concept among all methods. Electrical resistivity has already been applied in various fields such as exploration of groundwater, solute transfer delineation measurement, determination of composite characteristic of soils, soil texture, stone, salt, and humus contents, and arrangement of the genetic soil horizons, agronomical management, determination of soil horizon thickness and bedrock depth, assessing the soil hydrological properties [16]. Earlier researchers worked to establish a relationship between the variation of the property and the concentration, distribution and evaluation of the contaminants with electrical resistivity of soil [17].

Delaney [4] studied the behaviour of frozen and petroleum-contaminated soil using electrical resistivity and observed that with constant water content resistivity increases with the increase of petroleum content of soil. Along the vertical profile both resistivity and temperature of soil was measured. For uncontaminated silty sand electrical resistivity was found to increase about 10 times when soil was frozen whereas contaminated and frozen silty sand resistivity was increased about 2.5 times than before. From Fig.3 it can be noticed that, with increasing percentages of petroleum water mixed with soil apparent resistivity value decreases.

In this study for both laboratory and field technique direct current (DC) with Wenner array was used and it is also known as four probe Wenner method. For this purpose following equation is used to measure the apparent resistivity $\rho$ ($\Omega$ m) of soil,

$$\rho = \frac{2\pi a V}{I}$$  \hspace{1cm} (1)
In the experiment, depth of container was kept more than the value of “a”, to ensure the validity of the formula. In that study a major electrical effect was considered which makes the study remarkable than other similar types of studies. Delaney used Iris SYSCAL R1 Plus resistivity meter to reduce electrode polarization effects. In this resistivity meter direct current measuring systems was switched to induce the current flow direction at minimized rate [4].

Almost 17 samples were prepared by mixing 2%, 5% and 10% water with oven-dry silt. After that 20% solution of petroleum was added with each sample.

In 2001, Fukue developed a resistivity cone for determining the concentration of NaCl, KCl and light oil in quartz sand and Kibushi clay. The resistivity cone was penetrated into soil about a depth of 1m at a constant speed of 1cm/sec. For every 5 second interval the potential difference is measured. Fukue derived the following theoretical relationship on the basis on Ohm’s law,

\[
\rho = \frac{\pi^2 \Delta V}{CI}
\]

Here,

\[
C = \frac{1}{(d+\tau_M)} - \frac{1}{(d+\tau_N)} + \frac{1}{(d+\tau_{N')}}
\]

A typical schematic diagram of resistivity cone is illustrated below (Fig. 4).

Electrical resistance for quartz sand decreased from 200 Ω to 20 Ω with the higher concentration of KCl. Also an important matter can be observed that resistivity value does not change with increment of current for a certain limit. But after exceeding the limit resistivity decreases with increasing current flow through soil (Fig. 5). The starting point of decreasing slope defers with water content. The reason behind these phenomena was that, for zero or very low concentrations of KCl, low amount of current can cause higher electrical conductivity on soil. As the concentrations increases higher current flow is required to initiate electrical conductance on soil.
In the case of Kibushi clay, different trend can be observed than quartz sand. When KCl concentration is too low then resistivity slightly increases with increasing current flow. Then it do not change till a certain amount of current flow. Finally it decreases with increasing amount of current. For 30g/L KCl concentration resistivity value decreases with increasing current flow between 0.01 to 0.1. But after that resistivity value do not change with increasing value of current. (Fig. 5.b)

For NaCl, a container was filled up with three layers of soil. NaCl concentration was expressed in g/g × 100%; NaCl/soil. For low percentage of NaCl/soil resistivity decreases with depth but after clay layers of soil it again increases with depth. On the other hand, for higher percentages of NaCl/soil resistivity tends to increases with depth (Fig.6).

For light oil, Fukue mixed 5% and 20% of water and oil content with quartz sand. But oil content behaved completely opposite to the chlorides. The resistivity value of sand increased with the increase of oil content (Fig. 7) [6].
Fig. 7: Relationship between electrical resistivity and oil content in terms of water content [6].

Resistivity cone was effective equipment for measuring both chemical contamination and light oil, which was a new concept in soil investigation. Also using resistivity cone potential difference between the cones was measured. That was also unique in soil investigation methods. Current flow through soil particle was also considered. But for KCl and NaCl, effect of water content was not taken into account.

