IMPACT OF WASTE DISPOSAL SITE ON GROUNDWATER QUALITY AT RAFIN-TOFA SOLID WASTE DUMPSITE, KAMPALA, NIGER STATE, NIGERIA

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Abstract

A massive solid waste dumpsite at the outskirt of Minna metropolis was investigated using 2D electrical resistivity imaging (ERI), with the aims of determining the impact of the dumpsite on groundwater quality. By visual observation of solid waste dumpsite, it is found that it consists of various constituents such as paper, organic matter, metals, glass, ceramics, plastics, textiles, dirt, and wood among others. Resistivity data were collected from parallel survey profile lines using a Wenner-Alpha array configuration. Inversion of the data was carried out using 2D regularized least-squares optimization methods with robust (L1-norm) model constraints. Potential zone of leachate infiltration into the subsurface from the dumpsite was identified from the electrical imaging. A synthetic resistivity inverse model was used to discuss and validate the field results. The 2D ERI sections of the model resolve clearly the subsurface lithological variations. Interpretation of the field data showed that 2D ERI technique was effective in delineating groundwater contaminated zones. The vertical and horizontal sensitivity of the 2D Wenner-Alpha array for sub- surface resistivity variations made it possible to determine the position and extent of leachate infiltration into groundwater. The current work demonstrates the usefulness of the ERI technique as a complementary tool for environmental site investigation.

Keywords: 2D, waste, dumpsite, resistivity, leachate, infiltration, Wenner-Alpha, groundwater

Introduction

The Earth's surface which is the troposphere, sits at the interfaces of the solid lithosphere, the gaseous atmosphere, and the watery hydrosphere. Gases, liquids, and solids are exchanged between these spheres in three grand cycles. These cycles include the water or hydrological cycle, the rock cycle and the biogeochemical cycle. The Earth crust is also constantly being altered by geogenic and anthropogenic processes at extremely slow rates in human terms.

Geophysical principles have been used to unravel the dynamic nature of the earth (Rein hard, 2006). Various geophysical exploration methods have been and are used on land surface and beyond to solve a variety of subsurface detection problems (Ameh *et al.*, 2020). Each of these methods measures properties that are related to subsurface lithology and their geologic configurations (Gadallah & Fisher, 2009). The subsurface properties of the earth vary in diverse ways. These include; density, propagation velocity, magnetic susceptibility, electromagnetic wave reflectivity and transmissivity, self-potential, resistivity and induced polarization. These properties are measured using diverse formats. There are three basic ways in which the electrical current can be conducted within the earth, these includes Electrolytic, Ohmic and Dielectric conductions (Lowrie, 2007). In the electrolytic conduction (ionic conduction), the electrical current is propagated through the pores of the rocks or soil saturated with water, containing ions of minerals and dissolved salts. In the Ohmic conduction (electronic conduction), the electrical current is propagated via the crystalline structure of some materials in the rocks, mainly metals. Dielectric conduction has to do with the existence of an alternating electrical field which can cause ions in the structure of insulating materials to have a cyclic change in their positions. Geoelectrical properties are utilized in geophysics to exploit for materials in the subsurface which may be located by their anomalous electrical conductivities (Slater *et al.*, 2010). Resistivity method involves the introduction of electrical current into the ground and the resultant measured potential differences at the surface give an indirect indication of the subsurface resistivity distribution.

Any material that is discarded after its primary use is termed waste. Society produces different types of waste; domestic waste, industrial wastes, mining wastes and radioactive wastes (Ranke, 2001). Liquid or solid wastes, hazardous or non-hazardous wastes infiltrating into groundwater can cause some chemical reactions which may produce substances dangerous to environment & health (Ige, 2013). In the last decade the study area has witness a major increase in waste disposal on uncontrolled disposal sites. Waste disposal is an expensive urban environmental problem. The degradation of water quality is undesirable irrespective of whether it results directly from leachate escaping from the landfill or from geogenic processes (Rowe, 2011; Amadi *et al.*,2017). Leachate is formed when rainwater and runoff percolate through solid waste, leaching out soluble salts and biodegraded organic products. Due to downward Darcy velocity and diffusion, contaminants will migrate from the landfill through soil into the groundwater system (Franz, 1993).

