Integrated Geophysical and Geochemical Methods for Environmental Impact Assessment of a municipal dumpsite in King Williams town, Eastern Cape, South Africa

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Abstract

Electrical resistivity surveys and physico-chemical analysis were carried out on a landfill site to assess the impact of leachate pollution on groundwater quality. 2-D resistivity imaging and vertical electrical sounding were done across three profile lines (A, C and E) on the landfill. Physico-chemical properties of water samples from the leachate pond and two boreholes, BH1 and BH2, located at 80m, 130m and 200m respectively from the edge of the landfill were analysed. The results revealed that the surrounding soil and groundwater have been contaminated to a depth of 75m, well within the aquiferous zone. The soil stratigraphy showed high permeability which has significantly influenced the high level of infiltration of contaminants. High EC and TDS values observed in the groundwater samples indicate a downward transfer of leachate in to the groundwater. The difference in EC and TDS values for BH2 and BH1 (9892µS/cm/ 4939 mg/L and 6988 µS/cm/ 3497 mg/L respectively), indicated that concentration of contaminants decreased with increase in distance from the center of the landfill. Groundwater flow direction is towards the south-western part of the landfill along the direction of flow of the leachate, towards the built–up areas**.** In the absence of a leachate recovery system, the uncontrolled accumulation of leachate over time at the landfill over time, will pose a great threat to the groundwater quality. There is need to improve waste management practices in the study area to mitigate the effects of pollution.

Keyword: Landfill, Leachate, Groundwater, Electrical resistivity, contaminants

Introduction

In the South African context, waste is any undesirable or superfluous by- product of emissions or residue of any process or activity which has been discarded, normally accumulated or stored for the purpose of discarding or further processing through treatment (DEAT, 2001). Waste disposal dumps are common phenomena especially in industrial and highly populated cities where dumps are generated in tons on a daily basis and thus becomes a more important and efficient way of maintaining a clean environment in urban settings. In developing countries, unregulated landfills are commonly located adjacent to large cities, releasing harmful contaminants into a leachate and thereby polluting underlying aquifers (Mcfarlane *et al.,* 1983).

Municipal solid waste landfills/dumpsites have been identified as major environmental problem when located at high proximity to inhabited areas (Mor *et al.,* 2006). In most cases, dumpsites were originally located far from urban areas, but increasing expansion due to ever- increasing population and urbanization have resulted in development of land adjacent to dumps as either public buildings or residential houses. Humans are therefore exposed to a range of environmental hazards but particularly percolation of polluted leachate into the shallow aquifers which is the main source of drinking water in developing countries. In most cases in developing countries, disposal sites are not properly planned. Thus, periodical environmental auditing exercises become an inevitable task to ascertain the conditions of waste site with view to gain the knowledge of possible interaction between its dumps and the environment. The environmental challenges of waste dumps include: contamination of groundwater by pollutants generated by the dumps; migration of the pollutants away from the site via groundwater, surface water, or air routes; a combination of these, fire and explosion at the site, and direct contact with hazardous substances (Dimitriou *et al.,* 2008).The most common approach for investigating leachate plume migration from a dumpsite is to drill a network of monitoring wells around the site, these wells are however expensive to construct and maintain (Bernstone and Dahlin, 1997). Additionally, limited information on subsurface hydrogeology and/ or budget limitations frequently compels the sighting of monitoring wells at random. This approach is both technically and economically inefficient because monitoring wells give point measurements, whereas leachate plumes tend to migrate along preferential pathways, determined by subsurface heterogeneity" (Bernstone and Dahlin,1997). Therefore, even with a network of closely spaced monitoring wells, the risk that some contaminants could go undetected remains high. For these reasons, there is widespread interest in applying non-invasive and relatively inexpensive geophysical techniques, such as electrical resistivity imaging (ERI), electromagnetic methods, electrical conductivity (EC) logging, and seismic surveys, as means for mapping the occurrence and movement of leachate and for facilitating decision making regarding the location of monitoring wells (Busell and Lu, 2009; Butler *et al.,* 1999). This article reports the application of the electrical geophysical method involving the vertical electrical sounding (VES) and 2D profiling (Dipole-Dipole) techniques to map possible leachate distribution and migration processes from the landfill site in King Williams Town, Eastern cape, south Africa. The two techniques are based on the response of underground geologic features to a current flow field and are capable of detecting different subsurface units on the basis of the contrasts in electrical resistivity of earth materials (Zume *et al*., 2006). They are fast and cost effective. The former measures the vertical variations in resistivity of the subsurface earth while the latter involves the measurement of lateral and vertical variations of the apparent resistivity of the subsurface earth. The integrated use of geophysical and hydro physiochemical methods are often recommended in landfill studies (Bensoil *et al.,* 1983, Mathias *et al.,* 1994, Kayabali *et al.,* 1998). The specific objectives of this study, therefore, were to delineate groundwater contamination, identify lithologic layers, locate possible leachate plumes, and assess the risk of groundwater pollution as a result of the dumpsite. This is with the view of assessing the risk associated with the groundwater abstraction in the area. The outcomes of this study will help appropriate decision-making on how and where to abstract underground water and remediation methods to adopt.

