GROUND CONDUCTIVITY AND MAGNETIC SUSCEPTIBILITY MAPPING OF MUNICIPAL SOLID WASTE DEPOSITS: A CASE STUDY OF THE ASAWASE WASTE DEPOSIT SITE

by

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Declaration

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

Leachate resulting from the seepage of rain water into waste deposit can infiltrate and pollute the water table. The areas near the Asawase waste deposit site have a greater possibility of groundwater contamination because of the potential pollution sources of leachate originating from the solid waste deposit. Magnetic susceptibility and electrical conductivity measurements were carried out on six (6) traverse lines at the Asawase waste deposit site to evaluate possible infiltration of leachate flow. The magnetic susceptibility results showed that the central and south-eastern part of the area recorded very high concentration of ferrimagnetic materials in the top 100 mm of the land surface (713-920 $\times 10^{-6}$ SI). There are also traces of high probable ferrimagnetic concentrations in the north-eastern end. Results from the apparent electrical conductivity indicate that the moderate electrical conductive zone at a depth of 30 m underlying a high electrical conductive zone at a depth of 7.5 m is mapped in the north-eastern part. These two zones are underlaid by higher electrical conductive zone at a depth of 60 m. The subsurface of the east through to the south-eastern part of the area lies in a region of low to moderate apparent electrical conductivity and the direction of leachate flow is in the NE direction and very severe at a depth of 45 m.

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List of Symbols and Acronyms

μ and μ_o	Magnetic permeability of medium and free space
σ	Conductivity of the medium
X_m	Magnetic susceptibility
ε	Dielectric permitivity
π	pi
δ	Skin depth
EM	Electromagnetic
$FDEM$	Frequency domain electromagnetic
$TDEM$	Time domain electromagnetic
HD and VD	Horizontal dipole and Vertical dipole
M	Magnetisation
E	electric field intensity vector
H	Magnetic field intensity vector
B	Magnetic flux density vector
J	Electric current density vector
q	charge of a particle
H_p	Primary electromagnetic waves
H_s	Secondary electromagnetic waves
$HLEM$	Horizontal loop electromagnetic waves
$RF-EM$	Radio frequency electromagnetic waves

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CHAPTER 1

INTRODUCTION

Pollution of the environment from solid waste landfill is one of the main concerns to both environmental scientists and the individual citizens. Solid waste landfill (SWL) inevitably generates dangerous chemicals and these pollutants (chemicals) reach their surroundings such as soil, groundwater resources, and even the ambient air, because of environmentally unacceptable disposal of solid waste, or failure of lining system in the waste deposit sites. The issue of these pollutants if left unattended to can cause adverse impacts on the environment and to public health and property (Wildung and Zachara, 1981). Human activities pollute fragile systems by modifying their quality to such an extent that subsequent use becomes restricted (Beatriz et al., 1998).

The extent of pollution in the environment is dependent on the quantity and quality of the water that percolates through the landfill and reaches the surroundings. Leakage from municipal solid waste deposits is generally associated with high ion forming contaminants concentrations and hence very low resistivities. This makes geoelectrical imaging techniques particularly interesting for mapping the three dimensional extent of contamination around landfills (Bernstone and Dahlin, 1999).

Increasing amount of municipal solid waste emanating from residential, commercial and industrial areas, together with changing nature of waste over time, have led to the degradation of the quality of the environment. Kjeldsen et al. 2015 reported that landfills receive a mixture of municipal, commercial, and mixed industrial but exclude significant amounts of concentrated chemical waste. Landfill leachate generated from solid waste may be characterized as a water-based solution of four groups of contaminants: dissolved organic matter (alcohols, acids, aldehydes, short chain sugars etc.), inorganic macro components (common cations and anions including sulfate, chloride, iron, aluminium, zinc and ammonia), heavy metals (Pb, Ni, Cu, Hg), and xenobiotic organic compounds such as halogenated organics (such as polychlorinated biphenyl dibenzodioxins, dioxins etc.).

Municipal solid waste disposal in Ghana is particularly a growing problem in urban areas such as Accra, Kumasi, Tamale and Takoradi. Environmentally sound management and increasing difficulty in treating organic waste is of major concern in these cities. Available statistics indicated that the Kumasi Metropolis generates about 1200 tonnes of solid waste a day with Kumasi Metropolitan Assembly, the agency responsible for waste management, only able to collect about 70% of the solid waste generated in the metropolis (Ghana EPA, 2010). The rest of the waste are therefore left uncollected for days or end up in drains and rivers in the communities. Consequently, what were settlements are now surrounded by heaps and mountains of garbage. Inspite of that their peri-urban status still has not changed.

Most of Ghana's waste disposal sites for instance, the Asawase waste deposit site, are the uncontrolled open waste deposits. These waste deposits create serious threats to local environmental quality and public health. Consequently, the Asawase area faces a critical problem pertaining to its groundwater resources in the coming years if this problem of waste disposal sites which indiscriminately litters the area is not adequately addressed. One of the most common demands in metropolitan areas includes detecting the location and extent of contamination patches in areas as small as landfills (Abdullahi et al., 2011).

A number of problems frequently occur in connection with landfill surveys, and they tend to be interlinked and complex. There are often several issues that need to be resolved concerning old, buried, and poorly documented landfills due to environmental protection demands. Geological formations, soil layers, and bedrocks, underlying landfills are often contaminated as a result of leakage of contaminants from the waste, and the landfill often poses a severe threat to groundwater resources around landfills (Dahlin et al., 2010). Geophysical investigations are often required in order to gain sufficient understanding, since drilling and sampling alone are not enough for a complete picture. In such circumstance, the integrated use of geophysical methods provides an important tool in the evaluation and characterization of contaminants generated by urban residents (domestic and/or industrial) thus geo-electric, electromagnetic, magnetic and ground penetrating radar geophysical techniques can be applied in landfill investigations because dissolved plume (leachate) can influence resistivity/conductivity, dielectric constant, chargeability, and magnetic susceptibility (Abdullahi et al., 2011).

Clarkes et al. (2002) applaud the fact that while conductivities vary in response to differing soil types, metallic and ionic responses can often be distinguished by interpreting their characteristic behaviour. Dry accumulations of sand or gravel typically yield low responses while naturally occurring ions, fine-grained and/or saturated soils yield elevated backgrounds which can match magnitudes typical of ion-contaminated regions. In such scenarios, trend behaviour of the anomalous zone may suggest the cause of anomalous conductivities. In order to ensure a fast, efficient and cost-effective survey at the Asawase waste deposit site and to help map the subsurface conductivities as a result of contaminants or leachate from the waste deposit, the two geophysical techniques that were employed are electromagnetic and magnetic susceptibility. The equipment used for the electromagnetic survey is the Geonics EM34-3 and the Bartington MS2 (MS2D Field Loop Sensor) magnetic susceptibility system was used for the magnetic susceptibility.

The Geonics EM34-3, an instrument for the engineering geophysicists, geologists and hydrogeologists alike use electromagnetic (EM) inductive fields to delineate or help map subsurface conductivities, groundwater contaminant plumes and for groundwater exploration. Using the same patented inductive method as the EM31, the EM34-3 uses 3 intercoil spacings to give variable depths of exploration down to 60 m. In the vertical dipole (horizontal coplanar) mode the EM34-3 is very sensitive to vertical geological anomalies and is widely used for groundwater exploration in fractured, faulted and weathered bedrock zones.

Investigations into topsoil magnetism lead to useful applications in the fields of archaeology, hydrology and sedimentology, landslide characterization and environmental pollution. Since the 1970s, magnetic susceptibility has been used in environmental studies (Thompson and Oldfield, 1986), many of which mainly focused on identification of the sources of sediments. Magnetic susceptibility measures the magnetisability of a material. In the natural environment, the magnetisability gives an idea about the minerals that are found in soils, rocks, dusts and sediments, particularly Fe-bearing minerals. So the measurements provide information similar to that produced by other mineralogical techniques like X-ray diffraction or heavy mineral analysis (Dearing, 1999).

Environmental agencies from several countries have proposed different site investigation methodologies in order to diagnose and confirm different contamination levels in sites with diverse physical characteristics in order to guide the remediation plan whenever it is necessary (Mondelli et al., 2007). The idea of using this integrated geophysical approach to investigate the Asawase waste deposit site is to deduce the level of soil pollution or contamination associated with the topsoil and beneath the subsurface to specific depths of investigation and the results from these measurements would help educate the public on the impact of such waste sites on the environment.

1.1 Literature Review

Waste disposal is highly essential in an individual's daily activities and they are potential sources of pollution to the environment. The environmental pollution over the public health of the populace, over the decades has had increasing concern of poor management of solid waste materials which has led to potentially disastrous environmental and health hazards. Among the health hazards that have resulted from the lack of effective disposal systems are periodic epidemics and communicable diseases (Opeyemi, 2013). Ground water pollution in and around a waste disposal site occurs due solely to the contaminants (i.e. fluids residing beneath the dumping site) from the wastes. These leachates are solutions or suspensions of stable, essentially organic or inorganic complexes of biodegraded components of solid wastes flowing out from the refuse dumps, saturated with rainwater flowing through them (De Rooy, 1986). Conductivity geophysical techniques can be used to map out areas where conductive materials are concentrated and can also reveal potential pollution plumes and their direction of migration and therefore provide a basis for remediation if the environment is under threat (Opeyemi, 2013).

The magnetic susceptibility of the uppermost part of the soils (surface samples) can be enhanced due to the deposition of magnetic minerals from industrial plants. This phenomenon can be used as a proxy to determine the pollution of surface soil by the input of magnetic minerals, by wind transported over long distances (Hunt et al., 1984; Wang et al., 2006; D'Emilio et al., 2010; Kapicka et al., 2008; Kim et al., 2009). The frequency-domain electromagnetic data are affected by both magnetic susceptibility and dielectric permittivity. These geological parameters can be derived from multi-frequency EM data, and contain information about the geology in addition to the traditional electrical conductivity and total magnetic field maps. The effect of magnetic susceptibility is most often apparent as negative values in the low-frequency, in-phase component of the data, even over rocks of moderate magnetite content (Hodges, 2004). Huang et al. (1998) and Huang and Fraser (2000) showed that it was possible to detect and measure the magnetic permeability (susceptibility) and electrical conductivity simultaneously. Huang and Fraser (2000, 2002) also showed that one could measure the dielectric permittivity, magnetic permeability, and electrical conductivity simultaneously with a multi-frequency HEM system. Wherever the ground is moderately to strongly conductive, the conductivity parameter dominates the earth response. The soil susceptibility and dielectric permittivity will affect the data, but the effect will be considerably less than the effect of conductivity, and will normally not be apparent (Hodges, 2004).

The possible existence of latent subsurface structures as conduit for leachate and contaminant potential of pollution plumes from waste disposal/dump site along Ilesha-Ife express road, 1.5 km from Iwara junction, Ilesha, Nigeria was investigated by Opeyemi (2013). The depth to bedrock, distribution and orientation of fractures, probable zones of leachate concentrations, if any, and rate of transport of the contaminants from the dumpsite within the subsurface were investigated using a total of fifty-five (55) vertical electrical sounding points along ten (10) profiles within the vicinity of the site and one (1) profile (control) outside the area at about 300 m from the dumpsite, four (4) 2-D Wenner Electrical resistivity and four (4) profiles of very low frequency EM method of geophysical investigations. The area showed a wide distribution of conductive zones which are mostly depicted in up-dip incline pattern and occurred as pockets of conductive bodies as observed from Karous Filtering Pseudosection. The top layer had a resistive cover material of 34-950 Ωm and varied in thickness. The second layer was a low resistive zone of 10-130 Ωm and indicated a zone of fluid/ leachate activities. The weathered layer was thicker in areas with fractures in the bedrock. The third layer was a more resistive layer >200 Ωm which was the basement rock that underlies the study area. The 2-D electrical imaging result reveals a low resistivity signature in the eastern parts of the site and relatively higher resistivity in the western parts which indicated the presence of leachate/fluid activities in the eastern part. The cross-sectional map of the site revealed that the concentration of the contaminants was restricted to a particular zone and the leachate flowed towards the eastern direction of the dump site area and there were presences of near surface linear structures that may have acted as conduits for leachate emanating from the dumpsite.

The use of geophysical integrated techniques in the investigation of contaminant zones around waste deposit sites had been successful over the years. For instance in May 2000, the United State Geological Survey performed a surface geophysical investigation on a site used for disposal of unknown types of chemical waste in the 1960’s (Gregory et al., 2000). Methods used at the site focused on the electrical insulating properties of the nonmetallic (glass) containers, electrical conducting properties of possible leaking fluids, and electromagnetic properties of the disturbed regolith materials in the vicinity of the burial zones. The following geophysical methods were used at the site; electromagnetic conductivity, magnetic susceptibility, and 2D-DC electrical resistivity survey. This combination of geophysical tools was successful in delineating several types of subsurface anomalies consisting of buried metal and discrete high and low resistivity zones at various depths. These types od anomalies were used to characterize and identify areas of concern that could be possible locations of buried materials at the site.

Ramalho et al. (2013) described a case study concerning the use of integrated geophysical methods applied to environmental assessment. The study was focused on an old municipal solid waste sealed landfill site, located in Gaeiras, Central Portugal. The problem is related with leachate overproduction in this domestic and industrial waste landfill that became an environmental emergency and urgent assessment was needed so, that a solution could be planned. Due to the lack of accurate information regarding the shape, history and development of the landfill, the use of a set of classical geophysical methods was the option, since they are non-invasive and non-destructive. Electromagnetic RF-EM and Geonics EM34, spontaneous potential (SP), vertical electrical soundings (VES) and magnetic prospecting surveys were planned to understand the various problems that could be related with the leachate overproduction. The joint use of these classical geophysical methods was targeted to investigate bedrock depth and structure, waste and leachate characteristics and groundwater flow in the landfill. Geophysical results were correlated with hydro-geological information, integrated and interpreted, using geographic information system tools. The results obtained were important to understand the geological mechanisms that are responsible for leachate overproduction and to suggest remedial measures.

Sadiki et al. (2009) used magnetic susceptibility to assess soil degradation in the eastern Rif, Morocco. The soil in the Rif was thought to be seriously at risk because the increasing anthropogenic pressures were gradually transforming large natural areas into farmland. The distribution of magnetic minerals within the soil profile was used to assess soil development and degradation. The soils in the study area were severely eroded because of a combination of highly erodible soils, intense rainstorms and scarce vegetation cover. The sample of representative soil profiles, lithology, slope gradient and land use were considered. The ranges of magnetic susceptibility in the soil profiles distinguished between two primary soil groups. Magnetic susceptibility varied in the soil profile and along the soil toposequence, and the variations were related to the differences in the original magnetic composition and the influence of main erosion factors. An analysis of the main factors causing erosion helped to promote rational use of the land and to establish conservation strategies in such fragile agro-ecosystems.

Investigation of the relation between heavy metal contamination of soil and its magnetic susceptibility was conducted by Canbay (2010) to reveal the extent of industrial pollution in the soil in the province of Kocaeli, Turkey. In order to determine the environmental damages caused by the pollution, the magnetic susceptibility method has been used to detect the heavy metal concentrations in an area of 1 km^2. The sampling from the region was carried out periodically to observe the trends in pollution with time and to project predictions for the future. The soil profiles of 30 cm deep samples taken from 13 sampling stations at different coordinates that were suspected to be contaminated with heavy metals were investigated by magnetic susceptibility measurements both on site and in the laboratory. The value of magnetic susceptibility is observed to vary between 12×10^{-5} and 84×10^{-5} SI in the upper layers of the soil samples in on-site measurements.

Landfill operators require rapid site characterisations in order to optimise economics and meet environmental regulation during both site monitoring and expansion. Geophysical surveys are increasingly filling this need, with geoelectrical and seismic methods among the most commonly demanded methods. Martínez and Mendoza (2010) discussed two cases in which geophysical methods were applied to map the subsurface in landfills and their surroundings with the applications aimed to facilitate further expansions of the landfills while complying with environmental regulations. Direct current (DC) resistivity, self potential (SP) and very low frequency electromagnetic (VLF-EM) measurements were carried out to detect the spread of groundwater contamination and to locate possible pathways of leachate plumes that resulted from an open waste disposal site of Çanakkale municipality (Kaya et al., 2007). The dumpsite was being located at the catchment area borders of a small creek which is topographically at a high elevation relative to the urban area; the groundwater was hence expected to be hazardously contaminated. Interpretations of DC resistivity geoelectrical data showed a low resistivity zone (<5 Ωm), which appeared to be a zone, that is fully saturated with leachate from an open dumpsite. The VLF-EM and SP method supported the results of geoelectrical method relating a contaminated zone in the survey area.

Carpenter et al. (2012) identified groundwater contamination using resistivity surveys at a landfill near Maoming, China. The resistivity soundings and models showed the major differences between contaminated and uncontaminated areas around the Maoming north landfill. The most important result is that low Earth resistivity is recorded in areas with groundwater contamination. Higher resistivity was recorded in areas without groundwater contamination. Layered models from inverted Schlumberger array resistivity soundings made over contaminated areas exhibited conductive zones in the subsurface with resistivity ranging from 10-32 Ωm, in some cases extending more than 8 m below the surface. These zones probably represented leachate-contaminated groundwater within the contamination plume. Caution was exercised in this interpretation, since clayey layers are also conductive and may be misinterpreted as leachate contamination. This was especially important to emphasize since borehole logs were not available to provide subsurface control, and in areas without groundwater contamination lithologic variations are several hundred Ohm-m. One public health implication of this work was that no new water supply wells should be placed in areas of abnormally low resistivity, until the reason for this low resistivity can be assessed.