A study on the relationship between soil shape factor, formation factor, void ratio and water content with electrical resistivity of soil was carried out by Han Li [7].

- With increasing concentrations of pollutants, soil electrical resistivity value becomes low.
- As electrical resistivity is sensitive with temperature, a constant temperature must be maintained during the measurements of electrical resistivity in laboratory.
- It is better to measure electrical resistivity for contaminated soil when water content is low at site because for higher water content resistivity value changes a little bit.
- When contamination is too high this it is very difficult to correlate between electrical resistivity and concentrations of contaminants.

For the first time Han Li considered many driving factors that could affect electrical resistivity of soil. In 2009, Song-Yu and Yan-Jun applied soil electrical resistivity to determine contamination of cement solidified/stabilized soil. Two types of heavy metal salts ZnCl$_2$ and NiCl$_2$ were considered as pollutants.

After analysing all the results, following relationships were developed,

(a) Relationship between ZnCl$_2$ concentrations vs. electrical resistivity.

(b) Relationship between NiCl$_2$ concentrations vs. electrical resistivity.

Fig. 8: Effect of ZnCl$_2$ and NiCl$_2$ concentrations on electrical resistivity of soil for different percentages of water content [11].
From the figure (Fig. 8) it can be concluded that for both cases with increasing concentration of chlorides, electrical resistivity of soil decreases. Also increasing percentages of water content reduces the electrical resistivity. But in the case of ZnCl₂, the trend of lowering electrical resistivity with increasing concentration is much steeper than NiCl₂ for 25% and 30% water content. However, for similar percentage of water content and chlorate concentrations electrical resistivity of NiCl₂ is slightly higher than ZnCl₂ (Fig. 9).

![Graph showing electrical resistivity vs. chlorate content](image1)

**Fig. 9:** Relationship between NiCl₂ concentrations vs. electrical resistivity of soil for different percentages of water [11].

Song-Yu and Yan-Ju did splendid work on this study, but they only considered laboratory condition. Percentages of water content were varied but field conditions are different than laboratory. Only two types of chlorate were considered in that study. Thus further research can be done with more compounds using soil electrical resistivity [11]. In 2011, Metwaly & Khalil included the effect of cation exchange capacity (CEC) in determination of oil pollution using electrical resistivity (Fig. 10). In that study it was observed that crude oil have high electrical resistivity than processed and degraded oil [12].

![Graph showing resistivity vs. fluid resistivity](image2)

**Fig. 10:** Relationship between electrical resistivity and fluid resistivity in terms of CEC [12].

Recently Weerasiri and Wirojanagud [19] investigated the arsenic pathway in different goldmines in Thailand. That study was conducted to create an image of underground profiles of arsenic contamination. For obtaining ground cross section dipole-dipole array measurement was used. In that study two current electrodes (A and B) was employed. The spacing between electrode A and B was denoted as “a”. For increasing the depth of investigation, the spacing was doubled between A-B dipole. Seven arrays with different directions were used for this study. It was targeted to explore the depths of 5 m, 9 m and 30m, respectively. For this reason the spacing “a” of 1.5 m, 3 m and 10 m were used in the series of measurement. Many electrodes were deployed along transverse section. Measuring equipments were automatically switched the transmitting and receiving electrode pairs. After finishing the field survey, apparent resistivity values were determined and 2-D resistivity tomography was prepared using the inversion computer program [19]. The speciality of this study was that, electrode polarization effect was also considered in that study.
4. Observation in previous works for determining soil contamination:

Electrical resistivity is more suitable method among all conventional geophysical methods for soil investigation. Soil resistivity is a critical factor in design of systems that measure of how much the soil resists the flow of electricity. The major principle of electrical resistivity method is based on the behaviour of the earth to the flow of electrical current. Depending on moisture, temperature and chemical content, pH, void ratio, compaction of soil, grain size distribution soil resistivity value can vary within wide range. Basically previous researchers focused on soil contamination by different chlorate, chlorides, heavy metals, oil using different electrical methods without considering other soil properties such as soil pH, cation exchange capacity (CEC), soil salinity and electrolyte concentration. They also studied some physical properties of soil such as void ratio, grain size distribution of soil particles, compaction of soil etc. After analyzing the previous studies following table (Table 1.) can be found.