Location of the Study Area

The Eastern Cape Province lies on the south-eastern seaboard of South Africa (Figure 1). It is the second largest Province with an area of 169 580 km², representing 13.9% of South Africa's total landmass (Statistics South Africa, 2003) Waste management services in the Eastern Cape rely heavily on landfills for the disposal of waste, which account for the majority of licensed waste facilities. This is despite the existence of a range of alternative disposal technologies, (SAEO, 2012). Waste disposal facilities like landfill sites, waste storage facilities, recycling facilities, materials recovery facilities and waste transfer facilities, are crucial indicators in determining where municipal solid waste material ends up.

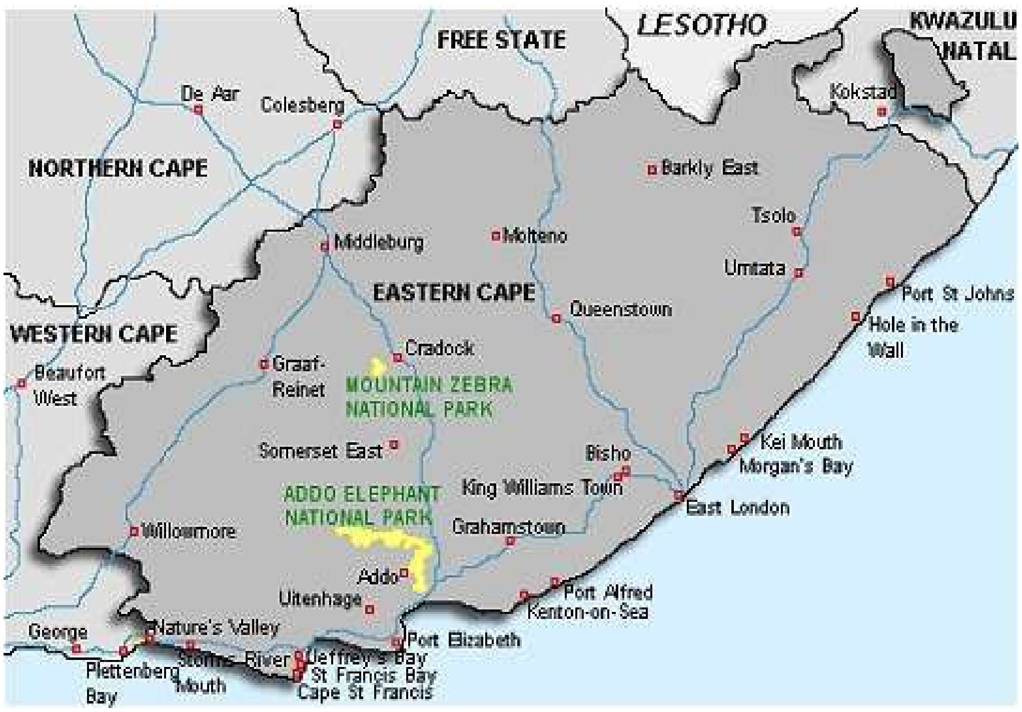


Figure 1: Map of Eastern Cape neighbouring communities

Based on the findings of the investigation (DEAT, 2001), it was revealed that there were 101operational waste disposal sites in the Eastern Cape Province, 74 sites reported from questionnaires, 7 sites from permitting records and 20 sites estimated by projection. It is estimated that only 8% of landfills in the Eastern Cape Province complied with DWAF minimum requirements (DWAF, 1998), 54% could potentially comply and 38% are currently unacceptable. Of the 37 landfill permits applied for, 43% had been granted. Only 19% of landfills in the Eastern Cape Province are permitted (DEAT, 2001).

The Buffalo City Metropolitan Municipality which is the catchment area of this research owns and operates two licensed landfill sites: one at King Williams Town, and the other called Round Hill at Berlin. The landfill site in King Williams Town is located around West Bank Primary School between longitudes27.394 – 29.3915 ° E and latitudes 32.8525 – 32.8495° S, covering an area of about 0.30km$^{2.}$ (Figure 1a – 1d). The landfill is an abandoned quarry in which landfilling started in 1983 by open dumping. The land fill receives a mixture of municipal, commercial, and mixed industrial wastes with hazardous and non-hazardous constituents. These often go into the landfill unsorted and releases large amount of gases, particles, and leachate into the surrounding soil and ground water.