Study Description

This study site is located on the SE of Zungeru sheet 163 which is NW of Minna metropolis (Figure 1.5). It lies within latitude 9°40′22.0″North and 9°41′01.9″North and longitude 6°26′6.7″East and 6°25′53.2″East, it occupies a total area of about 5.3 km^2. The site is located along Maikunkele-Zungeru road. A portion of this site is already been utilized for engineered open waste dumpsites serving the Southwestern part of Minna city. On a general note, all the sites under study are at the outskirt of Minna metropolis with good road network which allow for easy access to the sites.

Topographically the dumpsite area is mostly flat lying, with moderately undulating ridges within the vicinity of Maikunkele urban sprawls of Minna (Figure 1.1). The altitude of the area is about 280 meters above sea level. All streams around the area drain into the River Chanchaga catchment basin. Most tributaries of the River Chanchaga are ephemeral and dry up during the zenith of dry season. The drainage system of the study area is structurally controlled. The drainage pattern of the study area is characterized as dendritic in nature.

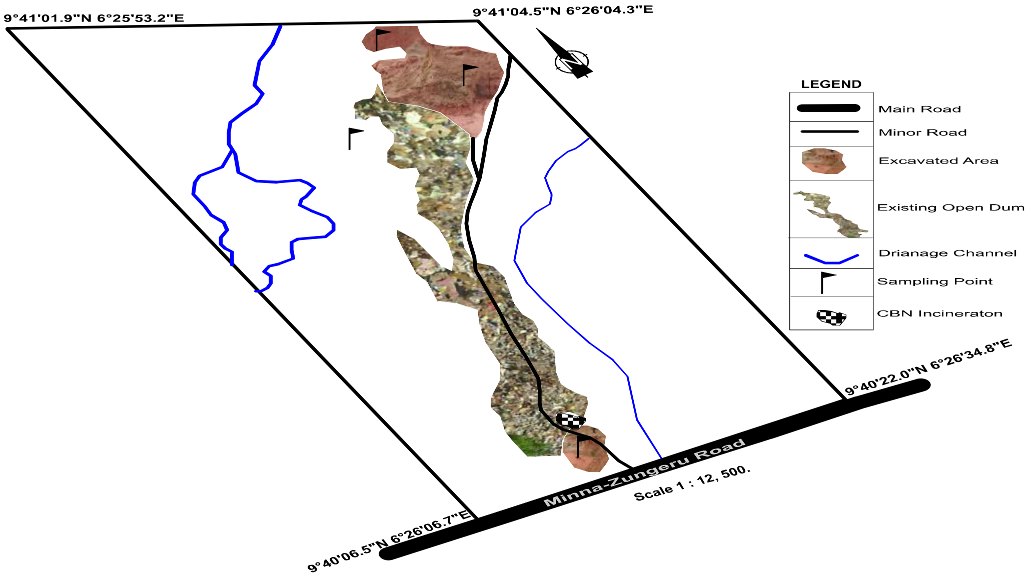

Figure 1.1: Study Area Location

Materials and Method

2D Electrical Resistivity Imaging (ERI) survey using a Wenner-Alpha array as outlined by Loke (1999) was conducted along six parallel profiles within the vicinity of the dumpsite. The selection of the ERI locations was dependent on the availability of areas free of heap of waste as an obstacle. When the conditions to enable the electrodes penetrate the natural soil was allowed, the roll-along technique was applied for getting continuous profile. The apparent resistivity measurements were acquired using ABEM SAS 4000 Terameter equipment. A pre-defined sequence of combinations of four stainless steel electrodes with current electrodes ($C_1 and\ C_2$) and potential electrodes ($P_1 and\ P_2$) for different electrode spacing (a) and data acquisition levels (n) was adopted.