Wemegah et al. (2014) explained that environmental pollution from solid waste landfilling is a serious risk to groundwater and downstream surface water, especially when land filling is carried out unengineered, with no protective layer underneath the waste deposits. They reported that research in Ghana and in other developing countries on unengineered landfills depend almost exclusively on hydrochemical and geochemical analysis, which is not necessarily representative of the entire dumpsite catchment area. For this reason, integrated and cost effective geophysical methods, namely direct current (DC) electrical resistivity, full waveform time-domain induced polarization and ground based magnetic measurements were employed to map out and characterize Ohwim dumpsites in the Kumasi Metropolis. The result from the magnetic survey showed the strength of magnetic data in the mapping of the lateral extent of the waste deposit while DC/full wave induced polarization tomography on the other hand mapped the vertical extent of the dumpsite and characterized the hosting geology. Also some regions were identified, where a pollution plume is likely to be present.

1.2 Research Problem Definition

Most of the concerns for waste management in Ghana is with the urban areas than the rural areas. Urban areas in Ghana produce a variety of waste. The predominant wastes being domestic solid waste, industrial waste and construction waste. These wastes are sent to a few waste deposit sites, but majority end up in drains, streams and open places. Waste is disposed off by open dumping, open burning, controlled burning and tipping at waste deposit sites. This has created a pressing sanitation problem as many towns and cities are overwhelmed with management of municipal solid and liquid wastes.

The current state of waste management leaves much to be desired. Less than 40% of urban residents are served with solid waste collection services and less than 30% by an acceptable household toilet facility (Anku, 2000). The traditionally applied methods of dealing with wastes have been unsuccessful, and the resulting contamination of water and land has led to growing concern over the absence of an integrated approach to waste management in the country. Major constraints and challenges facing waste management in Ghana is a direct result of a growing urban population, the changing patterns of production and consumption, the inherently more urbanized life-style and industrialization (Anku, 2000). The situation of waste management may be summarized as follows:

- Poor planning for waste management programmes.
- Inadequate equipment and operational funds to support waste management activities.
- Inadequate sites and facilities for waste management operations.
- Inadequate skills and capacity of waste management staff.

Asawase being a densely populated area has one of the oldest and largest waste deposit sites in the Kumasi Metropolis. There are many and different human activities taking place on or around the dumping site which pose the most serious problem to the waste management authorities in the metropolis. One can find wood processing workshops, a piggery, a mosque, a place of convenience, a cattle range, scrap metal dealers, fitting shops and even restaurants or food vendors and a community radio station. The waste deposit site is highly polluted with all kinds of waste. It is not surprising therefore that a recent survey conducted by the UN-habitat in 2006 indicated that between 40 and 70% of urban dwellers in developing countries live in slums where thousands tons of waste are generated annually. This poses serious challenges to city authorities in developing nations in managing sanitation and health problems. The situation in Ghana also follows the global trends. This rapid growth is caused by rural-urban migration or urbanization. The people living in these areas do not acquire land for shelter in the city. They therefore make use of the marginal or less, valuable urban lands.

The densely populated communities around the site and their pressing demand for water especially when pipe-borne water supply ceases to flow, had been a trend and worrying issue to the people. This has led to the population pressure on few wells and mechanized bore-holes in the communities few kilometers away from the huge waste deposit site. This deposit site is an indispensable part of everyday living. It may present long-term threats to ground and surface water that are hydrologically connected. By observing the size, age of the dumping ground, the population of the community and the probability of groundwater contamination, the study desire to investigate the spread of dissolved contaminants (leachates) using terrain magnetic susceptibility and electromagnetic conductivity datasets.

1.3 Objectives

The major objective of the research is to trace and monitor the the spreading of contaminants into the ground and the associated risks to the environments. This objective is subdivided into three specific objectives which are:

- To delineate subsurface contaminated zone, if any
- To determine the extent, depth and to predict potential direction of leachate migration
- To establish the structural control/direction within subsurface profile.

1.4 Structure of Thesis

The thesis work has five (5) chapters with each chapter addressing a main heading. Chapter one introduces the subject matter, outlining the background of the research, objectives of the research, as well as literature review. Chapter two outlines the main fundamental theory behind electromagnetic and magnetic susceptibility survey, taking into account some enhancement techniques applicable to magnetic susceptibility and electromagnetic data. Chapter three gives an overview of the location and accessibility of the research area, physiography, climate and occupation of inhabitants. The methods used to acquire the data and some available software for enhancing the datasets were introduced in this chapter. This chapter also outlines the processing steps employed in the data processing. Chapter four analyses the various maps obtained from the susceptibility and electromagnetic datasets. Interpretations to the deduced maps are also given in this chapter. Finally, this chapter correlates the magnetic susceptibility and electromagnetic data to deduce the flow of leachate and contaminant zones in the study area. Chapter five draws conclusions from the research and makes recommendations for future work.

CHAPTER 2

THEORETICAL BACKGROUND OF THE GEOPHYSICAL METHODS

2.1 Magnetic Susceptibility Method

2.1.1 Introduction

During the 1970s and 80s, scientists realised that magnetic properties were useful for describing and classifying all types of environmental materials such as soil, rocks (Dearing, 1999). All matter are magnetic and are affected by a magnetic field though effect may be extremely weak or even negative, but it exists and can be measured easily. As objects and materials can be described by their size, colour or chemical composition, so also can they be described by their magnetic properties (Dearing, 1999). The magnetic properties of soils are largely due to the presence of ironic compounds, in particular, oxides and sulfides of iron. The level of concentration of iron oxides in the soil depends on the age and nature of the soil, pedogenic and biological activities, and soil temperature (Klučiarová et al., 2007). The distribution of pollution in soil depends on many factors, of which distance from the source, landscape morphology, vegetation and dominant wind direction are the most influential (Boadi et al., 2014)

According to Maher (1988) magnetic susceptibility measures the magnetisability of a material. In the natural environment, the magnetisability gives the magnetic properties of minerals that are found in soils, rocks, dusts and sediments, particularly Fe-bearing minerals. So the measurements provide information similar to that produced by other mineralogical techniques like X-ray diffraction or heavy mineral analysis. In summary the measurements may enable us to (Dearing, 1999):

- Identify the Fe-bearing minerals that are present in a sample.
- Calculate their concentration or total volume with high resolution.
- Classify different types of materials.
- Identify the processes of their formation or transport.
- Create 'environmental fingerprints' for matching materials.

There is hardly any area of environmental research where magnetic susceptibility has not been used: a magnetic mineralogical approach is applicable to virtually all kinds of environmental research. The measurements have also been found to be diagnostic of specific processes, like burning or soil water logging. These types of diagnostic application are becoming increasingly important to particular areas of study, such as archaeology and soil science (Dearing, 1999).

The magnetic susceptibility measurements are simple and convenient. It is unusual to argue for the use of an analytical technique because it is convenient, but it is a fact that this has been an important reason why researchers have used magnetic susceptibility measurements. The advantages of convenience can be summarised as follows (Dearing 1999):

- Measurements can be made on all materials.
- Measurements are safe, fast and non-destructive.
- Measurements can be made in the laboratory or field with minimal training.
- Measurements complement many other types of environmental analyses.

Large number of samples may be measured economically and without limiting subsequent analyses. The measurements are therefore ideal in reconnaissance studies where a large sample set is needed in order to find 'average' or 'typical' samples for other expensive or time- consuming analyses (Dearing et al., 1997). Measurements made in situ in the field speed up the process of linking data to field observations, a point that is very important to people working in remote or foreign areas far from laboratory facilities. Therefore, magnetic susceptibility measurements offer a cost-effective option (Dearing, 1999) when choosing which analytical techniques to use. Increasingly, magnetic susceptibility is used as one of a number of environmental analytical techniques.

2.1.2 Background of Magnetic Susceptibility (χ_m)

Iron originates from the primary minerals contained in the parent materials, thus, it becomes concentrated in the weathered material because of its low solubility under oxidizing conditions at the natural pH (Boadi et al., 2014). Iron is less easily integrated than aluminum within the clayey secondary phylosilicates and, therefore, iron is generally in the form of iron oxides and hydroxides, such as haematite, limonite, goethite, lepidocrite, magnetite, and maghemite (Stacey and Banerjee, 1974). Rocks made of different minerals or crystals that vary in the strength of their attraction to a small magnet and if the rock was crushed to release the individual crystals this variable effect can be observed (Dearing, 1999).

A review of some deductions from Dearing et al. (1997) and Thompson and Oldfield (1986) indicate that some minerals, such as the iron oxide magnetite, are highly magnetic and jump to the magnet as it is passed across them. Other crystals are attracted to a magnet, but weakly. They stick to the magnet only when it is brought into contact with them. Others like the quartz grains in sand do not show any visible attraction to the magnet. Magnetic susceptibility is basically measuring the total attraction of the first two groups of minerals to a magnet; in other words the rock's magnetisability. Rocks with relatively high concentrations of magnetite, like basalt, have much higher magnetic susceptibility values than rocks, such as limestone which usually have no magnetite crystals at all. Therefore the measured magnetic susceptibility of the soil, is approximately proportional to the mass of constitute minerals.

When a long solenoid is placed within a magnetic field, H, the magnetic field inside the long solenoid is given by (Feynman, 2005)

$$\mathbf{B} = \mu n I = \frac{\mu N I}{l} = \mu \mathbf{H} \tag{2.1}$$

Here, n is the number of turns per unit length, I is the current through the solenoid, N is the total number of turns, and l is the length of the solenoid. The **H** is equal to nI and it is perpendicular to **B**. If there is a vacuum inside the solenoid, the **B**-field is $\mu_o \mathbf{H} = \mu_o n I$. If we now place an iron rod of permeability μ inside the solenoid, this does not change **H**, which remains nI. The B-field, however, is now $\mathbf{B} = \mu \mathbf{H}$. This is greater than $\mu_o \mathbf{H}$, therefore;

$$\mathbf{B} = \mu_o(\mathbf{H} + \mathbf{M}) \tag{2.2}$$

The quantity **M** is called the magnetization of the material expressed in Am^{-1}. There are two components to **B** that is $\mu_o\mathbf{H} = \mu_o nI$, which is the externally imposed field, and the component $\mu_o\mathbf{M}$, originating as a result of something that has happened within the material. The ratio of the magnetization **M** (the result) to **H** (the cause), which is obviously a measure of how susceptible the material is to becoming magnetized, is called the magnetic susceptibility χ_m of the material:

$$\mathbf{M} = \chi_m\mathbf{H} \tag{2.3}$$

On combining equations (2.2), (2.3) and $\mathbf{B} = \mu\mathbf{H}$, it is readily seen that the magnetic susceptibility (which is dimensionless) is related to the relative permeability $\mu_r = \mu/\mu_o$ by

$$\mu_r = 1 + \chi_m$$

Also that χ_m in equation (2.3) can be dependent on the applied magnetic field H. In this case, the magnetic susceptibility can defined as follows:

$$\chi_m = \frac{\partial\mathbf{M}}{\partial\mathbf{B}}$$

The magnetization can be defined as

$$M = -\frac{\partial\mathbf{E}}{\partial\mathbf{B}}$$

where **E** is the total energy of the system.

2.1.3 Classification of Magnetic Materials

According to Dearing (1999) magnetism is controlled by the inherent forces or energies created by electrons which make up atoms. Electrons spin around their axis, and also around the atom's nucleus in their own orbits. The way in which different electrons motion are aligned determines the total magnetic energy or moment of the atom. Different atoms have different numbers of electrons and types of motion. Atoms make up molecules and molecules make up materials, so that the overall type of magnetic behaviour of a rock mineral is defined by the configuration and interactions of all the electron motions in all its atoms. Generally all magnetic materials may be grouped into five magnetic classes, depending on the magnetic ordering, magnitude and temperature dependence of the magnetic susceptibility (O'Reilly, 1984). These classes are diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic and ferrimagnetic. There is no magnetic order at any temperature in diamagnetic and paramagnetic materials, whereas there is a magnetic order at low temperatures in ferromagnetic, antiferromagnetic and ferrimagnetic materials. The classification below is based on reviews from O'Reilly (1984), Thompson and Oldfield (1986), Dearing et al. (1997), Dearing (1999) and Feynman (2005).

2.1.3.1 Diamagnetic Materials

In diamagnetic materials the magnetic susceptibility is negative and usually its magnitude is of the order of -10^{-6} to -10^{-5} SI. The magnetic field interacts with the orbital motion of electrons to produce weak and negative values of magnetic susceptibility (χ_m). The negative value of the susceptibility means that in an applied magnetic field diamagnetic materials acquire the magnetization, which is pointed opposite to the applied field. In diamagnetic materials the susceptibility nearly has a constant value independent of temperature. Materials which fall into this group include many minerals which do not contain iron, like quartz and calcium carbonate. Other non-mineral diamagnetic substances are organic matter and water. Ionic crystals and inert gas atoms are diamagnetic. These substances have atoms or ions with complete shells, and their diamagnetic behavior is due to the fact that a magnetic field acts to distort the orbital motion. Another class of diamagnetic materials is noble metals.

2.1.3.2 Paramagnetic Materials

All the other classes of materials have positive susceptibility. Within these classes the magnitude of the susceptibility varies over a very wide range. However, at sufficiently high temperatures the susceptibility decreases with increasing temperature for all materials in these classes. It was found experimentally that all these materials follow the relationship

$$\chi_m = \frac{C}{T \pm T_c} \tag{2.4}$$

more or less exactly for sufficiently high T (material's temperature). C (Curie constant) and T_c (Curie temperature) are positive constants independent of temperature and different for each material.

Diamagnetism makes itself evident in atoms and molecules that have no permanent magnetic moment. Some atoms or molecules, however, do have a permanent magnetic moment, and such materials are paramagnetic. It was found that in some materials $T_c = 0$ and this equation is obeyed down to the lowest temperatures at which measurements have been made. This class of materials is called paramagnetic. When a paramagnetic material is placed in a magnetic field, the magnetic moments experience a torque and they tend to orient themselves in the direction of the magnetic field. In paramagnetic materials the magnetic susceptibility (χ_m) is positive - that is, for which **M** is parallel to **B**. The susceptibility is however very small: 10^{-4} to 10^{-5} SI. The best-known examples of paramagnetic materials are the ions of transition and rare-earth elements. The fact that these ions have incomplete atomic shells is what is responsible for their paramagnetic behaviour.

2.1.3.3 Ferromagnetic Materials

The magnetic susceptibilities (χ_m) of ferromagnetic materials are typically of order 10^3 or 10^4 SI or even greater. The magnetic moments are highly ordered and aligned in the same direction. These substances have a very high magnetic susceptibility, but will not normally be found in the environment. However, the ferromagnetic susceptibility of a material is quite temperature sensitive, and, above a temperature known as the Curie temperature, the material ceases to become ferromagnetic, and it becomes merely paramagnetic. When temperature approaches T_c the magnetic susceptibility tends to be infinite. An infinite susceptibility means that a finite magnetization can exist even in zero applied fields, which is the case in permanent magnets. The problem is that the magnetization of ferromagnetic materials in zero fields can have a range of different values and consequently cannot be regarded as a property of the material. However, it is found that if a relatively small magnetic field is applied to these materials, the magnetization tends to a constant value, which is called the saturation magnetization M_s or spontaneous magnetization. Among the elements, only cobalt, iron and nickel are strongly ferromagnetic, their Curie temperatures being about 1400, 1040 and 630 K respectively. Gadolinium is ferromagnetic at low temperatures; its Curie temperature is about 289 K (16 ^{o}C). Dysprosium is ferromagnetic below its Curie temperature of about 105 K. There are many artificial alloys and ceramic materials which are ferromagnetic.

2.1.3.4 Ferrimagnetic Materials

The most important category of magnetic behaviour in natural materials is ferrimagnetism. The magnetic moments are strongly aligned, but exist as two sets of opposing but unequal forces controlled by the crystal lattice structure of certain minerals. This category includes magnetite and a few other Fe- bearing minerals with high magnetic susceptibility values. Magnetite is a common mineral found in all igneous rocks, most sedimentary rocks and nearly all soils. Where these minerals are present they often dominate the magnetic susceptibility measurement. Ferrimagnetic materials have non-zero magnetization below the Curie temperature which is similar to ferromagnetic materials. However, significant departures from equation (2.4) occur over a range of temperatures. This behaviour is only followed at temperatures large compared with the Curie temperature. Another difference between ferrimagnets and ferromagnets is that in ferrimagnetic materials the saturation magnetization against temperature behaves in a more complicated way. For example, for some ferrimagnets the magnetization can increase with increasing temperature and then drops down.

2.1.3.5 Canted Antiferromagnetic Materials

Antiferromagnetic materials have small positive magnetic susceptibilities (χ_m) at all temperatures. At high temperatures they follow equation (2.4) with T_c usually having a positive sign. A critical temperature in this case is called Neel temperature (Dearing et al., 1996). Below the Neel temperature the susceptibility generally decreases with decreasing temperature. There is no spontaneous magnetization in antiferromagnetic materials. Lower positive magnetic susceptibility (χ_m) values are obtained for canted antiferromagnetic iron minerals, such as haematite (Dearing, 1999). In antiferromagnetic materials, the atoms or ions or molecules have a permanent dipole moment (resulting from unpaired electron spins), as in paramagnetic and ferromagnetic materials, and the crystals have a domain structure, as in ferromagnetic materials, but alternating ions within a domain have their magnetic moments oriented in opposite directions, so the domain as a whole has zero magnetization, or zero susceptibility (Dearing et al., 1997). An example of an antiferromagnetic material is manganese oxide MnO, in which the Mn^{++} ion has a magnetic moment. The crystal structures also give rise to well-aligned but opposing magnetic moments, but the forces virtually cancel each other out (Dearing et al., 1997). There are only a few minerals in this category and haematite is probably the most common, occurring in many rocks and soils, and responsible for much of the natural red colouration in the environment (Dearing et al., 1996). All metals and minerals in these three magnetic groups are able to remain magnetised in the absence of a magnetic field and may be identified using remanence measurements (Dearing et al., 1997).

Therefore, the magnetic susceptibility of an environmental material is the sum of all the magnetic susceptibilities of the ferrimagnetic, canted antiferromagnetic and paramagnetic minerals and diamagnetic components. Normally, the diamagnetic component is negative and very weak relative to the sum of the other three and can be ignored.