Figure 1a: Dumpsite surface composition viewed from the South

Figure 1b: Dumpsite surface composition viewed from the East

Figure 1c: Groundwater monitoring borehole located south of the landfill

Figure 1d: Leachate pond located south-west of the landfill

Water containing dissolved contaminants from the landfill is collected and contained in the leachate pond. There are two groundwater monitoring borehole located south and southeast of the site respectively (Figure 2). The landfill site is characterised by steep topography with the direction of dip in the Northeast- Southwest direction

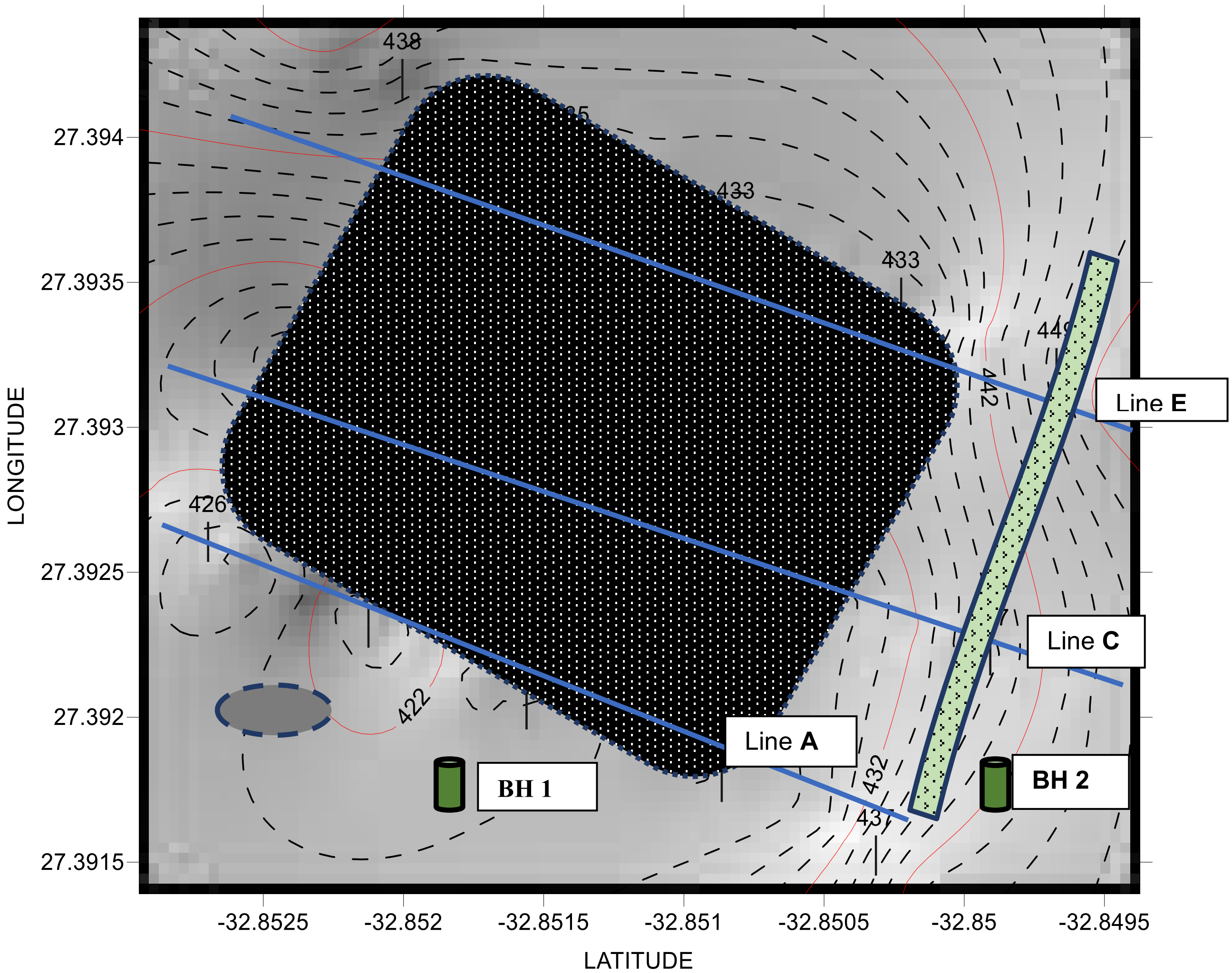
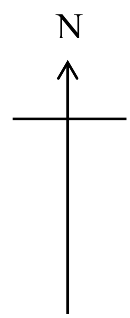


Figure 2: Data acquisition map of the area

KEY

-------	Minor contour lines
	Major contour lines
	Leachate pond
	Boreholes
	Traverse lines
	Active Landfill area
	Access road



Geology of the Study Area

The study area is geologically setting within the Beaufort group, Karoo Super group which is the dominant stratigraphic sequence in the Eastern Cape, South Africa. It consists of a sequence of units, mostly of non-marine origin, deposited between the late Carboniferous and early Jurassic, a period of about 120 million years ago (Schulter, 2008). The strata consist mostly of shale and sandstones (Hamilton and Finlay, 1928). Other groups under the Karoo Super group include;

The Dwyka Group; This is the earliest and lowest of the Karoo Super group of sedimentary deposits. They consist of diamictite, varved shale and mudstone. (Schulter, 2008). The total thickness of the group is about 600-700m (SACS, 1980)

- Ecca Group; This consist largely of shale and turbidites
- Beaufort Group; It is composed of a monotonous sequence of shale and mudstone with some interbedded sandstone (Trustwell, 1977)
- Stormberg Group; Stromberg group contains fossil remains with a remarkable array of insect and plant fossil found in the strata
- Drakensberg Group; forms the uppermost layer of the Karoo super group, forming about 1400m of the great escarpment. It consists mainly of dolerite sills at various depths (Trustwell, 1977).