The profile length (L) of the electrical cable spread was restricted 100m with a total of 21 electrodes on a profile line. At the initial series of measurement transverse the spacing in the middle of nearby electrodes (a) at 1a was set at 5m. For the initial measurement, electrodes numerals 1, 2, 3 and 4 represents C_1, P_1, P_2 and C_2. For the following measurement, numbers electrodes 2, 3, 4, and 5 represents C_1, P_1, P_2 and C_2 in that order. This arrangement was sustained till electrodes numbers 18, 19, 20 and 21 represents C_1, P_1, P_2 and C_2 in turn. Eighteen mid-points were established for the first measurement sequence. The entire measurement technique was replicated for 2a, 3a, 4a, 5a, 6a etcetera. Beginning at the first series of measurement 1a, a total number of 18 mid-points were established, and the mid-point decreases by three in successively sequences measured. For a profile of 100m, at 2a, mid-points =15, at 3a=12, 4a =9, 5a=6 and 6a=3 (Figure 1.2). The subsurface resistivity values acquired are arranged in apparent resistivity pseudo-sections which give a qualitative approximation of the subsurface resistivity distribution. An inversion procedure using the RES2DINV software ver. 3.71 (Loke, 2012) was used to generate 2D ERI sections from the apparent resistivity data. RES2DINV uses finite difference method based on the regularized least squares optimization procedure to produce a true 2D synthetic resistivity model is designed to discuss and validate the interpretation of the field data. The software iteratively determines the model blocks (Figure 1.3) resistivity that will closely produce the measured apparent resistivity data (Loke, 1997).

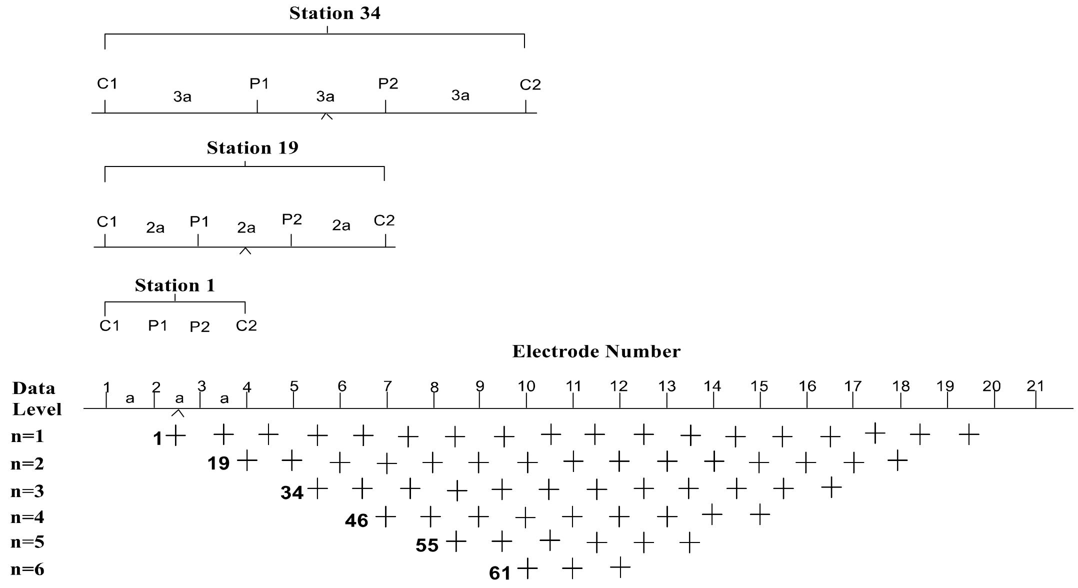

Figure 1.2 Sequence of 2D Wenner resistivity measurement to build a pseudosection (After Loke, 1999).