2.2 The Electromagnetic (EM) Method

2.2.1 Introduction

Electromagnetic (EM) surveys have been one of the specialist geophysical methods for many years. EM conductivity surveys measure ground conductivity by the process of electromagnetic induction. The principal electromagnetic systems used for site investigation are the Geonics EM 31, EM 34-3 and EM 38 ground conductivity meters. The systems work on similar principles consisting of a transmitter and receiver coil spaced at a fixed configuration, but use different operating frequencies to provide a range of depth penetration and resolution for different applications (Telford et al., 1990). Low frequency EM 34-3 systems can be effective for finding large underground cavities such as caves and mine workings but are rarely for smaller targets (Telford et al., 1990). The EM 31 operates at an intermediate frequency and is useful for locating discrete features such as sinkholes, abandoned mineshafts and underground storage tanks (UST's). The high frequency EM 38 system is best for detecting small targets buried at shallow depth, such as chemical waste drums and metal artifacts (Telford et al., 1990).

The electromagnetic techniques have the broadest range of different instrumental systems. They can be classified as either time domain electromagnetic (TDEM) in which measurements are taken as a function of time or frequency domain electromagnetic (FDEM) systems which uses one or more frequencies. Regarding survey in FDEM, transmitter produces continuous EM field, secondary field is determined by nulling the primary field (need two coils) whereas with the TDEM the primary field is applied in pulses (20-40 ms) then switched off and the secondary field measured (same coil can be transmitter and receiver, more often large coil on ground and move small coil around).

The terrain conductivity meter is used for the measurement of the electrical conductivity of subsurface soil, rock and ground water. The electrical conductivity (or its inverse, resistivity) is a function of the porosity, permeability and the fluids in the pore spaces (McNeill, 1980). In the landfill setting, the pore fluids dominate the measurement and thus the EM is an excellent tool for delineating buried waste, trench boundaries, drums and other metallic objects. The absolute values of conductivity obtained in a survey are not necessarily diagnostic but the variations in conductivity can be used to identify anomalies (Benson et al., 1988).

2.2.2 Basic Wave Properties

2.2.2.1 Maxwell's Equations

Maxwell's equations describe the interaction between electric and magnetic fields and the corresponding coupled process propagating as a three-dimensional, polarized, vector wave field, known as electromagnetic radiation (Balanis, 1989). The equations in vector form are:

$$\nabla \times \mathbf{E} = -\frac{\partial(\mathbf{B})}{\partial(t)} = -\mu\frac{\partial(H)}{\partial(t)} \qquad \text{Faraday's Law} \tag{2.5}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial(\mathbf{D})}{\partial(t)} = J + \varepsilon\frac{\partial(E)}{\partial(t)} \qquad \text{Ampere's Law} \tag{2.6}$$

$$\nabla . \mathbf{D} = q \tag{2.7}$$

$$\nabla . \mathbf{B} = 0 \tag{2.8}$$

where **E** is the electric field strength vector [volt/m], **H** is the magnetic field intensity vector [ampere/m], **J** is the electric current density vector (flux) in (ampere m^{-2}), **D** is the electric displacement current vector in (coulomb m^{-2}), **B** is the magnetic flux density vector (Tesla m^{-2}), q is the electric charge density (coulomb m^{-3}), t is time (s), and ∇ is the spatial vector derivative operator.

2.2.2.2 Constitutive Equations

Constitutive relationships are the means of describing a material's response to electromagnetic magnetic (EM) fields. For GPR, the electrical and magnetic properties are of importance. Constitutive equations (eqn (2.9) , (2.10), (2.11)) provide a macroscopic (or average behaviour) description of EM fields (Harry, 2009).

$$\mathbf{J} = \sigma \mathbf{E} \tag{2.9}$$

$$\mathbf{D} = \varepsilon \mathbf{E} \tag{2.10}$$

$$\mathbf{B} = \mu \mathbf{H} \tag{2.11}$$

Where σ is the electrical conductivity, ε is dielectric permitivity and μ is magnetic permeability. Electrical conductivity σ characterizes free charge movement (creating electric current) when an electric field is present. Resistance to charge flow leads to energy dissipation. Dielectric permitivity ε characterizes displacement of charge constrained in material structure to the presence of electric field. Charge displacement results in energy storage in the material. Magnetic permeability μ describes how intrinsic atomic and molecular magnetic moments respond to a magnetic field. For simple materials, distorting intrinsic magnetic moments store energy in the material (Harry, 2009). From equations (2.5) through (2.11) one can derive the electromagnetic wave equation for the electric field:

$$\nabla^2 \mathbf{E} - \mu\varepsilon \frac{\partial^2 \mathbf{E}}{\partial t^2} - \mu\sigma \frac{\partial \mathbf{E}}{\partial t} = 0 \tag{2.12}$$

The wave equation for the magnetic flux density is exactly the same, just substituted **B** for **E** in Equation (2.12)

$$\nabla^2 \mathbf{B} - \mu\varepsilon \frac{\partial^2 \mathbf{B}}{\partial t^2} - \mu\sigma \frac{\partial \mathbf{B}}{\partial t} = 0 \tag{2.13}$$

The resulting combination of the **E** and **B** fields is known as transversal wave. **E** and **B** are perpendicular to each other as well as the direction of propagation, i.e., they form a right-handed orthogonal set (Telford et al., 1990).

To understand the properties of electromagnetic wave propagation, consider a single-frequency, linearly polarized, EM plane wave travelling in the z direction. From Maxwell's equations, the following expressions for the complex electric **E** and magnetic **B** field vectors can be derived (Knight, 2001).

$$\mathbf{E}(z, t) = \mathbf{E}(z)e^{-i\omega t} \tag{2.14}$$

Substituting (2.14) into (2.12) and rearranging we get

$$\nabla^2 \mathbf{E} + K^2 \mathbf{E} = 0 \tag{2.15}$$

which is the Helmholtz equation describing the plane wave harmonic solution to (2.12). The propagation constant

$$K^2 = \omega^2 \mu\varepsilon + i\omega\mu\sigma \tag{2.16}$$

contains all information about the attenuation and velocity of the wave. The solution to equation (2.15) is

$$\mathbf{E} = \mathbf{E}_0 e^{-i(\omega t - kz)} \tag{2.17}$$

The square root of the propagation constant is known as the wave number, k. The wave number can be expressed as

$$k = a + ib \tag{2.18}$$

Using expressions (2.17) and (2.18) the solution takes the form

$$\mathbf{E} = \mathbf{E}_0 e^{-i(\omega t - az)} e^{-bz} \tag{2.19}$$

where a is the phase constant, b is the attenuation coefficient and z is the depth of exploration. The first exponential represents un-attenuated wave propagation and the second exponential accounts for the attenuation of the wave with depth.

2.2.2.3 The Electrical Conductivity

Electric conductivity results when an incoming electric field leads to a movement of unbounded charge carriers. For its description, one can start with the equation of motion according to Ludwig et al. (2011);

$$\frac{\partial^2}{\partial t^2}s(r,t) + g\frac{\partial}{\partial t}s(r,t) = \frac{q}{m}\mathbf{E}(r,t) \tag{2.20}$$

where s is elongation of particles from an initial position, g is damping term due to friction/collisions, m is mass of the particles, q is charge of the particles.

The movement of all particles with a particle density n leads to a resulting current density $\mathbf{J}$, which is given as

$$\mathbf{J}(r,t) = -nq\partial_t s(r,t) \tag{2.21}$$

Substituting equation (2.21) into equation (2.20) results

$$\partial_t\mathbf{J}(r,t) + g\mathbf{J}(r,t) = \frac{q^2 n}{m}\mathbf{E}(r,t) \tag{2.22}$$

After a Fourier-transformation, rearranging the equation and employing Ohms Law $\mathbf{J}(r,\omega) = \sigma(\omega)\mathbf{E}(r,\omega)$ gives

$$\sigma(\omega) = \frac{q^2 n}{(g - i\omega)m} \tag{2.23}$$

The electrical conductivity σ is an effect of unbounded charge carriers and is in general a complex function of frequency.

2.2.2.4 Depth of Penetration of Frequency Domain EM wave

A prime importance in EM surveying is a consideration of the depth of penetration of EM radiation and the resolution as a function of depth. In an isotropic resistive medium, EM waves would travel virtually indefinitely, however, in the real world, where surface conductivities are significant, the depth of penetration is often very limited (Reynolds, 1997). The depth of penetration is largely a function of frequency and the conductivity of the media present through which the EM radiation is to travel. At the usual frequencies (<5 kHz) used in the EM exploration (excluding ground penetrating radar) attenuation effects are virtually negligible, but signal losses occur by diffusion.

A common guide to the depth of penetration is known as the skin depth which Sheriff (1991) defines as the depth at which the amplitude of a wave has decreased to 1/e or 37 % relative to its initial amplitude A_o. Amplitude of EM radiation as a function of depth (z) relative to its original amplitude A_o is given by:

$$A_z = A_o e^{-1} \tag{2.24}$$

The skin depth δ (in meters) is given by:

$$\delta = \left(\frac{2}{\omega\sigma\mu}\right)^{\frac{1}{2}} = 503(f\sigma)^{\frac{1}{2}} \tag{2.25}$$

where $\omega = 2\pi f$, and f is the frequency in Hz, σ is the conductivity in S/m and μ is the magnetic permeability (usually ≈1). A realistic estimate of the depth to which a conductor would give rise to a detectable EM anomaly is $\approx \delta/5$. Reynolds (1997) indicated that, given a known frequency for a particular equipment system, the unknown is the vertical variation of conductivity with depth. Different instrument manufacturers commonly cite effective depths of penetration for their instruments. For example (McNeill, 1980), Geonics Limited gives the depth of penetration of the FDEM systems (EM38, EM31, EM34) as a function of the intercoil separation.

2.2.2.5 General Principle of Electromagnetic Survey

During the survey, EM fields are generated by passing an AC through a wire coil (transmitter). EM field propagates above and below ground and if there is conductive material in the ground, magnetic component of the EM wave induces eddy currents (AC) in the conductor. The eddy currents produce a secondary EM field which is detected by the receiver as shown in Figure 2.1. The receiver also detects the primary field (the resultant field is a combination of primary H_p and secondary H_s which differs from the primary field in phase and amplitude). In general this secondary magnetic field is a complicated function of the intercoil spacing s, the operating frequency, f, and the ground conductivity σ (Reynolds, 1997).

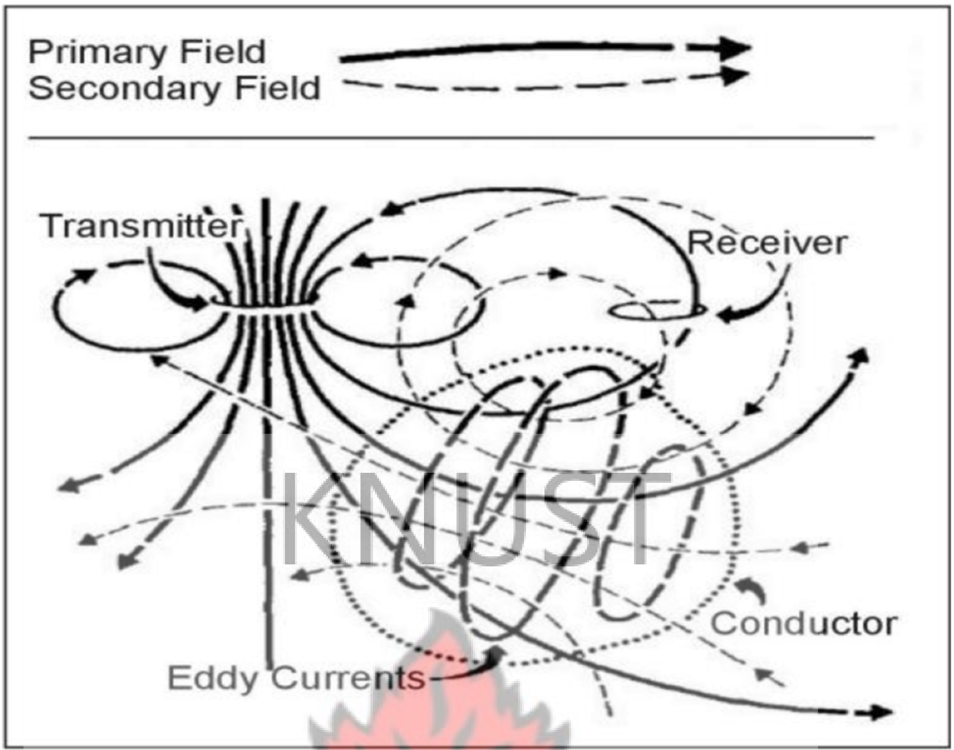

Figure 2.1: Physical Principle of Frequency Domain EM.

The ratio of secondary to primary magnetic field is shown to be (McNeill, 1980):

$$\frac{H_s}{H_p} \approx \frac{i\omega\mu_o\sigma s^2}{4} \tag{2.26}$$

where H_s is the secondary magnetic field at the receiver coil, H_p is the primary magnetic field at the receiver coil, $\omega = 2\pi f$, f is the frequency (Hz), μ_o is permeability of free space, σ ground conductivity (mho/m), s is intercoil spacing (in meters) and $i = \sqrt{-1}$.

2.2.2.6 Apparent Conductivity

The ratio of the secondary to primary magnetic field is now linearly proportional to the terrain conductivity meter as in equation (2.26) by simply measuring this ratio (McNeill, 1980).

Given H_s/H_p conductivity indicated by the instrument is defined from equation (2.26) as

$$\sigma_a = -\frac{4}{\omega\mu_o s^2}\left(\frac{H_s}{H_p}\right) \tag{2.27}$$

The apparent conductivity measurement (Telford et al., 1990) is the average conductivity of one or more layers in the ground in the proximity of the instrument, to a depth of investigation dependent on the coil spacing, orientation and the operating frequency of the instrument.

After compensating for the primary field (which can be computed from the relative positions and orientations of the coils), both the magnitude and relative phase of the secondary field can be measured (McNeill, 1980). The difference in the resultant field from the primary provides information about the geometry, size and electrical properties of the subsurface conductor. Secondary field can be converted to components in-phase and 90^o out of phase with the transmitted field. The out-of-phase (or quadrature-phase) component, using certain simplifying assumptions, can be converted to a measure of apparent ground conductivity and the in-phase component, while generally not responsive to changes in bulk conductivity, is especially responsive to discrete, highly-conductive bodies such as metal objects (Reynolds, 1997).

EM terrain conductivity surveys have been employed for landfill investigations for over 25 years (McNeill, 1980). Advantages of an EM survey include:

- Excellent resolution in conductivity.
- No current injection problems.
- Simple multi-layered earth calculations.

- Easy, rapid measurements.

Disadvantages of EM for exploratory investigations are few but include:

- Limited dynamic range.
- Setting and maintaining the instrument zero.
- Limited vertical sounding capability.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Kumasi Metropolis

3.1.1.1 Location and Accessibility

The Kumasi Metropolis is the second largest city in Ghana and located in Ashanti Region, Southern Ghana. Kumasi is located near Lake Bosumtwi, in a Rain Forest region, and is the commercial, industrial and cultural capital of Ashanti region. The Kumasi Metropolis attracts rural and urban migrant settlers due to its location as a commercial centre linking the northern and the southern sectors of the country. It is about 270 km north of the national capital, Accra and the geographic location of 652911 E and 737115 N. The topography of Kumasi ranges between 250 to 300 m above mean sea level and is undulating. It covers an area of about 254 km^2 (Ghana Statistic Service, 2002).

The metropolis has a circulatory road network pattern comprising five major arterial primary roads linking Kumasi to other parts of the country and they all emanate from the centre of the city. These are the Accra road, the Tamale road, the Wa road, the Sunyani road and the Cape Coast road. There are also four other primary roads, which link other districts in the Ashanti Region to Kumasi. All these primary roads are connected by a primary circular ring road, which was provided to channel extraneous traffic away from the city centre. This hierarchy of primary roads is supported by a network of existing and proposed district, local distributor and access roads. The total length of the road network is 430 km. Of this, asphaltic cement concrete is about 26% and that of surface dressing is 53%, while gravel and earth roads account for 21%. The major telecommunication service in the metropolis is run by Ghana Telecom, which offers a wide range of both internal and international dialing services. Studies have established a link between transportation infrastructure investment and economic development. Though figures are not readily available, the poor roads linking parts of the Kumasi metropolis is believed to be affecting productivity. Commuting within the city for daily business activities has become very difficult because of challenges to route access (Ghana Districts, 2006).

3.1.1.2 Climatic Conditions, Drainage and Vegetation

The annual rainfall of the Kumasi Metropolis averages between 150 to 170 mm and the pattern is found to be erratic as well as bimodal with major season. Two rainy seasons occur, one between May and July averages 160 mm per month and the other between September to October averages 186 mm per month. The driest period of the year is from January to March when the dry and dusty Hamattan wind blows southwards off the Sahara desert. During the dry season rainfall averages 54 mm per month. There is a short dry season in August, which at times stretches into September. The minimum monthly temperature is about 26 ^{0}C and the maximum temperature of 30 ^{0}C is recorded in March and April. Daily temperatures range from 22 ^{0}C to 30 ^{0}C, with humidity averaging 80% (Ghana Districts, 2006).

The vegetation is mostly semi-deciduous forest comprising open forest which covers the highlands (575 km^2) and closed forest covering the range (230 km^2). However, most of the original forest has degenerated into secondary forest and grassland due to indiscriminate felling of trees, bush-fire and poor farming practices, such as shifting cultivation and bush fallowing (Ghana Districts, 2006). The Kumasi Metropolis lies within the plateau of the South-West physical region which ranges from 250-300 m above sea level. The city is traversed by major rivers and streams, which include the Subin, Wiwi, Sisai, Owabi, Aboabo, and Nsuben. However, biotic activity in terms of estate development, encroachment and indiscriminate waste disposal practices have impacted negatively on the drainage system and have consequently brought these water bodies to the brink of extinction.