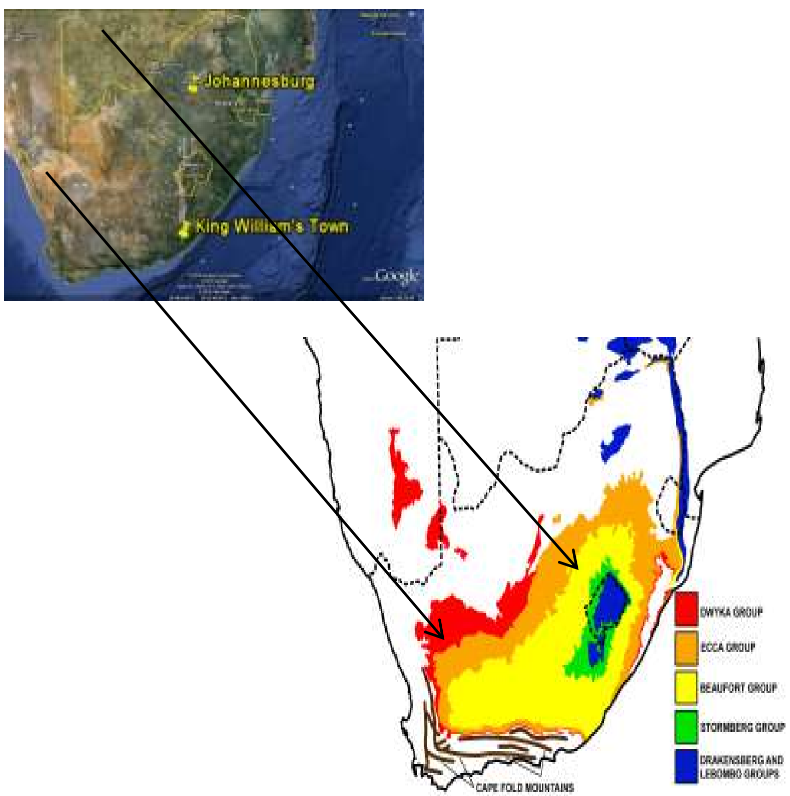


Figure 3: Geological map of the Eastern Cape Province

The local geology of the of the landfill site consists of superficial deposits of alluvium, the Balfour formation made up of grey to reddish mudrocks intruding into fine grained sandstones. The bedrock formation is made up of dolerite sills which are more pronounced at the southern parts of the landfill site.

The lithological formations of the landfill site are characterised by low porosity and permeability, consequently affecting the hydraulic properties of aquifers around the landfill site.

Materials and methods

The electrical resistivity method and physico-chemical analysis of water samples from the leachate pond and boreholes within the vicinity of the landfill was carried out to investigate possible contamination to groundwater by leachate from the dumpsite. Two dimensional

(2-D) and vertical electrical sounding (VES) were carried out using a multi-channel resistivity meter (SYSCAL –PRO). Three parallel profiles (A,C, and E) were ran at inter – profile spacing of 100 meters and a profile length of 360 meters in the East-West direction.

(Figure 2). There is an access road about 10meters wide on the eastern flank of the site which runs in a North – south direction. Measurements were made at increasing offset distance (a-spacing) of 10 meters which also runs over the access road in order to image the subsurface around the immediate vicinity of the landfill site.

The measurement protocol is computer controlled using a laptop microcomputer together with an electronic switching unit used to automatically select the relevant four electrodes for each measurement. Selection of minimum electrode spacing was based on the target (Leachate). Werner electrode configuration was chosen for its relative sensitivity to vertical changes in the sub- surface resistivity below the centre of the array and for its ability to resolve vertical changes that is. horizontal structures (Loke, 2004). The measured 2 – D resistivity data were processed using RES2DINV inversion software (Loke, 1999). The program uses the least – squares inversion scheme to minimize the difference between the calculated and measured apparent resistivity values, by iterative process. The results are displayed as inverted sections of the true resistivity of the subsurface rocks (Figures 4 a - c). The sections were subsequently, visually inspected to delineate areas of anomalously high or low resistivities related to subsurface structures.

The Vertical Electrical Sounding (VES) field data were measured using the Schlumberger array which also measures simultaneously with the 2-D resistivity data on the multi-channel resistivity meter and the interpretations were also done with the RES2DINV program. In this case, this computer program automatically generates model curves using initial layer parameters (resistivities and thickness) derived from partial curve matching of the field curves with standard curves, and calculates the true layer parameters of the geo-electric section. The results are presented in terms of the resistivities, thicknesses and depths of the geo-electric section for the VES positions (Figures 5a-c)

In-situ data which reflects the physico-chemical properties of the water samples were also taken. The leachate pond is about 80 meters from the edge of the landfill while the two boreholes BH1 and BH2 are at a range of 130 -200 meters from the landfill respectively. Parameters of the water samples such as temperature, Ph, Electrical conductivity, total dissolved solids, salinity and turbidity were measured using the PHARO-100 spectrophotometer. This is a device that measures chemical or physical properties of samples by influencing a substrate to determine the presence of possible contamination and the degree. The degree of contamination will be determined by juxtaposing the results obtained with threshold values which are usually World Health Organization (WHO) standards.