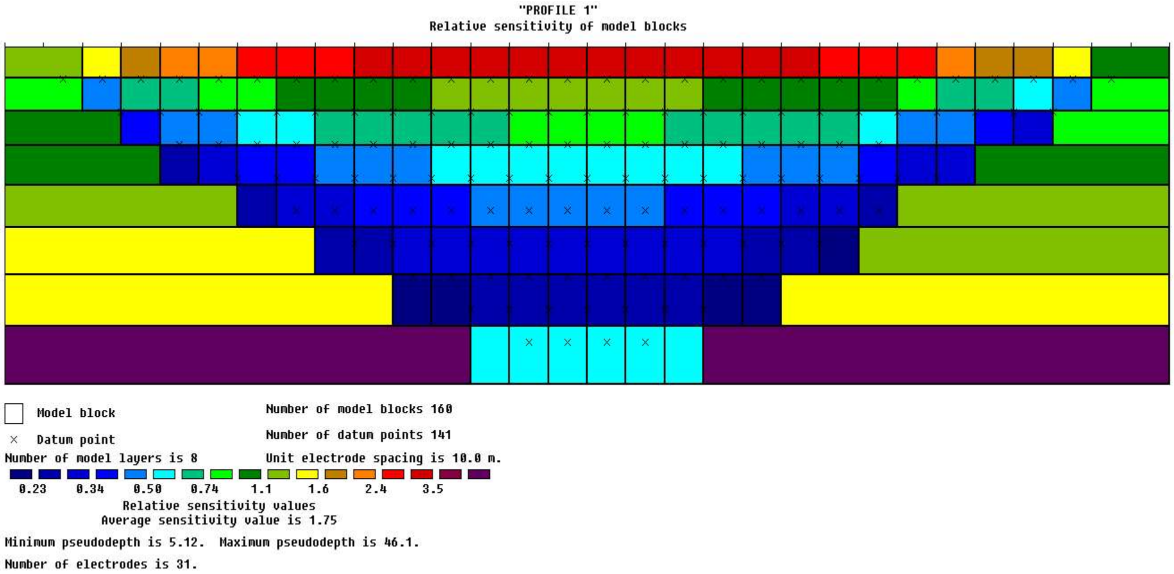

Figure 1.3: Relative sensitivity of the apparent resistivity model block

Results and Discussion

The 2D Earth resistivity imaging obtained along profile 01 is shown in Figure 1.4. The inverse model of this profile shows a clear disparity between low, moderate and large conductive zone within the subsurface. From the surface to about 6 m depth on the profile, the resistivity response is of a moderate range between 13 ohm-m to 41 ohm-m. This is interpreted as unpolluted lateritic soil with a minimal leachate contamination zone observed at 65 m to 70 m on the surface profile distance to the depth of about 6 m. From 0.0 m to 40.0 m distance on the surface profile line, the profile is characterized by low resistivity value range of 2 ohm-m to about 8 ohm-m. This is interpreted as possible polluted zone due to leachate infiltration from the dumpsite. From about 45 m to 100 m on the profile, from the depth of 12.0 m to 19.8 m, the profile is characterized with high resistivity value range of about 70 ohm-m to above 131 ohm-m. This zone is interpreted as unsaturated and unpolluted fresh basement rock.