3.1.1.3 Occupation of Inhabitants

Majority (86%) of the population in Kumasi are economically active. The economic activities sustaining the livelihood of the residents in the Metropolis can be categorized into Agriculture, Industry and Service (Kumasi Metropolitan Assembly, 2006).

Agricultural Sector

Agriculture in Kumasi consists of farming, aquaculture, horticulture and some animal rearing. Farming is limited to small-scale staple crops production including maize, plantain, cocoyam, cassava and traditional (tomatoes, pepper etc) and exotic (carrots, cabbage etc) vegetables in the peri-urban areas. In terms of food crops it is a net importer. Most of the foodstuffs are brought in from the adjoining districts as well as distant areas such as Techiman, Nkoranza and Ejura.

Industrial Sector

Kumasi is a hub for scattered pockets of industrial activities in the country. Notable among them are the agglomerated small-scale mechanical garages, wood processing companies and food processing companies as well as construction firms. This sector has contributed quite significantly to productive employment creation (23%) and revenue generation. Suame Magazine (the biggest mechanical garage in West Africa) and Asafo mechanical garages have impacted positively on productive employment creation and revenue generation in Kumasi. Suame Magazine, which is located at the northern section of Kumasi, is a hub of agglomerated small-scale mechanical garages that both manufacture vehicle parts and provide other mechanical services not only to the Metropolis but to the whole West Africa sub-region. Its presence in the Metropolis has made Kumasi a well-known mechanical garage in the sub-region. Other industrial centers that have contributed immensely to job creation and sustainable source of income for a section of the active labour force in the Metropolis are the beverage processing industries. Notable among them are the Guinness Ghana Brewery Limited (GGBL) and the Coca Cola Bottling Company. In addition to these large scale companies are micro, small and medium-scale enterprises that produce fruit juice and fresh yoghurt among others. Timber processing firms and plywood manufacturing companies located along the Asokwa-Ahinsan-Kaase stretch are other industrial centers that have significantly contributed to sustainable livelihood in Kumasi by providing employment and revenue. The semi-finished products of these companies are exported to the international market to generate foreign exchange as well as sold to domestic furniture workers to create jobs. Another area of interest is the handicraft industry which comprises of cane basket weaving, pottery and wood carving. Although they are spread metro wide, majority of them are concentrated at Ahwia.

Service Sector

The service sector is the economic backbone of Kumasi. Majority (72%) of the economically active labour force are employed in this sector. This sector has made Kumasi a hub for commercial activities in the country. The activities carried out by players in this sector are wholesale and retail in nature. They cover all kinds of commodities ranging from food stuffs, clothing, building materials, office and educational stationery to herbal and orthodox medicines. The need for ancillary services to support economic activities in the Metropolis has attracted other relevant service providers. The banking and insurance sector coupled with other relevant institutions have contributed immensely in creating conducive environment for smooth running of business transactions in Kumasi. Another group of service providers that have contributed tremendously to the creation of productive employment ventures and revenue generation in the Metropolis are the telecommunication sector, transport sector, hotels, restaurants and traditional catering (chop bars), hairdressers and dressmakers/tailors.

3.1.2 Asawase area (Project site)

The survey area (Figure 3.1) is located in the Ashanti Region of Ghana within the Kumasi metropolis, and has the following projection coordinates referenced to the World Geographic System (WGS) 84 and Zone 30N UTM categories with units in meters: (653720 E, 741380 N) representing upper right corner, (653660 E, 741380 N) as upper left corner, (653660 E, 741220 N) and (653720 E, 741220 N) representing lower left and lower right corners respectively.

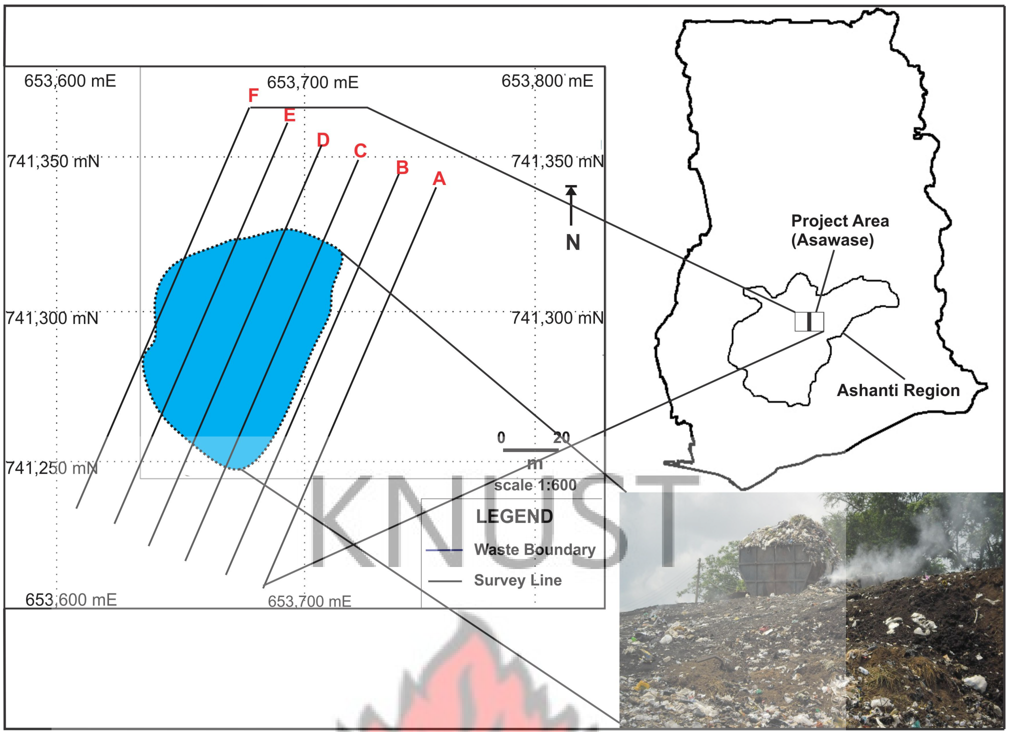

Figure 3.1: Survey plan map for Asawase waste deposit site showing profile lines A, B, C, D, E and F.

Asawase is the most populated predominant slum settlement in the Kumasi Metropolis. It is adjacent to the Manhyia palace of the Asantehene. It has a population of about 53,678 and 9,144 households (Ghana Statistical Service, 2002). It occupies an area of about two square kilometers (2 km^2). It is originally a Ministry of Works and Housing built estate for public servants. Traditionally, it is part of the Manhyia stool lands, but politically, it is the headquarters of the Asawase sub-metropolitan area. It has one of the largest waste dumping grounds in the entire metropolis (Ghana Statistical Service, 2002).

The maximum difference in elevation between the top of the solid waste and the surrounding area is 5 m. The north-eastern through the south-eastern part of the site are used as piggery, saw-mill workshop where wood waste is regularly produced and also for cattle rearing where organic waste is in abundance. There are several constructions undertaken close to the waste deposit site such as a place of convenience for the community, a filling station along the downstream of the waste site, streets and a mosque constructed along the edge of the waste deposit site. The Asawase area is dominated by middle Precambrian rock. It is within the plateau of the south-west physiological region, which ranges between 250 and 350 m above sea level. Groundwater occurs under water table conditions in the clay sand/sand aquifer and under semi-confined to confined conditions in the weathered/fractured zone (Kumasi Metropolitan Assembly, 2006).

Asawase being a densely populated community in the Kumasi metropolis, lack adequate services including poor sanitation, irregular water supply among others. Waste deposit sites that spring up often in these areas pose a major threat to groundwater resources (Fatta et al., 2000). The emphasis here is poor sanitation and irregular water supply which in the view of this study is caused by huge generation of waste and its poor management practices resulting in soil contamination and groundwater pollution. Asawase waste deposit site was one of the oldest dump sites in the Kumasi Metropolis. The site was originally a public cemetery with mini landfill close to it and later converted into a complete waste deposit site for the community for several decades. People from other suburbs such as Menhyia, Akwatia, Aboabo and Dekyemso deposit refuse here. Small and large manufacturing industries such as food and beverage companies, wood processing, poultry and animal raising industries also dump their waste over here. Asawase refuse dump was centrally located and serves as the main and only place for depositing waste for most people (Devas and Korboe, 2000). Among the material often deposited in large quantities included cow-dung, human excreta, scrap metals, paper products and many other organic and inorganic wastes. In recent times dumping (Kumasi Metropolitan Assembly, 2006) of waste has been control by city authorities of the Kumasi Metropolitan Assembly (KMA) and waste management companies such as Zoom Lion (International and Local waste management company).

3.2 Data Acquisition

Geophysical methods, particularly electrical techniques, can be used to study those different environmental characteristics which are important during the site characterization for waste disposal and the monitoring of migratory contamination plumes (Abdullahi et al., 2011; Ibe and Njoku, 1999). The major advantage of these methods is that the measurements of soil and contaminant properties are indirect. It allows a quick investigation of a large area avoiding direct contact with contaminants.

3.2.1 Materials and Equipment

The geotechnical investigation for both the magnetic susceptibility and electromagnetic was conducted on six survey or traverse lines (labeled profile A from the right to profile F to the left). The survey lines were designed to trend in the NE-SW direction (Figure 3.1) to traverse the dip direction. This is to measure the different susceptibilities associated with defferent soil types along the profile. The average length of the survey line was 200 m. Including a handle-held GPS, the geophysical equipment used for magnetic susceptibility measurements were the magnetic MS2 meter connected to the MS-2D Bartington loop sensor as shown in Figure 3.2 A and B. To acquire the terrain conductivity of the Asawase waste deposit site; two loop sensors (coils), three intercoil spacing cables (10, 20, and 40 m), a transmitter and a receiver were used.

The MS-2D loop is simple and quick to use and is employed mainly in mapping and reconnaissance surveys (Dearing, 1999). Insitu surface volume magnetic susceptibility measurements were performed (Figure 3.2 B) using the MS-2D Bartington loop sensor with a diameter of 185 mm designed to make surface measurements of soils, rocks, stream channels just a few to mention at the various stations. This loop probe is designed for rapid assessment of the concentration of ferrimagnetic materials in the top 100 mm of the land surface (Dearing, 1999). The probe can only be operated in conjunction with the MS2 probe handle. The system is developed for detecting very low quantities of magnetic Fe- oxides in compact (rocks) or loose substrates (mineral soil, humus layer). The susceptibility meter has a sensitivity of 0.1 to 1×10^{-5} SI units and can be used in a single readout mode with soil samples were taken from various points around the waste deposit site.

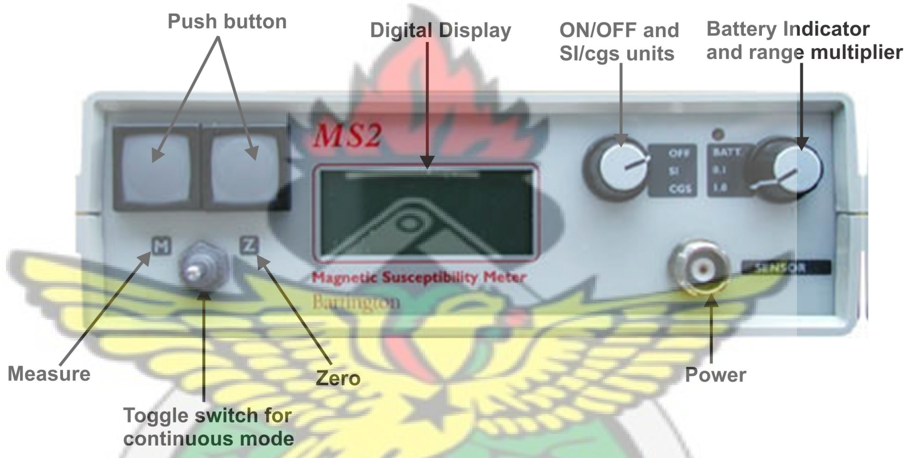

Figure 3.2: MS2 meter.

3.2.2 Magnetic Susceptibility Measurements

The MS-2D sensor comprises a loop and probe respectively attached to a handle with an electronic unit, through which the MS2 meter is attached.

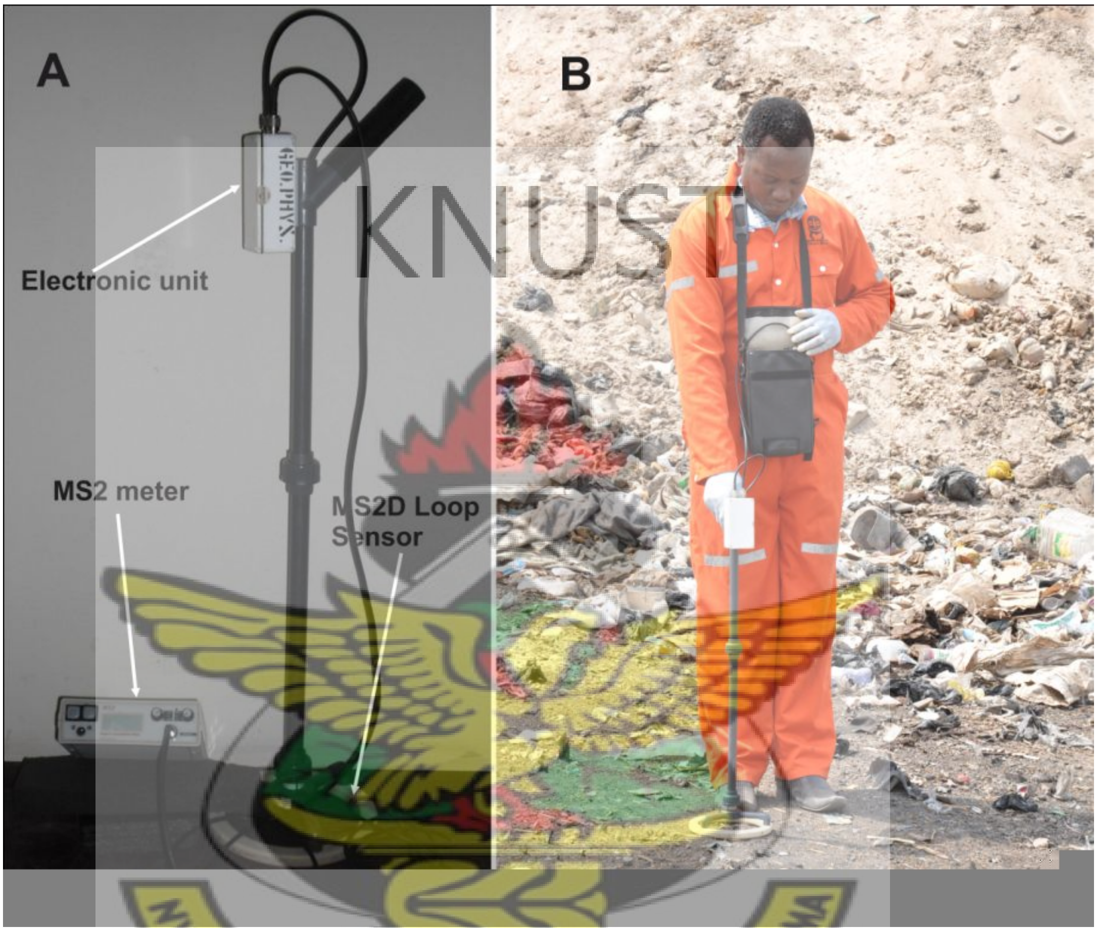

Figure 3.3: A: MS2 meter connected to the MS-2D Bartington loop sensor B: A field assistant taking insitu magnetic susceptibility measurements.

The MS-2D Bartington loop sensor attached to the MS2 meter (Figure 3.3) was operated as below to measure the magnetic susceptibility on each survey line (Figure 3.2 B). Two field assistants were needed to conduct this survey with one taking the magnetic susceptibility reading and the other taking the altitude variation on the survey lines using the hand-held Garmin Global Positioning System (GPS).

- The sensor was connected to the meter which was then switched on and the SI units chosen: a measuring range of 1.0 is normally selected and the M/Z toggle switch centered.
- The sensor was zeroed by holding the sensor in the air, at least 100 cm away from other objects, and pushing the Z button. The meter display was cleared and by pushing the M button, air measurements were taken.
- The sensor was placed onto a surface and the M button pushed to obtain a reading. Magnetic susceptibility measurements were taken at 5 m intervals along these profiles. In order to reduce errors, observations at each station were taken two (2) times and the average found.
- The sensor was held in the air to re-measure air. The mean of the two air readings were deducted from the measured value to adjust for drift in the measurement sequence.

Where a large number of sample readings are required it may be more convenient to run the meter in continuous mode. After zeroing in air, the toggle switch was set to M and the probe or sensor was placed on the surface until a maximum reading was obtained, usually after two or three beeps. It should be noted that air readings can be taken at any time by simply holding the sensor in the air. The measured X_m values were relatively high (>50×10^{-5} SI) and the drift between air readings was low indicating how quicker this method had been (Dearing, 1999).

3.2.3 Terrain Conductivity Measurements

In order to investigate the subsurface structures that may provide pathways for groundwater and contaminant transport, apparent electrical conductivity data were collected on top and around the waste deposit along the traverse or survey lines.

Figure 3.4: Field assistants taking terrain conductivity measurements A: Vertical dipole mode (VD) B: Horizontal dipole mode (HD).

The survey was carried as follows:

- Three field assistants were needed for this survey; two knowledgeable in the use of the EM 34-3 and the other using the hand-held Garmin Global Positioning System (GPS) to measuring the longitude, latitude and elevation along the traverse or survey lines.

- Starting with the 10 m intercoil spacing, the transmitter and a coil is carried by one field personnel and the other carried the receiver and the other coil.

- At the beginning of the survey along the survey line, the transmitter personnel leads the receiver holder by a distance of 10 m. The GPS holder takes elevation readings at the station where the receiver records an apparent electrical conductivity value.