Results and Interpretation

2-D Resistivity Imaging

The resistivity distribution derived from the 2-D inversion in the West – East direction is given in Figures 4a –c.

Profile A;
This profile lies at about 30m from the south edge of the landfill and point elevation of 420m. The low resistivity zones with resistivity between1.59-14.4 ohm-m (deep blue) occurs at surface points between 120-230m, around the mid-point of the section. This low resistivity values show an infiltration of leachate into the subsurface to a depth of about 47m. This is interpreted to be mudstones and sandstones saturated with leachate. The high resistivity zones (brown to purple) with resistivity values between 1172- 3520 ohm-m at the flanks of the section indicates non-conductive, impermeable layer formed by part of the road sub-base to the east and doleritic bedrock to the west. Sandwiched between these zones of low and high resistivity anomaly is an intermediate zone (light green to yellow), showing rock materials having varying moisture content and composition.

Profile C;
Profile C is located at about 100m from profile A around the center of the landfill site at point elevation of about 415m. The low resistivity zones (< 7.39 ohm-m) are more pronounced on this profile. The most dominant of this low resistivity anomaly occurs at 30-230m surface points at a depth of 75m to the west of the profile. This is interpreted as mud and sandstone saturated with contaminant leachate. The shape of the leachate plume showed movement of low resistivity materials leaking towards the south-western edge of the landfill. A major reason for this is the dipping topography between line A and C. Two high resistivity anomalies were identified on this profile - a high resistivity zone at surface points 240-290 m and depth of 45m to the east of the profile (light brown colour). This is interpreted as landfill gases, probably methane, ammonia or carbon dioxide, released by the decomposing leachate materials. The

high resistivity zone to the west of the profile shows the continuation of the bedrock from line A.

Profile E:

This lies towards the edge of the landfill at 200m and 100m from profiles A and C respectively. The low resistivity is less pronounced when compared with the other profiles. This is due to the higher point elevation of the profile (450m). The natural soil conditions are returning at this line which possibly implies escape of chemical components into the atmosphere with increased distance from the center of the landfill. There is a reduced depth of contaminant pollution (35m).