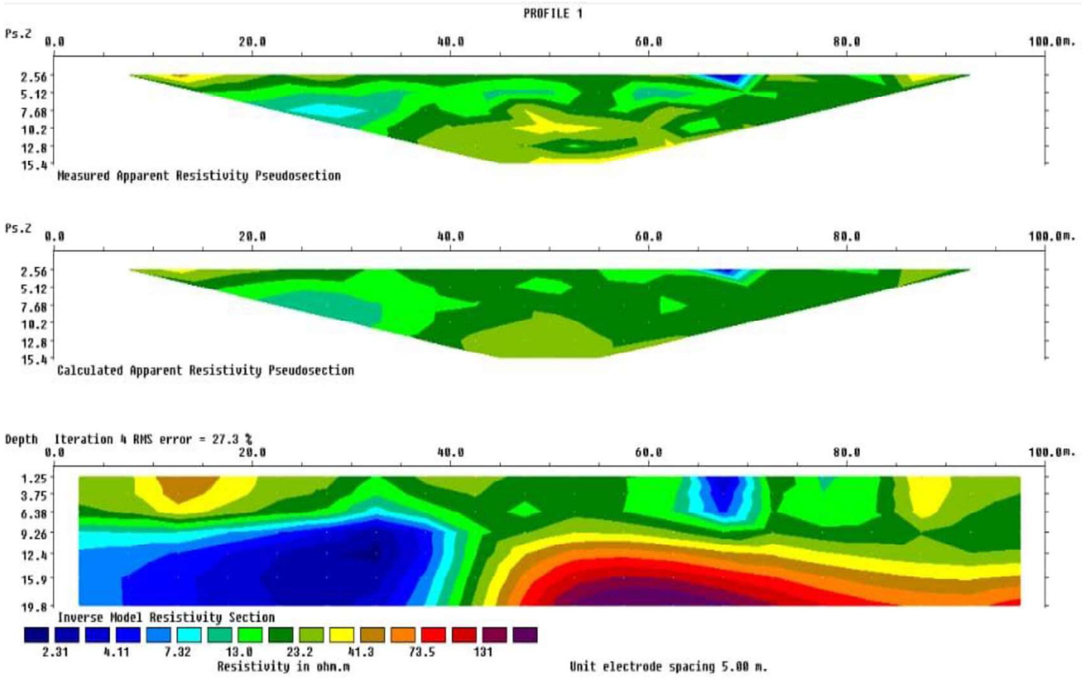

Figure 1.4: 2D Inverse ERI Plot for Profile 01

A more resistive zone representing the fresh basement rock zone with unsaturated waste underlain a much conductive leachate saturated top layer (Figure 1.5). Unfractured basement rock are often less infiltrated due to the competent nature of the materials that defined the rock. Irrespective of the disposal of a range of waste types with differing resistivity were at the site, the 2D ERT model shows relatively little variation within the area of the landfill. It is likely that this may be due to mixing of leachate within the landfill, which has led to the homogenization of saturated waste resistivity.

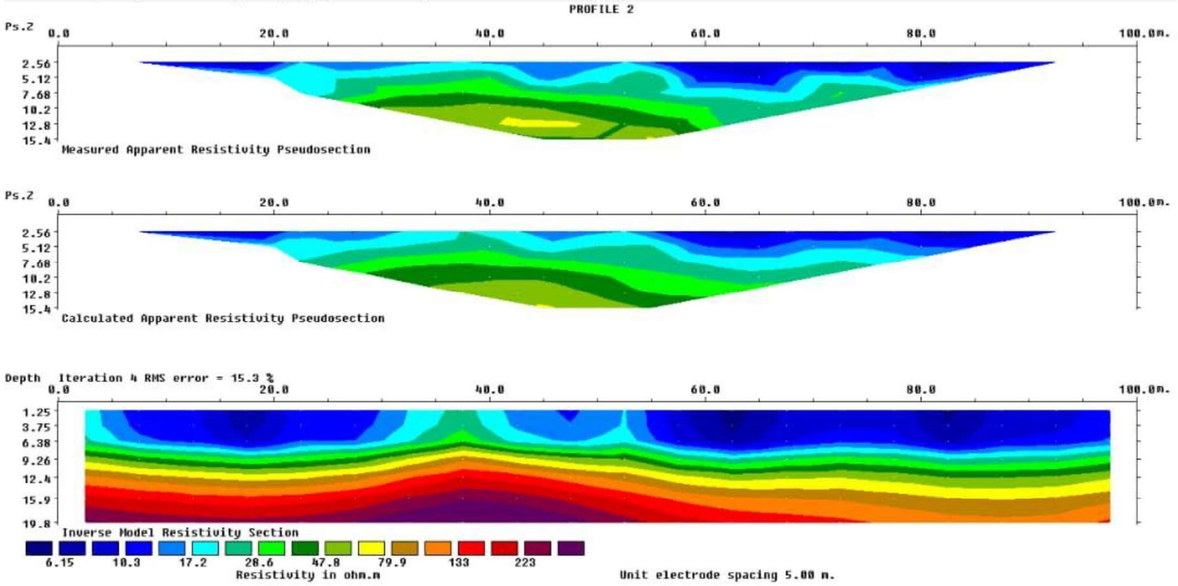

Figure 1.5: 2D Inverse ERI Plot for Profile 02

The model reveals homogenous low electrical resistive zone (< 8.0 Ohm-m to 17.8 Ohm-m) at depth ranging from 1.25-19.8 m across the model (Figure 1.6). This reflects a leachate infested shallow subsurface. From the depth of 12.4 m - 19.8 m across the profile the moderately high resistivity response (87.9 Ohm-m to >131.0 Ohm-m) of this zone on the profile is observed reflects an unsaturated subsurface lithology. It is evident that this area is free from leachate contaminations.