- The apparent electrical conductivity measurements for a particular station were recorded in two modes namely the horizontal dipole mode (HD) and vertical dipole mode (VD) as shown in Figure 3.4. Using the 10 m intercoil spacing the depth of investigation for the HD mode was 7.5 m and the depth of investigation for the VD mode was 15 m. To measure terrain conductivity (apparent electrical conductivity) the transmitter operator stopped at the measurement station, while the receiver operator moved the receiver coil backwards or forwards until the meter indicated correct intercoil spacing and the terrain conductivity from a second meter was read. The procedure took 10 to 20 s. The coils were normally carried with their planes vertical (horizontal dipole mode) since in this configuration the measurement was relatively insensitive to misalignment of the coils. In the event that greater depth of penetration is desired, the two coils in the vertical dipole mode must be properly aligned with the appropriate intercoil spacing ensured. This is because relatively short intercoil spacing with incorrect alignment which is usually not difficult to achieve do not give desired results.

- This procedure was repeated for the other survey lines. The survey is also carried out using the 20 m (depth of investigation for the HD mode is 15 m and the depth of investigation for the VD mode is 30 m) and 40 m (depth of investigation for the

HD mode is 45 m and the depth of investigation for the VD mode is 60 m) intercoil spacing.

It is shown that in the vertical dipole mode (coils in a horizontal coplanar) the relative response is zero for near-surface materials, increasing to become a maximum at a depth approximately 2/5 of intercoil spacing, and decreasing slowly thereafter (McNeill, 1985). Conversely in the horizontal dipole mode (coils in a vertical coplanar) the response is a maximum to near-surface material, decreasing monotonically thereafter (McNeill, 1985). The integrated data were collected with a view of identifying and detecting lose ground, faults or fractures that may be responsible for the migration of the contaminant plumes outside the waste disposal sites as well as studying the effectiveness and response of each of the methods used on top of the dump that represents unconsolidated materials.

3.3 Data Processing

The major GIS software used to process and enhance the geophysical data was the Geosoft (Oasis Montaj) and the other software that were used to enhance the data in a variety of formats was MapInfo 10.5-Discover 11.1, and Matlab 12. The methodology applied involved the acquisition of two different geophysical datasets (apparent electrical conductivity and magnetic susceptibility), building of databases (projects), data processing and interpretation. Two databases were generated to process the acquired datasets; using Geosoft software for processing the apparent electrical conductivity and magnetic susceptibility data. This section gives an overview of the processing of the two geophysical datasets.

The survey station (station on the profile lines where measurement for both geophysical survey were carried out) on each profile line had a corresponding geographic location obtained using the GPS. So for example on profile A, at a particular station where magnetic susceptibility or apparent electrical conductivity measurement was acquired, the GPS was used to obtain the longitude and latitude of that station. The datasets from the two surveys assigned to columns in excel spreadsheet were imported in the Oasis Montaj and Matlab.

Two spreadsheets were developed namely MAGSUS.xls (having columns for Magnetic susceptibility, Altitude, Latitude and Longitude) and APPEM.xls (having columns for HD conductivity, VD conductivity, Distance on the profile (increment of 5 m), Altitude, Latitude and Longitude). Both spreadsheets were imported into the Geosoft Oasis Montaj to create two databases (MAGSUS.dbs and APPEM.dbs). The minimum curvature technique was applied using the GRID AND IMAGE tool in gridding the following columns in both databases (MAGSUS.dbs and APPEM.dbs):

- Elevation (altitude above mean seal level), of the stations.
- The magnetic susceptibilities.
- The apparent electrical conductivity in horizontal dipole (HD) mode for the individual intercoil spacings 10, 20, and 40 m.
- The apparent electrical conductivity in horizontal dipole (HD) mode for the individual intercoil spacings 10, 20, and 40 m.

The excel spreadsheet APPEM.xls was imported into Matlab to generate the profiling of the HD and VD on the same graph plotted against distance along the profile. This procedure was executed for the six profile lines as will be seen in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

Properly utilized geophysical methods can provide valuable information in waste disposal site characterization. The nonintrusive nature of geophysical investigations is consistent with the concept of preserving the integrity of a proposed waste disposal site, minimizing intrusive characterization methods such as drilling, trenching, and other exploratory excavations that can potentially compromise the integrity of the disposal site (McGinnis et al., 2011). Magnetic susceptibility and terrain electromagnetic datasets were used to delineate the subsurface contaminated zone, determining the extent, depths and predict potential direction of leachate migration and the establishment of structural control/direction within subsurface profile. These datasets generated high resolution maps that show major contaminant zones and direction of leachate flow present in the Asawase waste deposit site.

4.1 Digital Elevation Model (DEM)

The project site has an undulating nature due to the topography of the land. The area lies in the geological formations of the south-western part of Ghana. The digital elevation of the waste deposit site depicts that the elevation of the ground surface of the site is above sea level. The topography strikes in the NE-SW direction and dips in the NW-SE direction. It allows the simulation of areas with high risk of leachate flooding. The highest elevated region (A) is recorded at the south-western end of Figure 4.1 (from 291 to 294 m above sea-level).This region (A) represented by the dotted line is the main waste deposit. The areas marked by B1 and B2 at the eastern end of Figure 4.1 are separated by a low elevated region. The north and south-eastern end of the area also have very low elevation (C1 and C2).

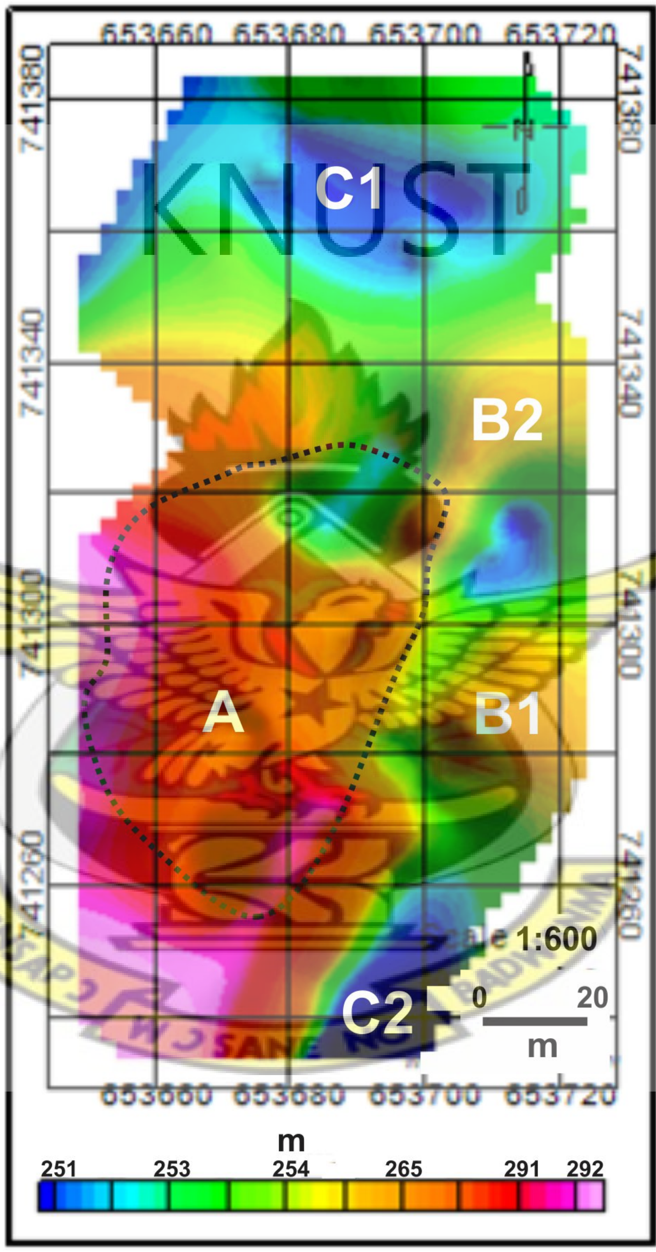

Figure 4.1: Digital elevation model of the Asawase waste deposit site.

4.2 Magnetic Susceptibility

Magnetic susceptibility is a parameter that characterizes the magnetization of a substance when it is subjected to a magnetic field. Magnetic susceptibility is the important parameter in magnetic exploration. Soils with high magnetic susceptibilities will have a high content of magnetic minerals or magnetic elements (Lowrie, 1990).

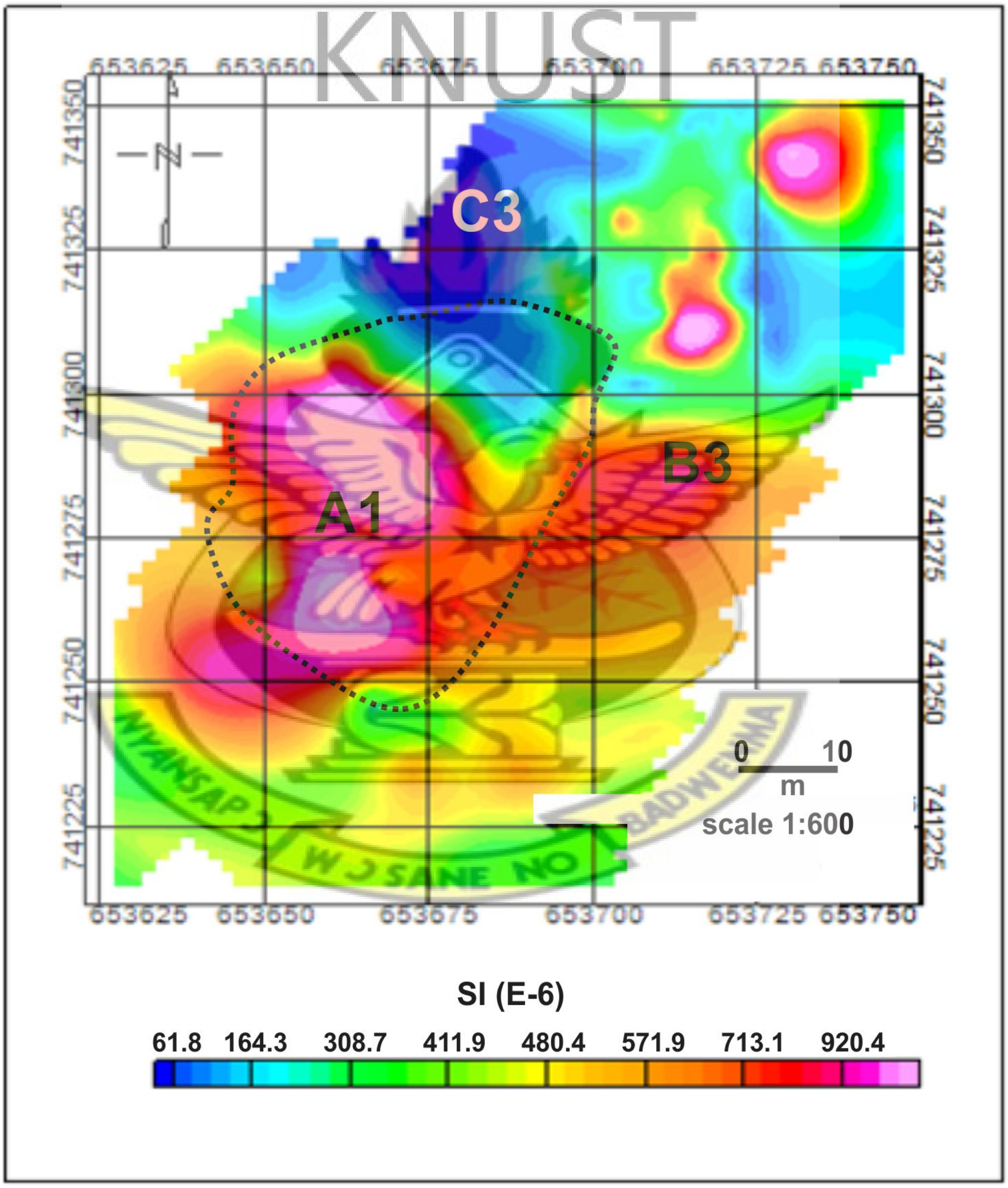

Figure 4.2: Magnetic susceptibility map of the Asawase waste deposit site.

Magnetic susceptibility is a characteristic parameter of a mineral. Its measurement gives information on Fe-bearing minerals especially magnetite (Fe_3O_4) which is about the main ferromagnetic mineral (Boadi et al., 2014). The project was undertaken to investigate the variability of the magnetic susceptibility measurements contaminating different waste materials with concentration of heavy metals.

The magnetic susceptibility measurements carried out purposely to get an insight into the general distribution of the magnetic susceptibility over the study area led to the result in Figure 4.2. The south most part of the site recorded moderate susceptibility readings as compared to the north most part with the central part recording the highest magnetic susceptibility readings. The north of region A1 in Figure 4.2 recorded very low magnetic susceptibility reading as compared to the south of the same region which recorded fairly high magnetic susceptibility reading. This indicates that the soil at the north of A (Figure 4.1) has a low content of magnetic minerals or magnetic elements whereas there is a high magnetic mineral content or probable ferrous minerals at the south of A.

The distribution for probable ferrous or magnetic mineral content within the area can be regarded as relatively high. The region marked A1 of Figure 4.2 is observed to record the highest magnetic susceptibility readings. A1 can be estimated to lie in a similar region as A of Figure 4.1 at the south-western end of the project area. Reconnaissance study of the Asawase waste deposit site indicates that the regions marked by A and A1 of Figures 4.1 and 4.2 respectively corresponds to where the waste deposit is actually located. This explains the high elevation and high magnetic susceptibility readings in these regions. Also the region B3 of Figure 4.2 which records high magnetic susceptibility readings lies in a similar region as B2 of Figure 4.1. The high magnetic susceptibility areas (A1, B3 and some areas of the north-eastern end of Figure 4.2) are associated with probable iron forming minerals such as magnetite (Fe_3O_4). The high magnetic susceptibility readings (Figure 4.2) through the east, south to the west depicts the probable directional flow of contaminants and leachate.

Some regions with low magnetic susceptibility readings are observed at the north-western end (C3 of Figure 4.2) which corresponds to some part of C1 of Figure 4.1. This may be caused by the fact that the dipping nature of the topography is in accordance with the direction of flow of contaminants and leachate caused by rain water. Also susceptible minerals such as magnetite within the region is destroyed by heat through burning of waste at the site. The lowest average susceptibility of the area is an indication of the likely presence of paramagnetic materials with low Fe ion concentration. This region may also be considered to be dominated by paramagnetic materials over the anti-ferromagnetic materials because measured average susceptibility is slightly positive.

The high magnetic susceptibility recorded at the north-east and south-east of B3 is due to the fact that regions B1 and B2 of Figure 4.1 each slopes in the north and south direction, a course likely to be taken by run-off water with probable magnetic minerals. This can be appreciated with the region marked by C2 in Figure 4.1 recording high susceptibility readings compared to the west of region C1.

The Figure 4.1 indicates the central and southern half of the area recorded higher magnetic susceptibility readings (more probable ferrous or magnetic minerals) than the northern half. Comparing measured magnetic susceptibility values to that of some materials considered by Dearing (1999), it can be inferred that, the lateral variation of susceptibility within this region is indicative of antiferromagnetic and paramagnetic materials. This is because the magnetic susceptibilities measured are positive (antiferromagnetic) and slightly positive (paramagnetic) as compared to strongly positive values which characterize both ferromagnetic and ferrimagnetic materials.

According to Boadi et al. (2014), the enrichment of soil of the environs of the project area with other metals such as Pb (Lead), Zn (Zinc) and battery waste may be caused by the emissions from the vehicles as well as the long distance transportation from remote sources of emissions. The transport of these emissions by wind and run-off which has its course channeled in the south-west direction is a major cause of the distribution of the magnetic susceptibility in the area. The anthropogenic emission sources in the study area are that of atmospheric particulates from vehicular emissions, domestic and industrial waste disposal.

4.3 Electromagnetic (EM)

Environmental pollution from solid waste landfilling (SWL) is of major concern to both environmental scientists and individual citizens. SWL inevitably generates chemicals or pollutants that reach their surroundings, such as soil, groundwater resources, and even the ambient air, because of environmentally unacceptable disposal of solid waste, or failure of lining system in the waste deposit sites. This can cause adverse effect on the environment and to public health and property (Wildung and Zachara, 1981). Human activities pollute fragile systems by modifying their quality to such an extent that subsequent use becomes restricted (Beatriz et al., 1998).

The electromagnetic prospecting technique is the most commonly used method in mineral exploration with the exception of magnetic. It is used occasionally to locate buried cables for the detection of land mines, and for mapping surficial areas infiltrated by contaminants.

The major reason explained earlier in this report for carrying out the electromagnetic conductivity sounding survey was to determine vertical and horizontal changes in conductivity around the waste deposit and its subsurface materials. The results are displayed for the various profiles (for the intercoil distances 10, 20, and 40 m) in both the vertical and horizontal dipole modes. The problem this survey seeked to address was to detect and map the extent of the contamination in the presence of conductivity variation caused by a parameter such as changing lithology. This will help create awareness of the dangers associated in siting bore holes near such areas.

4.3.1 Terrain Conductivity Profiles in Vertical Dipole (VD) and Horizontal Dipole (HD) Modes

The electromagnetic ground conductivity results in the VD and HD modes with the 10, 20 and 40 m intercoil spacing are presented below (using profle A as a case study). In such a profile interpretation of some of the important lookouts are the nature of the VD and HD lines with respect to the distance away from the source, which distance away from the source recorded the highest and lowest VD and HD values and also the intersection of the both the VD and HD lines at particular distance away from the source. The depth of exploration of the 10 m intercoil spacing for the horizontal dipole and vertical dipole mode is 7.5 and 15 m respectively.