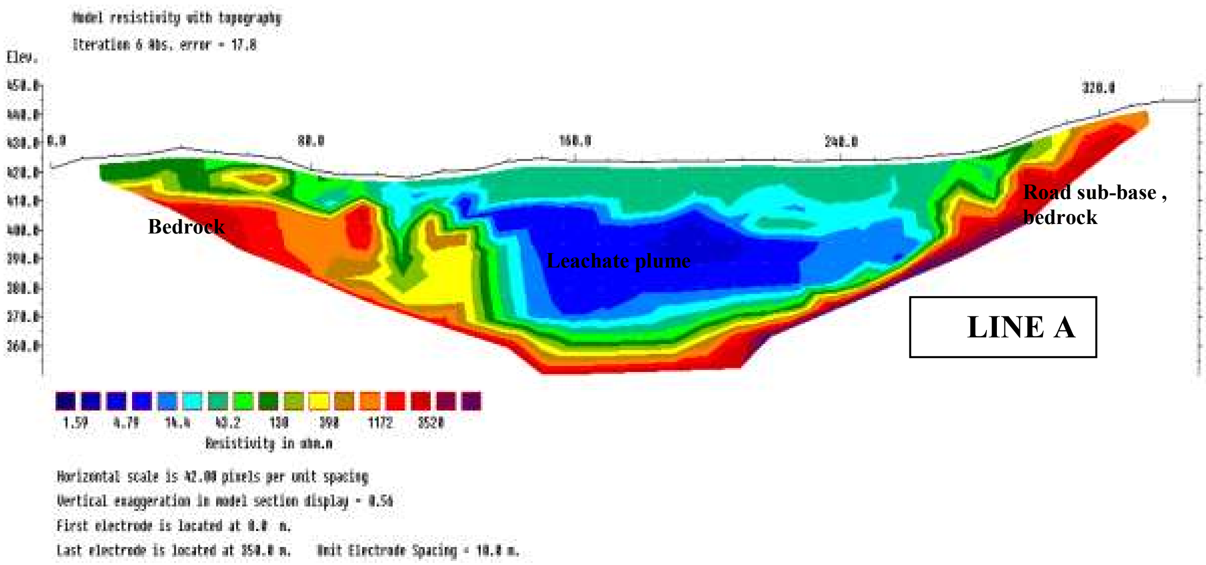


Figure 4a: Dipole-dipole resistivity data along Line A

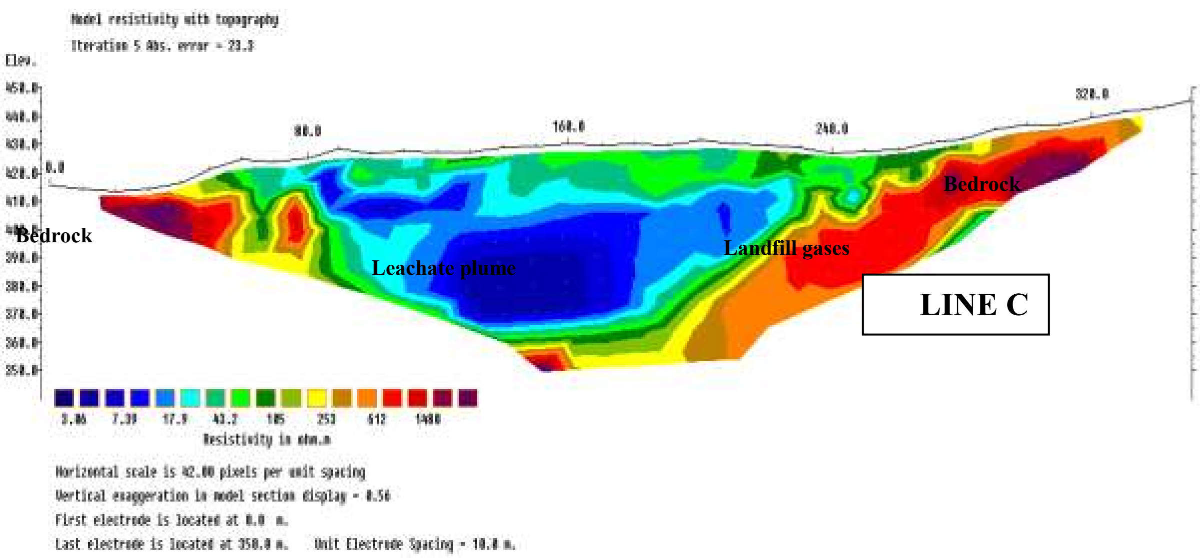


Figure 4b: Dipole-dipole resistivity data along Line C

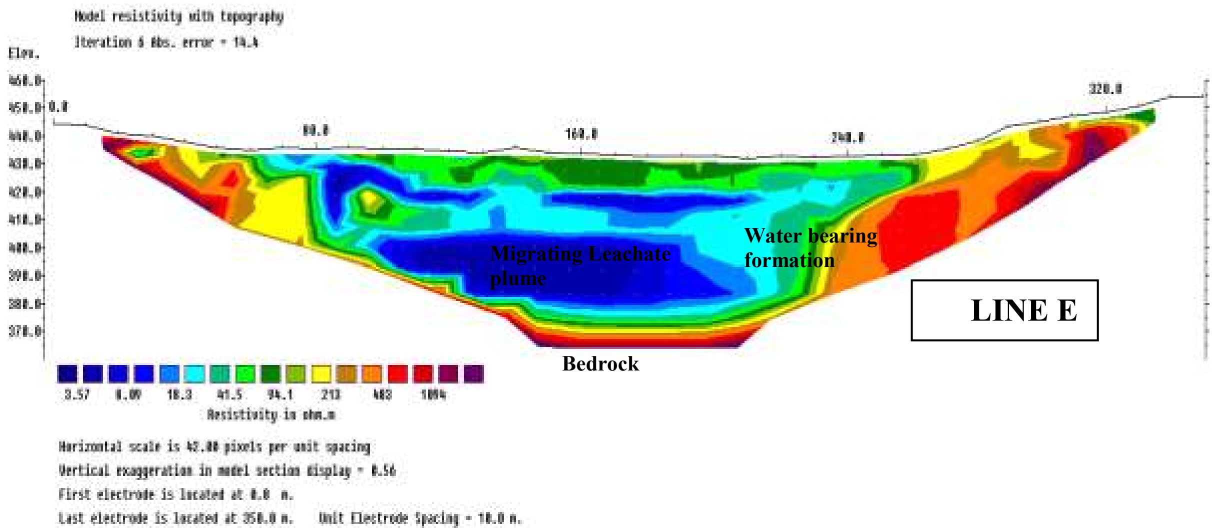


Figure 4c: Dipole-dipole resistivity data along Line E

Vertical electrical sounding (VES) Interpretation

Results of the VES data were modelled to generate geoelectric sections along the profile lines as shown in Figure 5a – c.