Table 1: Effect of electrical resistivity for different properties and contamination of soil.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Inversely proportional</td>
</tr>
<tr>
<td>Water content</td>
<td>Inversely proportional</td>
</tr>
<tr>
<td>Chemical or heavy metal contamination</td>
<td>Inversely proportional</td>
</tr>
<tr>
<td>Oil contamination</td>
<td>Proportional</td>
</tr>
</tbody>
</table>

In previous investigations, water content of soil was one of the vital factors affecting electrical resistivity. Also some researchers used complicated, time consuming and expensive methods to find water content along with resistivity of soil.

5. Present study on electrical resistivity ratio between layers of soil:

To avoid the effect of water content in measuring electrical resistivity of contaminated soil, resistivity ratio between soil layers could be considered. In the following figure (Fig. 11) there are three layers of soil.

![Fig. 11: Estimation of electrical resistivity ratio from different layers of soil.](image1)

When water from rain or other sources infiltrate gradually from layer 1 to layer 2, the resistivity value of layer 1 and 2 must be decreased from its dry condition. But the ratio of electrical resistivity between two layers will not change as water infiltrates through both layers. Same condition will be true for layer 2 and 3.

As current pass through into the soil, the electric potential ($V$), electric field strength ($E$) and electrical resistivity($\rho$) vary according to variation of the parameters ( grain size distribution, water content, cation exchange capacity, pH value etc) with depth of soil layers[8].

![Fig. 12: Multi-layer resistivity ratio measurement model [8].](image2)

Electrical resistivity ratio can be calculated using following equation[3].
\[
K_n = \frac{\rho_{n+1}}{\rho_n}
\]  

After analysis, a relationship can be obtained relating depth against resistivity ratio in a graph. The relationship can also be compared with relationship between depths against heavy metal concentrations with considering other parameters that affect soil resistivity. For ensuring the accuracy of using resistivity ratio the concentration of metal can be cross checked using X-Ray Fluorescence (XRF) [5], ASV (Anodic Stripping Voltammetry) or Colorimetric test kit values with empirical relation of resistivity.

In this method layers of soil must be determined to get reliable results. For this purpose Geo-Sw@t, a soil analysing software can be used for produced 2-D tomography of the section so that specific thickness between the layers can be determined. Although measuring soil resistivity ratio is more complicated and time consuming procedure as the measuring probes must reach to the specified depth of soil, the effect of water content in the electrical resistivity measurement could be eliminated in an effective way.

6. Some concerns of using electrical resistivity:

Although electrical resistivity ratio is one of the suitable solutions for finding heavy metal contamination in soil, but at present it has some concerns and limitations. Some of these major are described below,

- It is difficult to separate the layers of soil. Soil profiling must be done using soil resistivity before separation of layers.
- Initial cost is higher than other procedures as initially many electrical devices will be required to setup the whole system.
- Skilled persons will be required to operate devices or conduct tests.
- Electrical resistivity ratio depends on many other properties such as soil pH, grain size distribution, void ratio, cation exchange capacity etc. So these properties of soil must be considered during the tests.
- When contamination is too high, electrical resistivity ratio alone cannot provide the actual magnitude of the contamination in soil. Natural scatter level of soil will be one of the major factors of contamination. Hence, the scatter levels at any site and the minimum degree of contamination should be measured along with electrical resistivity ratio [9].

7. Conclusion:

In conclusion the electrical resistivity method is more suitable compared to others conventional methods for soil investigation. From many years so many researches has tried to improve this geophysical method. But still due to many drawbacks, it is not the common method being used for measuring soil contamination. If this procedure can be used for measuring soil contamination by heavy metals, both time and cost can be reduced. When heavy metal concentration increases or decreases linearly, then resistivity ratio model can provide almost similar resistivity ratio. For this reason more specified research is required to consider electrical resistivity ratio between different layers of soil. Using electrical resistivity ratio with considering all related factors, can effectively remove the obstacles due to changing of water content in soil.

REFERENCES