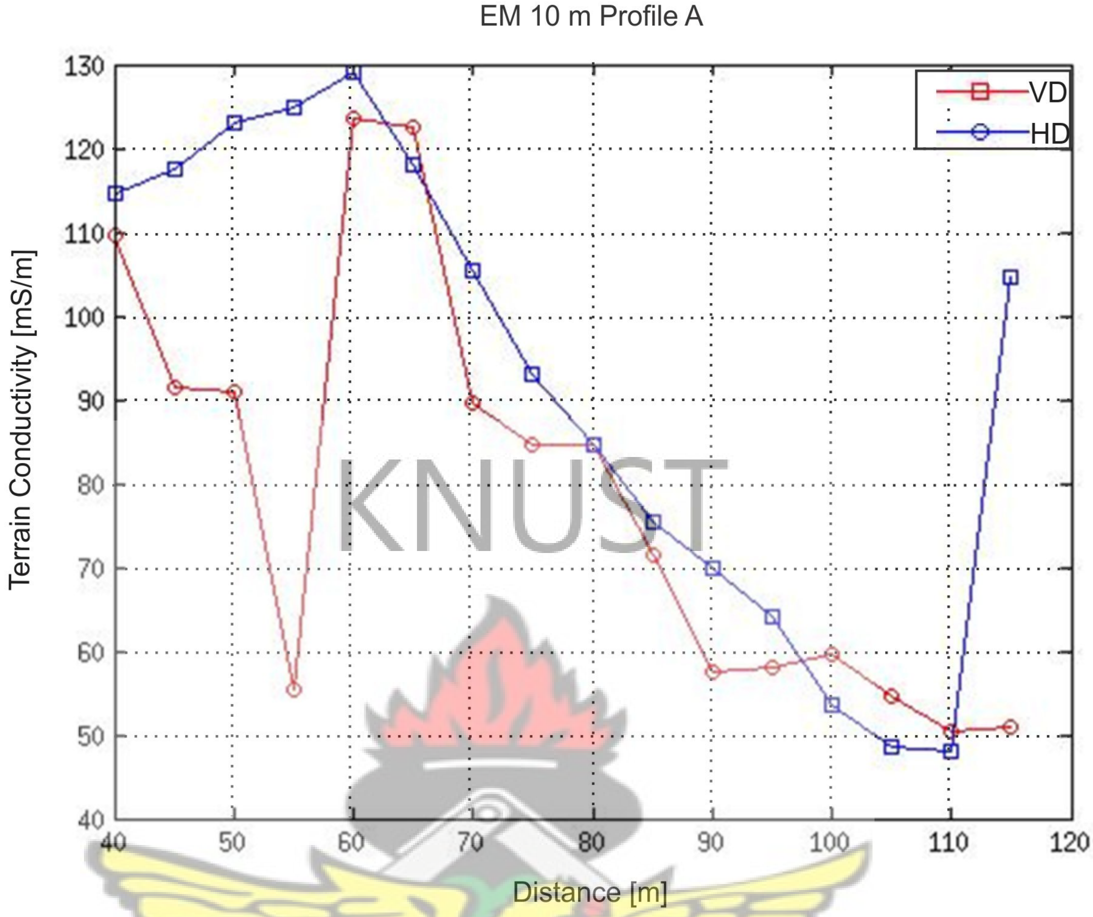

Figure 4.3: Plot of EM conductivity against distance along profile A using a 10 m coil spacing at Asawase waste deposit site.

The Figure 4.3 shows that the highest and lowest terrain conductivity for the HD occurred at a distance approximately 60 and 110 m (approximately 130 and 48 mS/m respectively) whereas the highest and lowest terrain conductivity for the VD mode occurred at a distance approximately 60 and 115 m (approximately 124 and 52 mS/m respectively) away from the waste deposit. At a distance of 40 m away from the waste deposit shows the terrain conductivity values for the HD modes show a gradual rise from 115 mS/m to 130 mS/m at a distance of 60 m away from the waste deposit. This indicates that conductive materials or probable landfill leachate increase steadily away from the waste to 60 m at a depth of 7.5 m. After 60 m from the waste deposit there is a gradual drop in terrain conductivity to approximately 50 mS/m at distance of 110 m from the waste deposit. It can be inferred that the flow of leachate or contaminants in solution decreases with distance after 60 m.

Similarly, the terrain conductivity values along the profile for the VD mode in Figure 4.3 show similar behaviour as the HD mode at a distance of 60 m away from the waste deposit. It can be seen that there is an erratic drop in conductivity from 110 mS/m for 40 m to approximately 55 mS/m for a distance of about 55 m. There is a sharp increase to about 125 mS/m at a distance of 60 m from the waste deposit; an indication of an abrupt change in the conductive materials (metalliferous materials) at both distances (55 m and 60 m) at a depth of 15 m. The Figure 4.3 also shows there is a gradual undulating decrease in the terrain conductivity from a distance of 60 m to about 115 m (50 mS/m). So clearly, both the VD and HD of Figure 4.3 reveal that the terrain conductivity decreases with distance away from the massively contaminated waste deposit site after 60 m which tends to indicate a reduction in the volume of leachate accumulation and or probable landfill leachate in the subsurface at a depth of 15 m.

Some conductivity crossover anomalies of the HD and VD modes in Figure 4.3 occur approximately at 65, 67, 98 and 110 m (Figure 4.3). This indicates the material composition and the conductivity characteristics of the lithology at these distances (65, 67, 98, and 110 m) away from the waste deposit, remains the same through the subsurface to a depth of 15 m. According to McNeill (1985), a disadvantage of operating in the horizontal dipole mode (HD) is the high sensitivity to near surface conductivity since variations in this conductivity can mask changes at greater depths.

Figure 4.4 is a graph of terrain conductivity against distance away from the waste deposit using the 20 m intercoil spacing along profile A on the Asawase waste deposit site. The

Figure 4.4 shows that the highest and lowest terrain conductivity for the HD mode are 97 ms/m and 40 ms/m occurring at distances 50 and 105 m respectively. Whereas the highest and lowest terrain conductivity for the VD mode are 85 mS/m and 45 mS/m occurrig at distances 50 m and 105 m respectively away from the waste deposit site. The depth of exploration of the 20 m intercoil spacing for the horizontal dipole and vertical dipole mode are 15 and 30 m respectively.

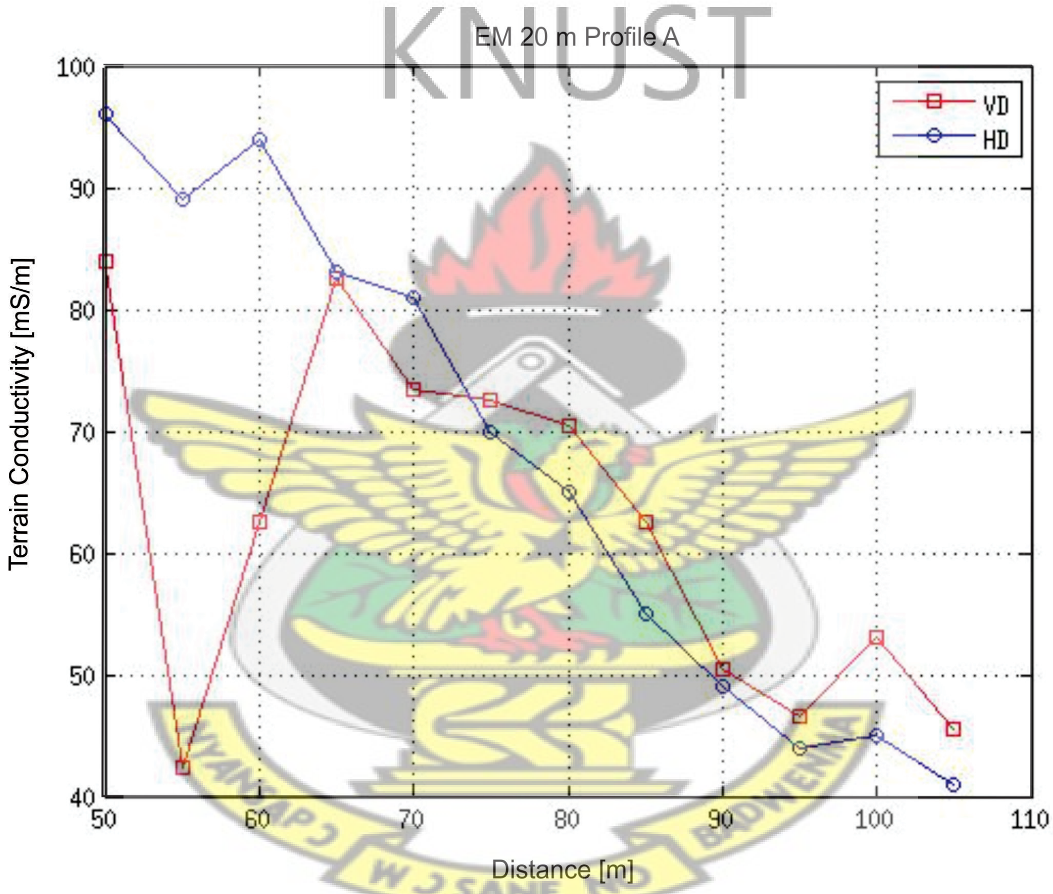

Figure 4.4: Plot of EM conductivity against distance along profile A using a 20 m coil spacing at Asawase waste deposit site.

The terrain conductivity values for the HD modes (Figure 4.4) decrease gently with the associated near surface materials at a depth of 15 m (conductive and or possible iron forming contaminant) from about 95 mS/m (50 m away from waste deposit) to about 40 mS/m (115 m away from waste deposit). Thus the HD mode (coils vertical coplanar) responded in maximum to near surface conductive materials and then decreased monotonically thereafter. Comparing the HD modes Figure 4.4 to Figure 4.3, it can be noticed that at a depth of 7.5 and 15 m the presence of contaminants or the flow of leachate kept decreasing gradually after a distance of 60 m away from the waste deposit.

At a distance of 55 m away from the waste deposit in Figure 4.4 and corresponding to a depth of 15 m, the terrain conductivity values for the VD mode shows a sharp change in conductivity as observed for the VD mode of Figure 4.3. This could be attributed to the presence of a fracture or local fault 10 m away from the 50 m distance mark. In Figure 4.3 since the depth of exploration (7.5 m) for the HD mode was not as deep as that of Figure 4.4 (15 m), the sharp decrease and increase of the terrain conductivity at the 55 m distance mark was not obvious. It can be deduced that the structure or anomaly (fault or fracture) responsible for such an anomaly at a depth of about 8 m. The conductivity decreases gradually again after a distance of 65 m from about 82 mS/m to about 40 mS/m at 105 m. Again comparing the VD modes of Figure 4.4 and Figure 4.3, it can be noticed that at a depth of 15 to 30 m, the decrease in terrain conductivity can be assigned to a distance of approximately 65 m away from the waste deposit site.

The intersection of the terrain conductivity of the HD and VD profiles in Figure 4.4 at distance of about 65 m away from the waste deposit continues through from a depth of 15 m (Figure 4.3) to 30 m. This means the same conductive material composition or the probable landfill leachate of the subsurface traverses through from the surface to a depth 30 m. At a distance of about 74 m away from the waste deposit site in Figure 4.4, there is another terrain conductivity crossover of the HD and VD anomaly but this extends to a depth of about 15 m at the same distance for Figure 4.3. This implies that at distance of about 74 m from the waste deposit along the profile, there is a lateral variation of the soil, mineral and contaminant composition occurring at a depth of 15 m from the Earth's surface.

The most important outlook for plotting VD and HD on the same graph is to see the points of intersection and crossover. Throughout Figure 4.3, Figure 4.4 and at about 89 m on Figure 4.5, there are records of series of intersections and crossovers located at maximum depth of 7.5 m and 15 m which are the depth of investigation for the 10 and 20 m intercoil spacing respectively in the HD mode. At points where the VD and HD intersect are indicative of the same electrical conductive material traversing the subsurface to that depth of investigation.

Also in Figure 4.3 and Figure 4.4 it can be observed that at the points where VD and HD begin to decrease with distance away from the waste deposit. This is likely to be associated with materials with similar electrical conductivity properties within that depth at which the closeness of the anomalies occur.

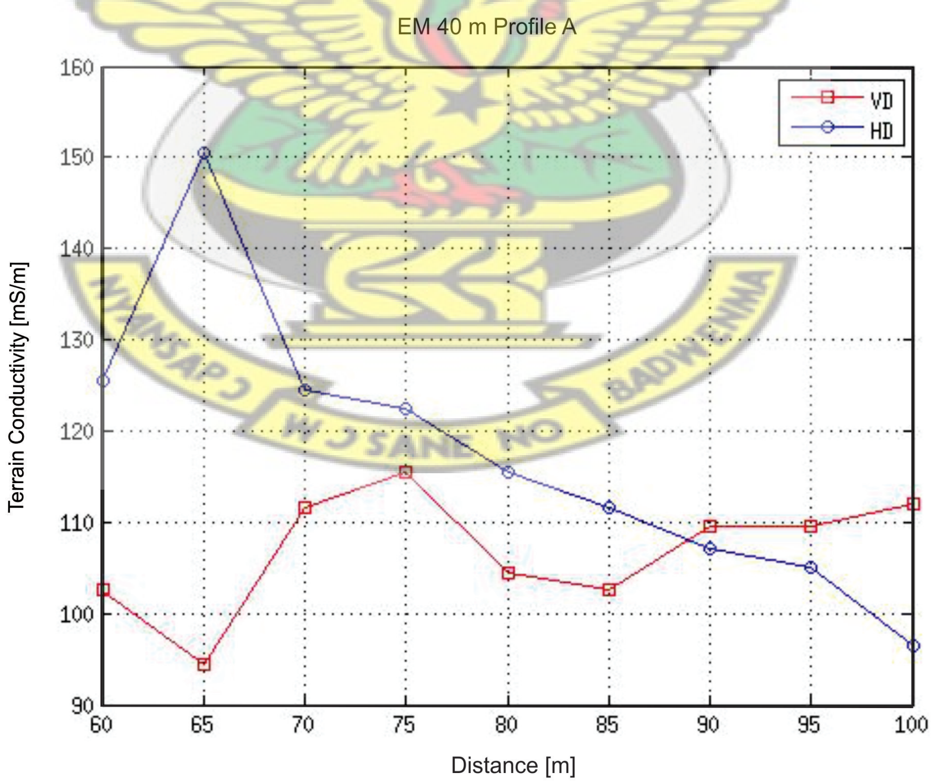

Figure 4.5: Plot of EM conductivity against distance along profile A using a 40 m coil spacing at Asawase waste deposit site.

The depth of exploration of the 40 m intercoil spacing for the horizontal dipole and vertical dipole mode is 45 and 60 m respectively. Figure 4.5 shows a graph of terrain conductivity plotted against distance away from the waste deposit using the 40 m intercoil spacing along profile A. This plot shows that the highest and lowest terrain conductivities are 150 ms/m and approximately 97 mS/m for the HD occurring at distances 65 m and 100 m respectively. Whereas the highest and lowest terrain conductivity for the VD mode are 115 mS/m and 94 mS/m occurring at distances approximately 75m and 65 m respectively away from the waste deposit site.

Similarly to Figure 4.3, the terrain conductivity in the HD mode decreases with increasing distance away from the waste deposit. This decrease in terrain conductivity is sharp at approximately 65 to 70 m (150 to about 124 mS/m) and the gradually decreases to 100 m recording a conductivity of about 96 mS/m. On the other hand, the profile of the terrain conductivity in the VD mode displayed an uncharacteristic undulating nature (series of increase and decrease of conductivity).

At a distance of 85 m (Figure 4.5) and a depth of 60 m away from the waste deposit, the VD increase gradually to a distance of about 100 m whereas at the same distance for Figure 4.3 (at a depth of 15 m) and Figure 4.4 (at a depth of 30 m) the VD decreases to a distance of 100 m away from the waste deposit. It can be deduced that from the top soil to a depth of about 30 m lies soil composition with moderately high contaminants or probable iron forming mineral and below this depth to about 60 m, the soil composition comprises strongly high conductive materials.

The VD and HD of Figure 4.3, Figure 4.4 and Figure 4.5 at distance of 75 to 85 m showed a similar decrease in terrain conductivity trend as expected with increase in distance away from the waste deposit. Though of similar trend (at distance of 75 to 85 m), both the terrain conductivity of the VD and HD of Figure 4.5 are higher than that of Figure 4.3 and Figure 4.4. This implies that the conductivity at such distance along the topsoil is largely influenced by the conductive soil materials that lie within a depth of 30 to 60 m

Moving from a distance of 60 to 70 m in Figure 4.5 away from the waste deposit, at a depth of 45 m, there was a sharp increase and decrease in the conductivity in the HD mode from about 125 to 150 mS/m and back to 124 mS/m with only one conductivity crossover anomaly occurring about 89 m with the VD mode but the HD of Figure 4.3 and 4.4 decreases gradually and steadily at the same distance thus conductivity values along the HD mode shows a greater availability of leachate as the EM waves gets to the exploration depth of 45 m.

The terrain conductivity values along the profile for the VD mode in Figure 4.5 shows reversal behaviour as the HD mode at a distance of 60 to 70 m away from the waste deposit. It can be seen that there is a slight drop and erratic rise in conductivity from 100 to 94 mS/m through to 112 mS/m respectively; an indication of an abrupt change in the conductive materials or probable landfill leachate along both distances at a depth of 45 and 60 m.

It can be deduced from Figures 4.3, 4.4 and 4.5 that the horizontal dipole (HD) mode (coils in a vertical coplanar) conductivity responded in maximum to near surface conductive materials, decreasing monotonically thereafter where as for the vertical dipole (VD) mode (coils in a horizontal coplanar), the relative responds is zero at near surface materials, increasing with depth and decreasing slowly thereafter as confirmed by McNeill (1985). Furthermore since the depth of exploration for the HD mode is not as great as in the VD mode, the apparent conductivity is expected to stay linear with true conductivity to much higher values of half space conductivity.

4.3.2 Terrain Conductivity Map in Horizontal Dipole (HD) Mode

A continuous geophysical profile reflecting the mean electrical conductivity (apparent electrical conductivity) was recorded at the Asawase waste deposit site using the induction principle with the Geonics EM 34-3, oriented in the horizontal dipole (HD) with intercoil distance of 10, 20, and 40 m and the depths of penetration or investigation (DOP or DOI) through the subsurface in this mode are approximately 7.5, 15, and 45 m.