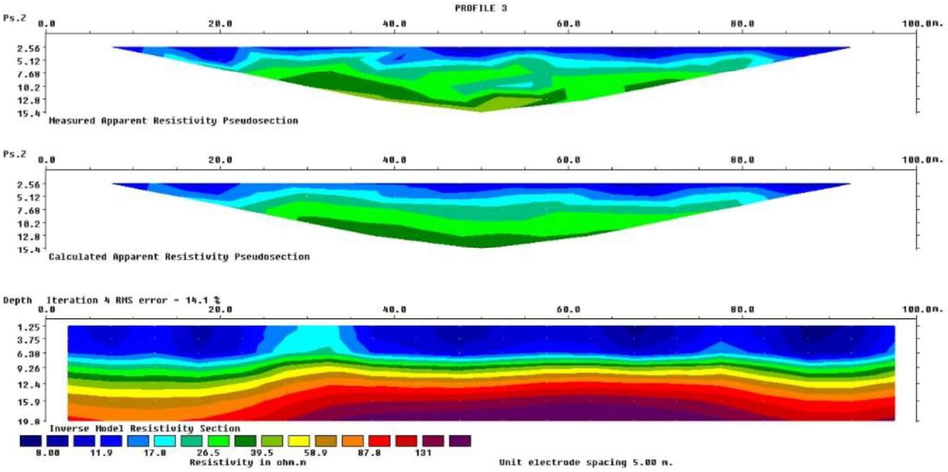

Figure 1.6: 2D Inverse ERI Plot for Profile 03

The ERI generally shows lower resistivity zones from about 6 m to 16 m depth of the profile (Figure 1.7). This area on the profile is characterized with low resistivity value range of less than 4 ohm-m to about 15 ohm-m indicating that this zone is highly conductive. The zones of low resistivity as expressed in the middle layer extend to both end sections of the profile; this zone is identified as anomalous zone with the greatest potential for association with leachate infiltration. The shallowest exposed bedrock is found around 25 m to 40 m, 50 m to 55 m and 85 m to 90 m on the surface of the profile, with resistivity values ranging between 88 ohm-m to above 204 ohm-m. This layer represents weathered to moderately weathered basement rock, as observed on the surface.

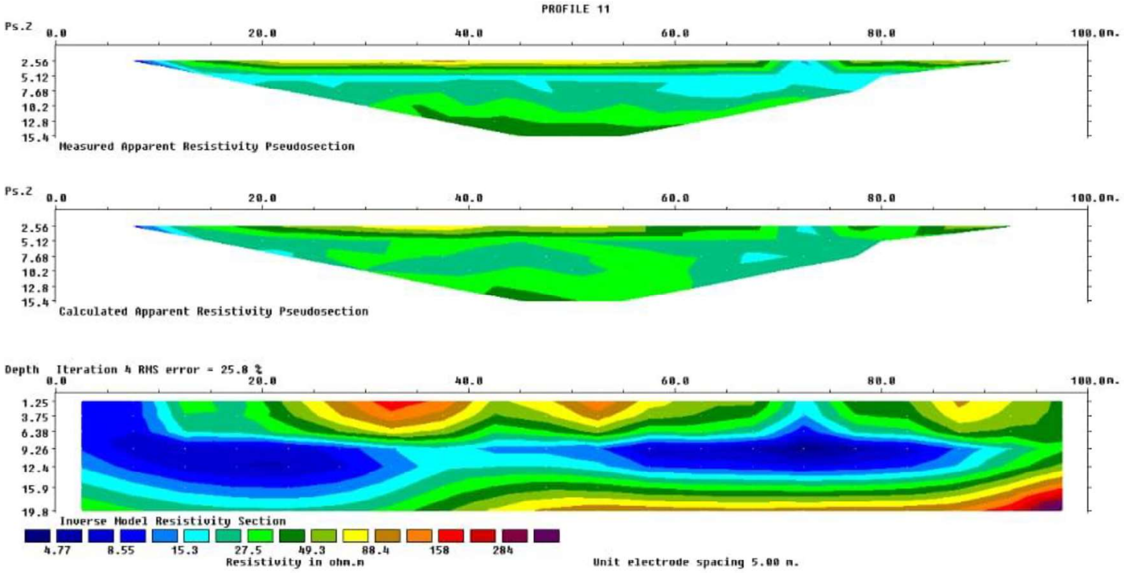

Figure 1.7: 2D Inverse ERI Plot for Profile 04

Conclusion

Electrical resistivity imaging surveys have been undertaken at an un-engineered waste dumpsite. Data from these surveys have been modeled using 2D inversion algorithms. By visual observation of the solid waste dumpsite, it is found that it consists of various constituents such as paper, organic matter, metals, glass, ceramics, plastics, textiles, dirt, and wood among others. The ERI results provide 2D subsurface images with good spatial resolution along the survey profile. From the interpretation of the 2D inverse models, it was established that low resistivity zones below the waste dumpsite are indicative of leachate migration into the groundwater that is contained in the bedrock. The disposal of waste on the dumpsite is a potential threat to the contamination and pollution of groundwater resources within the vicinity of the dumpsite and beyond.

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