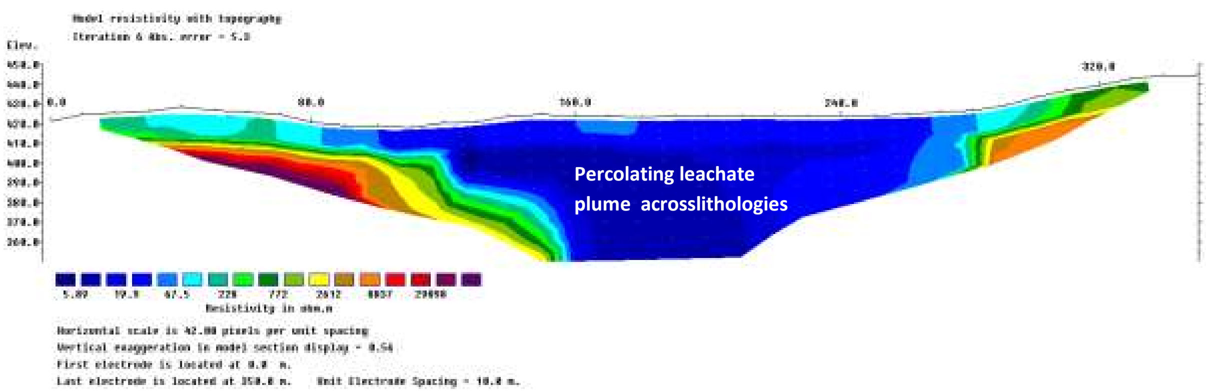


Figure 5a: Schlumberger array resistivity data along Line A

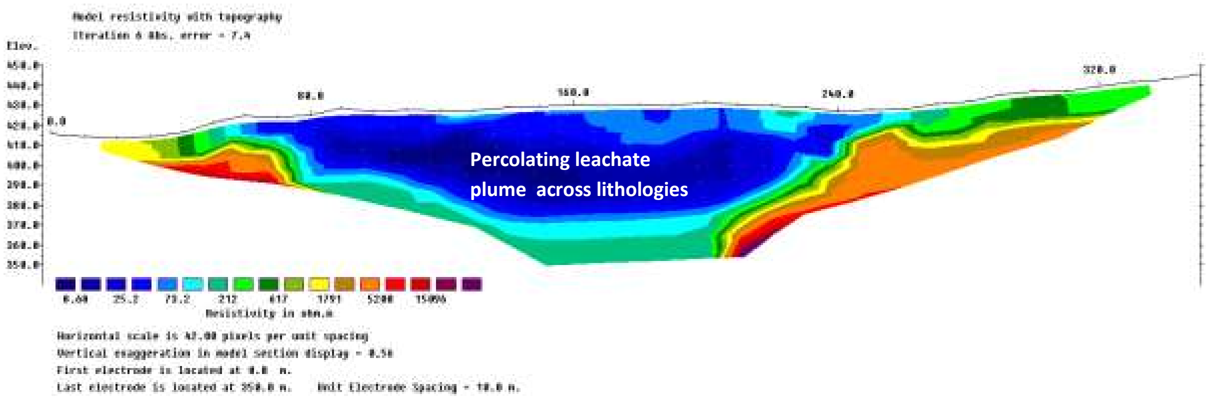


Figure 5b: Schlumberger array resistivity data along Line C

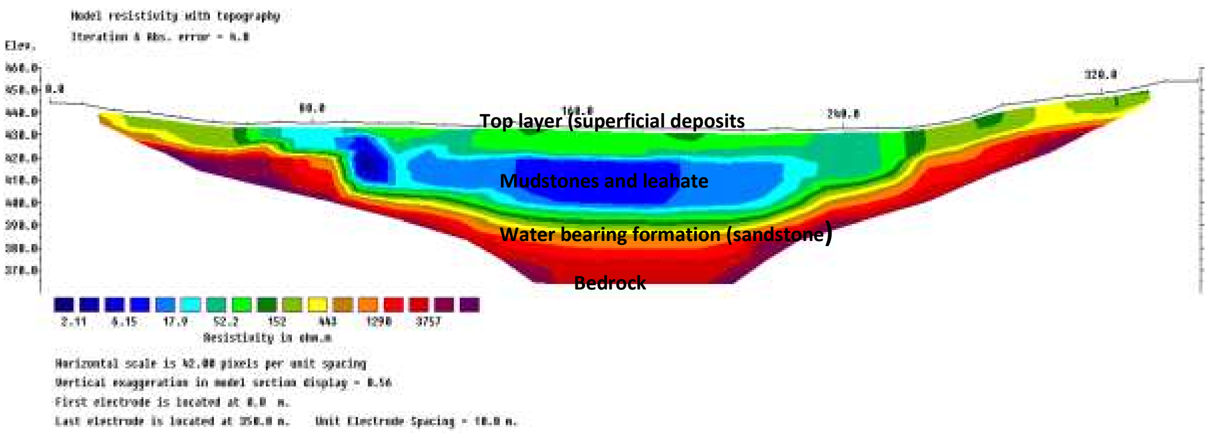


Figure 5c: Schlumberger array resistivity data along Line E

Figures 5a- c showed a 4-layer geoelectric section with varying thicknesses and resistivity across the profile lines. The composition of the lithologic layers has been considerably altered by the percolating leachate. The underlying water bearing formation is also not spared from the contamination effects (Figures 5a and 5b).