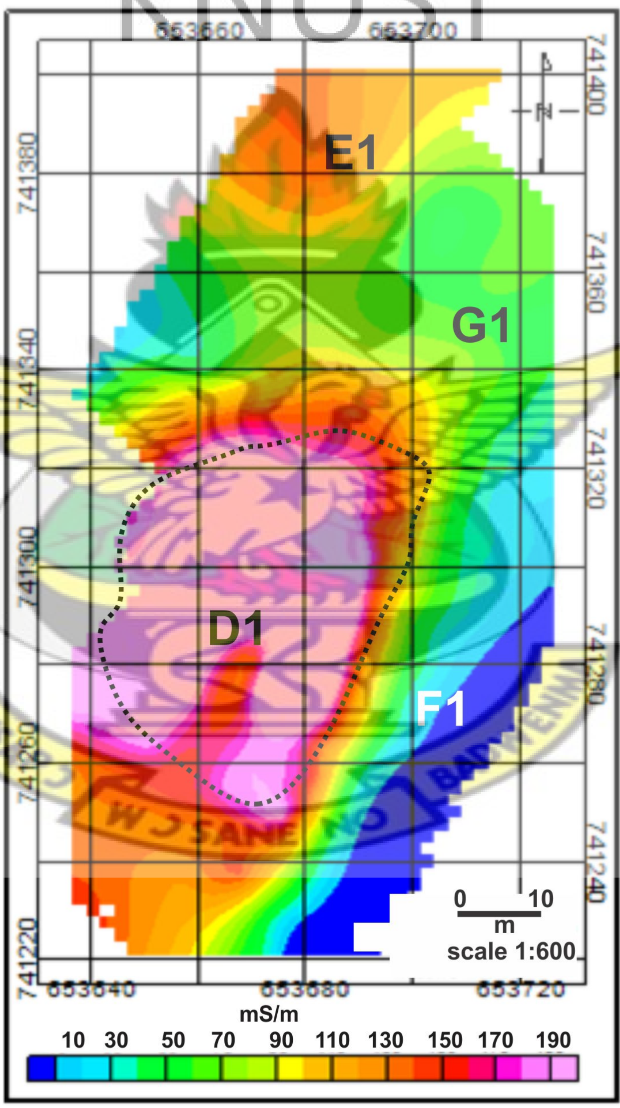

Figure 4.6: Terrain conductivity map using 10 m intercoil spacing in HD mode (DOP = 7.5 m).

There is no unique relation between (saturated) sediments and conductivity, because the conductivity is mainly determined by the salinity of the pore water, while the porosity and the material are of secondary importance but in a limited area however, it is possible to infer a certain relation between different sediments and apparent electrical conductivity (Seijmonsbergen et al., 2004).

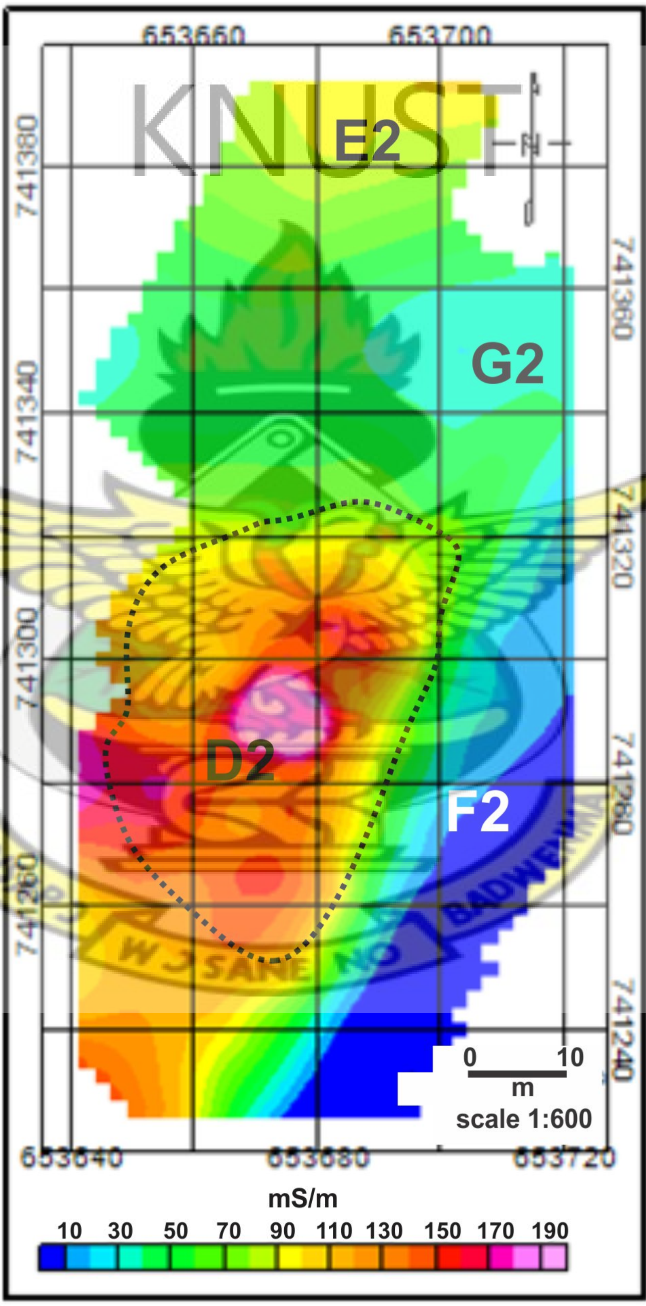

Figure 4.7: Terrain conductivity map using 20 m intercoil spacing in HD mode (DOP = 15 m).

According to Seijmonsbergen et al. (2004) the apparent electrical conductivity is a bulk conductivity measured at the surface to which underlying sediment layers, which have certain specific conductivities, contribute.

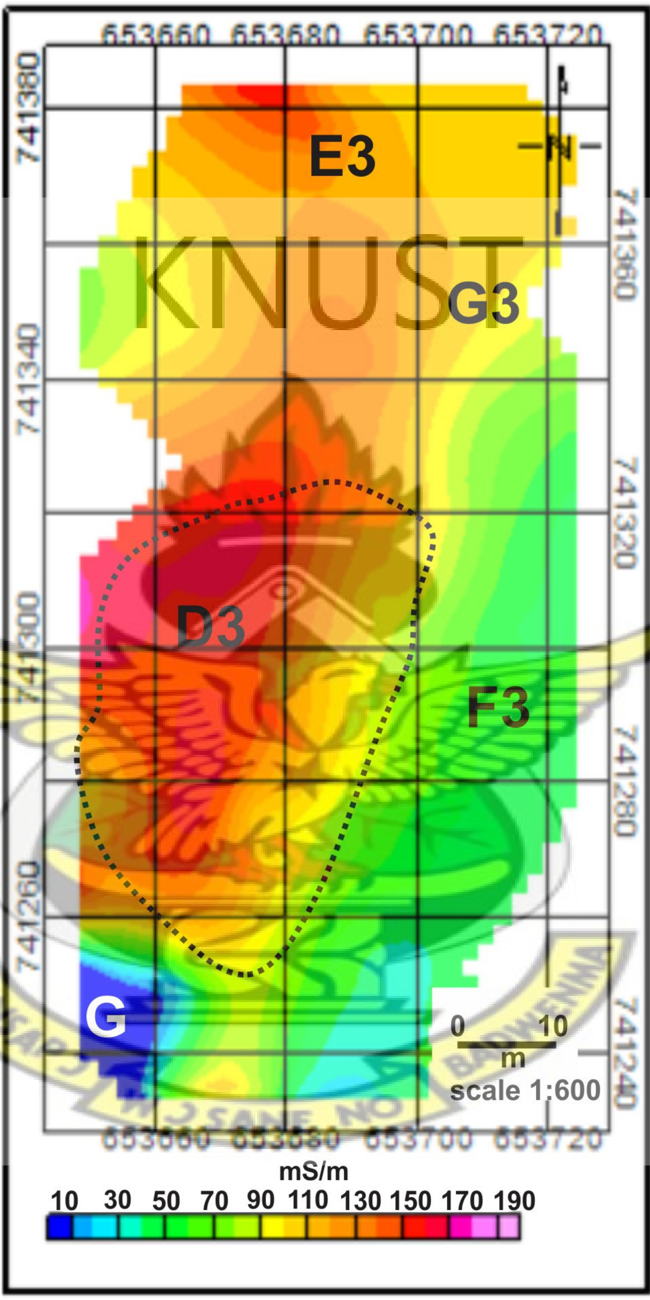

Figure 4.8: Terrain conductivity map using 40 m intercoil spacing in HD mode (DOP = 45 m).

In as much as the conductivity of the subsurface exists, these contributions however, decrease with the penetration depth of the conductive materials. High apparent electrical conductivity values are reached when the conductive layer is thick and close to the surface (Seijmonsbergen et al, 2004). The apparent electrical conductivity of the Asawase waste deposit site was recorded using the 10, 20 and 40 m intercoil spacing and the result gridded and displayed in Figures 4.6, 4.7 and 4.8 as shown above. These images show the relation between the apparent electrical conductivity of the subsurface and the geological in terpretation with respect to depth. The apparent electrical conductivity variation with amplitude in all the three images can be subdivided into low apparent electrical conductivities, low to medium apparent electrical conductivities and high apparent electrical conductivities which reflect the level of saturation of the contaminants in the subsurface.

The south-western part of the Asawase waste deposit site at a depth of 7.5m (Figure 4.6) has a high apparent electrical conductivity marked by the region D1 with high variation in amplitude between 110 to 200 mS/m. Although the anomaly in Figures 4.6, 4.7 and 4.8 strikes in the NE-SW direction, it can be proposed that D1, D2 and D3 of Figures 4.6, 4.7 and 4.8 respectively lies in the same region as A1 of Figure 4.2 which locates the waste deposit site. The regions D1(figure.4.6), D2(figure.4.7) and D3(figure.4.8) revealed that there could be electrical conductive materials and fractures (or high porous saphrolite) that may have allowed the flow of leachate from the waste deposit through the subsurface to a depth of 30 m (Figure 4.8). The decrease in size by A (Figure 4.1) in relation to D1 (Figure 4.6) to D3 (Figure 4.8) depicts that conductivity in this region decreases with depth. The region marked by E1 (Figure 4.6) which correspondingly lies in a low elevated area in Figure 4.1 with low magnetic susceptibility readings in Figure 4.2, is observed to be highly contaminated based on the high apparent electrical conductivity recorded at that region.

The region C3 was previously interpreted as having low magnetic susceptibility readings (low magnetic mineral composition) based on the fact that the magnetic susceptibility survey only mapped the susceptibility of the top soil of this region to a few centimeters down and also the depth of investigation is not as deep as observed by electromagnetic survey in the HD mode (using the 10 m intercoil spacing with a 7.5 m depth of investigation as displayed by Figure 4.6). These could be attributed to the reasons why the region E1 (Figure 4.6) now shows high contamination. The apparent electrical conductivity image of Figure 4.6 has indicated that at a depth of 7.5 m, the region C3 (which is represented as E1 in Figure 4.6) is highly conductive or has high leachate concentration. This region can be inferred to be porous or fractured to 'house' conductive materials or contaminants in solution.

A critical look at Figure 4.7 depicts the region E2 (which corresponds to E1 in Figure 4.6) has relatively high apparent electrical conductivity at the depth of 15 m thus a similar range of the electrical conductivity properties of the materials in both regions. Compared to Figure 4.8, the region E3 recorded very high apparent electrical conductivity and geologically, it can be inferred that at a depth of 45 m (Figure 4.8) there are more linear structures such as fractures that link the region E3 to the waste deposit than there are at the depth of 15m (Figure 4.7). This evidence is also observed in the regions marked G1 and G2 and G3 of Figures 4.6, 4.7 and 4.8 respectively. The regions E1, E2, E3, G1, G2, and G3 show that northern half of waste deposit site has a thick conductive layer and, the electric conductivity or the level of leachate concentration increases with depth and the direction of flow of leachate are intense in the north-east.

The apparent electrical conductivity is very low at the region marked G in Figure 4.8 as compared to the same regions in Figure 4.6 and Figure 4.7. This can be attributed to the fact that there is less conductive (highly resistive) material or no fractures to link the flow of leachate from the waste deposit to this region at the depth of 45 m. At the south-eastern part of the project area, the regions F1 (Figure 4.6) and F2 (Figure 4.7) recorded very low apparent electrical conductivity through subsurface to a depth of 15 m. Compared to F3 in Figure 4.8, it can be argued from the geological point of view that the south-eastern part of the project area hosts a resistive layer (having conductivity amplitude varying between 10 to 30 mS/m with less or no fractures, faults or pores to direct the leachate flow) to a depth of 15 m underlaid by a moderate conductive layer (40 to 100 mS/m) to a depth of 45 m.

An analytic statement by Seijmonsbergen et al. (2004) showed the electrical conductivity of a saturated material is a function of the water content and its conductivity (i.e the conductivity of water), porosity and the matrix conductivity but the latter two are related to lithology. Regarding this survey layers deeper than the maximum depth penetration of the instrument in this case 45 m for the entire project area, have no influence on the apparent electrical conductivity. Evidence deduced from the Figures 4.6, 4.7 and 4.8 helps to interpret electrical conductivity of the Asawase waste deposit site at a depth of 45 m to be an area with the northern part having a moderate conductive layer underlaid by high conductive layer, the central through to the south-western parts hosting a conductive layer to the depth of 45 m, and the east through to the south-eastern part has high resistive layer underlaid by moderately high conductive layer. The northwestern part of the landfill presents low to moderate electrical conductivity, characterizing a granitic base. The site is occupied by waste deposited onto tertiary stream sediments, and the groundwater level appears at around 5 meters depth. The contours of the waste disposed at the site can be identified based on the values of apparent electrical conductivity higher than 50 mS/m. The contamination plume can also be observed to flow to the west, marked by high values of apparent conductivity outside of the waste filled area.

4.3.3 Terrain Conductivity Map in Vertical Dipole (VD) Mode

It was known that EM methods effectively map locations of buried metallic objects, disturbed soils, and potential conductive ion leachate plumes emanating from landfills (Bisdorf and Lucius, 1999). Again, measuring soil conductivity with the EM 34-3 in VD mode, it is possible to detect locations of disturbed moisture-bearing soil and conductive leachate areas as was obtained. Reviewed works of Stanton and Schrader (2001) and Loke (1999) confirmed that disturbed soils generally have a higher porosity than undisturbed soil, with subsequent higher water content and therefore higher conductivity.Therefore, the soil in the burial zone such as that of the Asawase waste deposit site appeared to be more conductive unless mixed with less conductive materials. The investigation at the Asawase waste deposit site was successfully carried out using the Geonics EM 34-3 oriented in the vertical dipole (VD) mode with intercoil distances of 10, 20, and 40m whose depths of penetration or investigation (DOP or DOI) through the subsurface were approximately 15, 30, and 60 m. The results of the apparent electrical conductivity measurements was able to map the distribution of waste and identify zones of leachate contamination within and below the waste deposit. The investigation showed a wide distribution of conductive materials, which represent a zone of active leaching which is mostly concentrated in the south-western end of the waste deposit site.

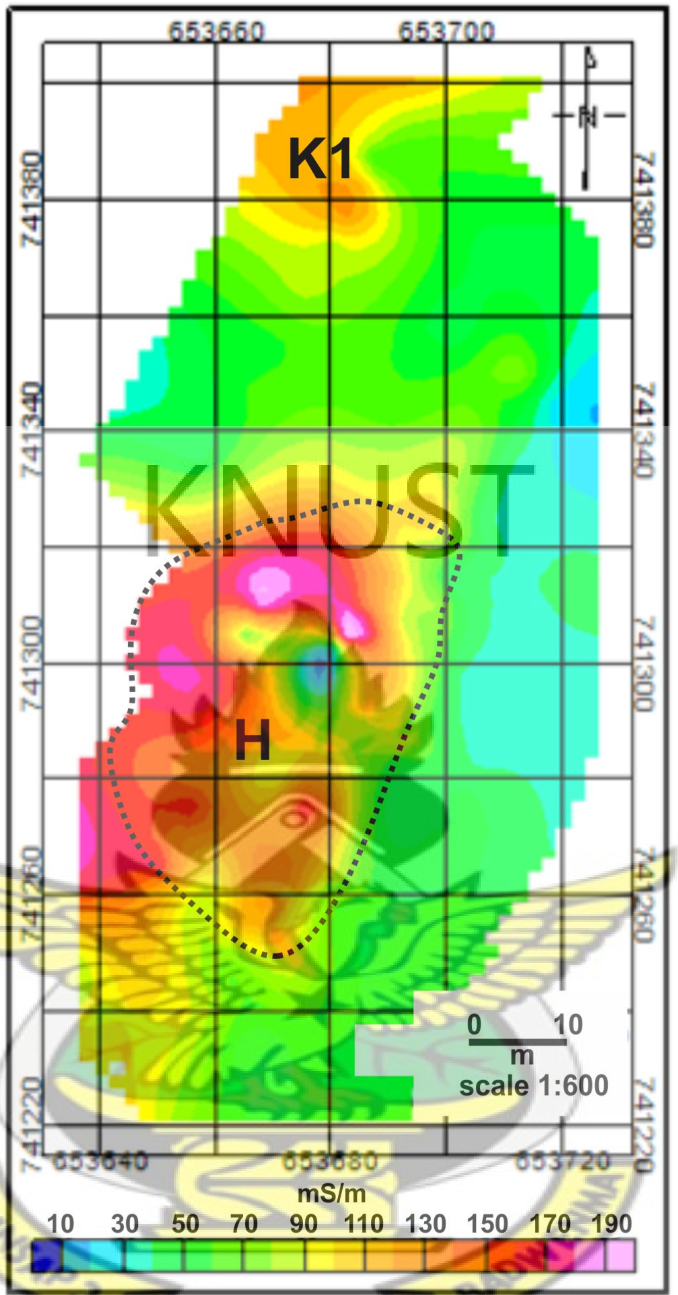

Figure 4.9: Terrain conductivity map using 10 m intercoil spacing in VD mode (DOP = 15 m).