Across line E, towards the northern edge of the landfill, contamination effects were not as pronounced as the other two profiles. This is as a result of the increasing distance from the center of the landfill and higher point elevation as compared to the other two profiles (Figure 5c). from this profile the top layer, consisting mainly of superficial deposits has an average resistivity of 52-152 ohm-m and thickness between 7-10m. The underlying mudrock has an average resistivity of 6.5 -17.9 ohms–m. the low resistivity values are due to the permeating leachate plume. The average thickness of this layer is 25-30m. The water bearing sandstone formation underlying the mudstones has an average resistivity of 152-443 ohm-m and thickness of about 15-20 m. the depth to the bedrock layer is estimated to be about 85 m.

Hydro-physicochemical analysis

Many authors have noted that, besides the vertical in- filtration of leachate from the solid waste, the hydro- logical groundwater flow also play a prominent role in contaminant distributions beneath the subsurface of a landfill or dumpsite, (Pastor and Hernandez, 2012; Ahel et.al 1998). This accounts for the contamination of groundwater aquifer not directly or vertically located on dumpsites or landfills across the globe.

Water samples from the leachate pond (LP), having an area of about 20m^2, located south-west of the landfill and two boreholes (BH1) and (BH 2), located at the south and south-west of the landfill with depths to the top of the water column of 2.5m and 1.5m respectively were collected and analysed on the site for their physico-chemical properties using the PHARO-100 spectrophotometer. The obtained results were then compared with world health organization (WHO) standards (WHO, 1997), to determine the degree of contamination of the water samples. The summary of the results is given Table 1.

Measurements of the physico-chemical properties of the water samples were made at an average temperature of 25^{0}c. pH. Of groundwater samples from the boreholes ranged from 6.87 – 7.47 while the leachate pond has a pH of 7.65. These values are within the limits of the WHO standard for water. The low salinity of the water samples is as a result of the freshwater nature of their source.

However, specific conductance of the samples showed high ion concentration well above the permissible limits. This is influenced by the presence of inorganic dissolved solids such as chloride, nitrates, phosphates etc. TDS values ranged from 3497 -4939 mg/l in the groundwater samples. This is above the threshold for potable water, while the leachate pond has the least TDS of 3298 mg/l. A possible reason for this is due to an increase in the percolation of leachate with depth. High TDS values produce toxic effect on living organisms through high alkalinity and hardness thus causing living cells to shrink. The oxidation reduction potential which is a measure of the cleanliness of the water samples showed positive values for the three water samples collected. A direct implication of this is an increase in the oxidizing properties of the samples, thus making them unfit for consumption.

Discussion of Results

Results of the 2-D resistivity imaging and physico- chemical analysis showed the presence of contaminants in the groundwater systems due to the landfilling. The leachate generated from the landfill has maximum impact on the groundwater quality in the locality. The soil stratigraphy being predominantly mud and sandstones has high permeability and this has significantly influenced the high level of infiltration of contaminants into the water bearing formation to a depth of 75m. High resistivity values encountered indicated the presence of non-conductive waste materials and the road sub-base towards the east of the profiles.

The very high electrical conductivity and total dissolved solids (TDS) values observed in the groundwater samples suggests a downward transfer of leachate into groundwater. The difference in electrical conductivity and TDS values for BH1 and BH2 indicates that the concentration of the contaminants normally decreases with increase in distance from the center of the pollution source.

In the absence of a leachate recovery system, the uncontrolled accumulation of leachate over time at the landfill site will pose a great risk to the groundwater quality. This will be further compounded by the steep topography of the landfill base which showed groundwater movement in the south-west direction as water moves from regions of high altitude and concentration towards the built–up areas around the landfill which are lying in the region of lower concentration and altitude.

Table 1; Physico-chemical properties of water samples from the landfill site

PARAMETER	BH2	LP	BH1	WHO,2007
Ph voltage (mVpH)	-34.6	-79.7	-69.4	-
pH (pH)	6.87	7.65	7.47	6.5 –8.5
Oxidation-Reduction Potential (mVORP)	104.1	58.7	73.1	0- -400
Electrical conductivity EC (µS/cm)	6988	6580	9892	500 – 5000
(µS/m^{A})	70.36	66.49	99.84	5 – 50
Molar conductivity(mΩ^{-}cm)	0.0001	0.0002	0.0001	-
Total dissolved solids (TDS) (mg/L)	3497	3298	4939	500
Salinity (PSU)	3.83	3.60	5.55	2- 42
Surface tension(σt)	0.0	0.0	1.1	
Temperature (℃)	25.35	25.45	25.50	25
Pressure (psi)	13.758	13.758	13.758	
Dissolved oxygen (DO) (mg/L)	0.91	0.63	7.24	
Turbidity (NTU)	19.4	2.46	1.46	

Recommendations

The impacts of landfilling action on biological constituents and geotechnical properties of the underlying soil have not been considered in this study. It is therefore recommended that detail studies focusing on these aspects, as a complement to this work should be carried out. However, based on the negative impact already identified by this study, a total closure of the site and evacuation of the waste is also recommended. This is in addition to a suggested improved environment-friendly waste management strategy.

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