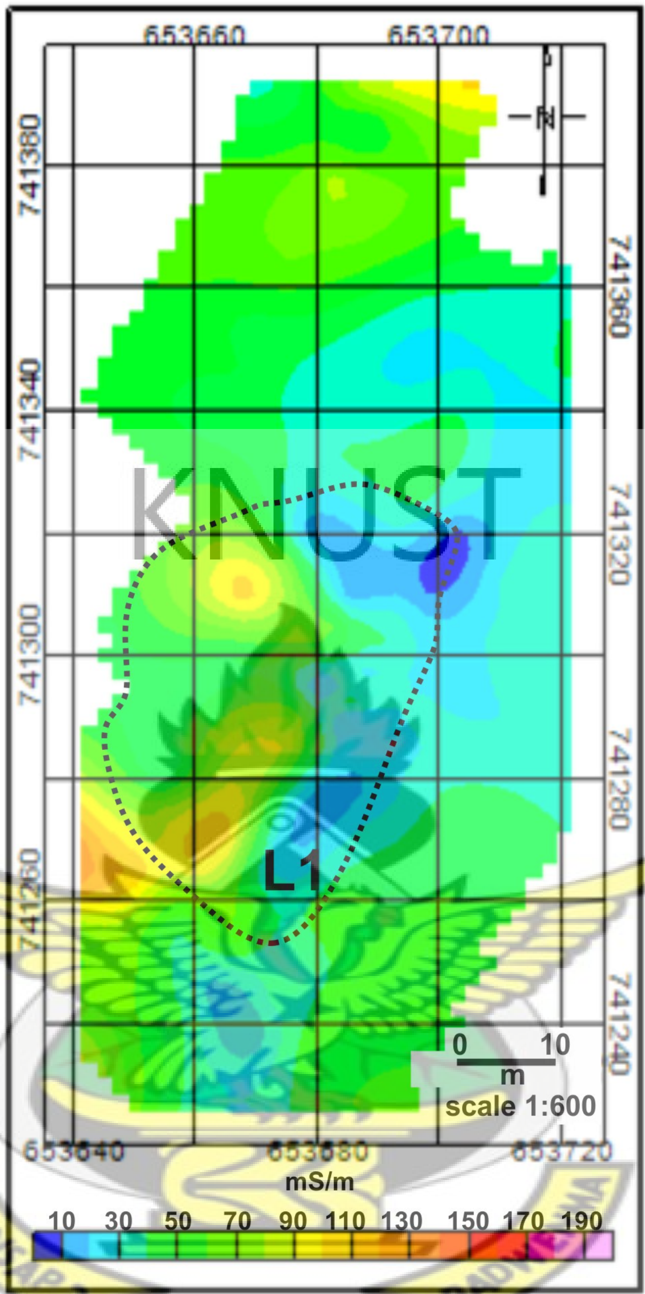

Figure 4.10: Terrain conductivity map using 20 m intercoil spacing in VD mode (DOP = 30 m).

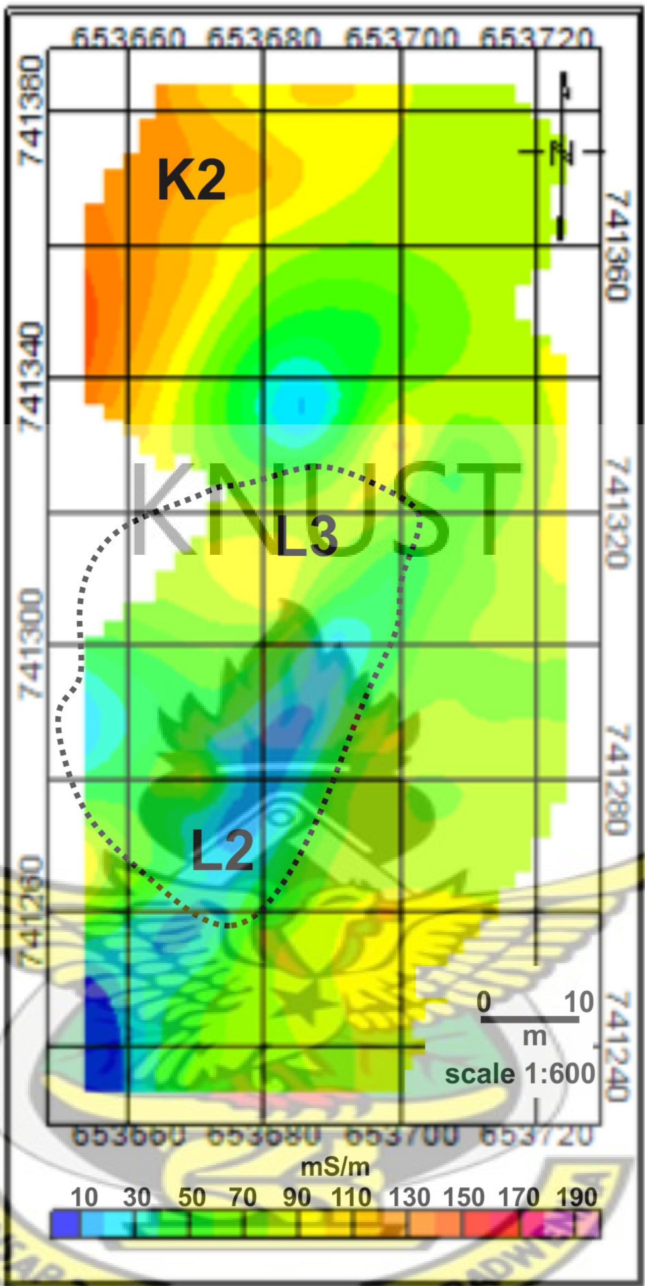

Figure 4.11: Terrain conductivity map using 40 m intercoil spacing in VD mode (DOP = 60 m).

By studying the maps above revealed that, high apparent electrical conductivity recorded at the south-western part of the deposit at a depth of about 15 m in Figure 4.9 (H), is noted to lie in the same region as the waste deposit. The VD mode in Figure 4.9, HD mode in the above results (Figure 4.6, Figure 4.7 and Figure 4.8) and Figure 4.2 have helped establish the fact that, the position of the waste deposit corresponds to the very high magnetic susceptibility reading and high apparent electrical conductivity region at the west and south-west regions of the project area.

At a 15 m depth of investigation, the 20 m intercoil spacing in HD mode (Figure 4.7) mapped lower apparent electrical conductivity (highly resistive) region F2 trending in the NE direction at the south-eastern end of the project area but the 10 m intercoil spacing in VD mode (Figure 4.9) recorded low to moderate apparent electrical conductivity in the same region. Gregory et al. (2000) made mention that very low apparent electrical conductivity values usually indicate that the instrument is oriented perpendicular to a highly conductive object whereas extremely high positive values of apparent electrical conductivity indicate that the metallic object is aligned parallel to the orientation of the instrument. The F2 region (Figure 4.7) is parallel to the survey line thus this is an indication that the region F2 corresponds to a laterally resistive layer rather than a conductive vertical layer. Also Figure 4.9 shows that the region marked E1 (with high apparent electrical conductivity) in Figure 4.6 which was inferred to be a conductive layer only at a depth of 7.5 m, is still a high conductive layer (K1) at a depth of about 15 m as compared to E2 in Figure 4.7 at the same depth.

A low conductive anomaly (highly resistive) and a moderate conductive anomaly striking in the NE-SW direction at a depth of 30 m is inferred in Figure 4.10 which underlies the region occupied by the waste deposit but the enhancement of their definitive boundaries are made clear in Figure 4.11 (L2 and L3) at a depth of 60 m representing two different geological formations with different electrical conductivity properties. Also the high apparent electrical conductivity attributed to the contaminant concentrations from the waste deposit shown in Figures 4.6, 4.7 and 4.8 is noted to have decreased at a depth of 60 m in Figure 4.11. Geologically this implies that a highly conductive layer underlies the west and south-west of the waste deposit site which is underlain by a discrete moderate resistivity zone with associated high resistivity zone below, possibly suggesting the presence of buried nonconductive material, with no leaking conductive fluid and presence of disturbed regolith associated with burial.

Electrical conductivity can be said to be increasing with depth at the south-eastern end of the waste deposit site. This is the area located at the east of the region marked L1 and L2 in Figures 4.10 and Figure 4.11 respectively. Contaminants in solution or leachate from the waste deposit are likely to flow through fractures to this part of the project site.

The apparent electrical conductivity trend in the east of the project site can be constructed based on the evidence deduced from the HD and VD mode images; to be increasing with the depth of investigation (even at 60 m). This type of anomaly is an indication that the area is a low resistivity zone with another low resistivity zone below it, possibly suggesting buried conductive material and leaking conductive fluid below it. Meanwhile that cannot be said about the northern half of the project area at a depth of 60 m since Figure 4.8 (DOP = 45 m) and Figure 4.11 (DOP = 60 m) have shown that the apparent electrical conductivity decreases with depth. This suggests that fracturing, porosity, contamination from leachate and conductive materials decrease with depth at the northern part of the Asawase waste deposit site.

Despite the above methods used,electrical geophysical prospecting methods are also capable of detecting the surface effects produced by electric current flow in the ground. Using electrical methods, one can measure potentials, currents, and electromagnetic fields which occur naturally or are introduced artificially in the ground. In addition, the measurements can be made in a variety of ways to determine a variety of results. There is a much greater variety of electrical and electromagnetic techniques available than in the other prospecting methods, where only a single field of force or anomalous property is used. Basically, however, it is the enormous variation in electrical resistivity found in different rocks and minerals which make these techniques used in this workrr possible (Telford et al., 1976). Conductivities of the Asawase waste deposit site are noted to vary in response to differing soil types. From a literature point of view, dry accumulation of sand or gravel typically yield low responses while naturally occurring ions, fertilized, fine-grained and/or saturated soils yield elevated backgrounds. Elevated backgrounds have magnitudes typical of ion-contaminated regions (Clarke et al., 2002). In such scenarios, trend behaviour of the anomalous zone may suggests the cause of anomalous conductivities. Metallic and ionic responses can often be distinguished by interpreting their characteristic behaviour and such behaviour is a function of geometric coupling between the instrument and buried metallic materials (Clarke et al., 2002).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Geophysical surveys are preferred over intrusive methods since geophysical techniques are relatively inexpensive, evaluate more area, and take less time (Gretsky et al., 1990; Heald, 1992). Geotechnical investigation was conducted using the magnetic susceptibility meter and MS-2D Bartington loop sensor, and electromagnetic instrument (Geonics EM 34-3) on different areas around the Asawase waste site deposit.This helped to find solution to the current problems of environmental liabilities and inadequate techniques for the investigation of contamination at the waste deposit sites.

The magnetic properties of soils are largely due to the presence of compounds of iron, in particular, oxides and sulfides of iron. The level of concentration of iron oxides in the soil depend on the age and nature of the soil, pedogenic and biological activities, and soil temperature. The distribution of pollution in soil depends on many factors, of which distance from the source, landscape morphology, vegetation and dominant wind direction are the most influential (Klučiarová et al., 2007). The electrical conductivity of a saturated material is a function of the water content and conductivity, porosity and the matrix conductivity. The latter two are related to lithology. The apparent electrical conductivity is a bulk conductivity measured at the surface to which underlying sediment layers, which all have certain specific conductivities, contribute. These contributions, however, decrease or increase with the penetration depth of the measurements.

The magnetic susceptibility measurements carried out purposely to get an insight into the general distribution of the magnetic susceptibility over the study area led to the observation that the southmost part of the site recorded moderate susceptibility readings as compared to the northmost part with the central part recording the highest magnetic susceptibility readings. The apparent electrical conductivity readings were contributed by the findings of the magnetic susceptibility readings. The high apparent electrical conductivity obtained is attributed to the contaminant concentrations at the waste deposit located at the central part of the area.This is noted to have decreased at a depth of 60 m in Figure 4.11. Geologically the central part of the survey area is underlain by a discrete moderate resistivity zone with associated high resistivity zone below, possibly suggesting the presence of buried nonconductive material,where no leakage of conductive fluid and presence of disturbed regolith associated with burial. The northern half of the project site has a thick conductive layer and, the electric conductivity or the level of leachate concentration increases with depth up to 45 m (Figure 4.8) and the direction of flow of leachate are intense in the north-east.

The measurements have shown that the geological formations around the Asawase waste site deposit can be typified according to their apparent electrical conductivity. It was also shown that important lateral changes in sediment types and layer thickness were identified. Regarding this survey layers deeper than the maximum depth of penetration of the instrument i.e 45 and 60 m (horizontal dipole mode and vertical dipole mode respectively) for the entire project area, had no influence on the apparent electrical conductivity.

At points where the VD and HD intersect (regions which appear at common depths that is comparing Figure 4.7 and Figure 4.9 at a depth of 15 m) are indicative of the same electrical conductive material traversing the subsurface to that depth of investigation. Furthermore since the depth of exploration for the HD mode is not as great as in the VD mode, the apparent conductivity is expected to stay linear with true conductivity to much higher values of half space conductivity for homogeneous material compositon.

The contamination or the direction of leachate flow, the conductivity and the level of fracturing in the Asawase waste site deposit can be proposed base on the findings of this survey area as follows:

- The highest elevated region marked A in Figure 4.1 (representing the central and the south-western part of the area) is the waste deposit (with a well defined boundary; the yellow anomaly around the region A in Figure 4.1) which has magnetic materials such as magnetite contributing to the high magnetic susceptibility readings.Other materials such as scraps,battery waste and electronic waste and other ferrous metals also contributed to these high readings. This region due to high level of iron forming contaminants was also mapped by the apparent electrical conductivity images (Figure 4.6, Figure 4.7 and Figure 4.8) in the horizontal dipole.

- The northern part of the project area had three subsurface layers based on their conductivity responses. The first is moderately conductive with moderate conductive materials which has less or no fractures at a depth of 30 m. Above this layer is a high electrical conductive zone at a depth of 7.5 m and these two zones or layers are underlain by higher electrical conductive zone below which conductivity decreases to the depth of investigation of 60 m.

- The directions of leachate flow is in the NE direction and vary from a depth of 45 m (Figure 4.8). The high apparent electrical conductivity measured in the north-eastern part at this depth (45 m) is because the subsurface may be highly fractured linking the flow of leachate to this region. The north-western part is the other region expected to pose more contaminants after the central and south-western part. Conductivity in this region is also noted to decrease with depth.

- One of the important information deduced from terrain conductivity images (Figure 4.6, Figure 4.7 and Figure 4.8 in the HD mode and Figure 4.9, Figure 4.10 and Figure 4.11 in the VD mode) is that the subsurface of the east through to the south-eastern part of the area lies in a region of low to moderate apparent electrical conductivity. There is no much distinction in the electrical conductivity at this part of the project area at the various depths of investigation. This region can be said to be moderately compacted, resistive or has disturbed regolith. Comparing terrain conductivity images in the HD mode indicates electrical conductivity increases moderately with the depth of investigation and the same conclusion can be drawn from comparing terrain conductivity images in the VD mode.

The enrichment of soil of the environs of the project area with other metals such as Pb (Lead), Zn (Zinc),roofing sheets,batteries and electronic wastes may be caused by the emissions from the vehicles,industries as well as the long distance transportation from remote sources of emissions. The transport of these emissions by wind and run-off which has its course channelled in the south-west direction is a major cause of the distribution of the magnetic susceptibility in the area. The anthropogenic emission sources in the study area are that of atmospheric particulates from vehicular emissions, domestic and industrial waste disposal. The research results were aimed at the appropriate monitoring and proper installation of sanitary landfills. Therefore, one of the conclusions drawn from the exercise is that it is fundamental to know exactly all the goals, local interests, background factors and resources involved in each case, for an effective and optimized geoenvironmental site investigation.

The integrated techniques employed to measure different physical properties of the subsurface have assisted in the precise description of the subsurface as well as reducing ambiguity and improvement of the models interpretation. The study has also shown that both the magnetic susceptibility and electromagnetic methods can be effective diagnostic tools to investigate lechate flow due to municipal solid waste in an area.

5.2 RECOMMENDATIONS

The profile plot of horizontal dipole mode and vertical dipole mode for the 10, 20 and 40 m intercoil spacing on the same graph for Asawase waste site deposit has shown the possibility of intersection of the two profile line. Electrical resistivity sounding is thus recommended to be carried out to investigate the depth to which this intersections occur because variations in the resistivity of earth materials, either vertically or laterally, produce variations in the relations between the applied current and the potential distribution as measured on the surface, and thereby reveal something about the composition, extent, and physical properties of the subsurface materials.

Environmental pollution from solid waste landfills is of major concern to both environmental scientists and individual citizens. SWL inevitably generates chemicals or pollutants that reach their surroundings, such as soil, groundwater resources, and even the ambient air, because of environmentally unacceptable disposal of solid waste, or failure of lining system in the waste site deposits. This can cause adverse impacts on the environment and to public health and property. The detection of a concentration of several constituents of leachate (like heavy metals, metals, chloride, organic compounds, chemical oxygen demand and biological oxygen demand), solutions and effluents collected during the tests, need to be chemically analyzed, using emission or atomic absorption spectrometers, flame photometry, chromatography and any other appropriate techniques.

Self-potential measurement is recommended to be carried out at the waste site deposit. This survey will help measure the electro filtration potential and liquid-junction potential created due to the movement and infiltration of the leachate from the waste site deposit into the soil and the difference in concentration between the leachate and the water in the pores of the rocks. The self-potential measurement will be used in the monitoring of the contaminant plume movement around the waste site deposit. Moreover impact assessment model can be developed to model the level of pollution to see its long term effect on the environment. The discharge from the waste site deposit into the water bodies can be modelled using Water Quality Analysis Simulation Program (WASP) and Discharge Monitoring Report (DMR).

References

1. Allen, D. G. (2011). The Fahiakoba gold project Ghana, West Africa. Technical report, Asante Gold Corporation.

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Appendix A

A.1 Plot of EM conductivity against distance along profile B using a 10, 20 and 40 m coil spacing at Asawase waste dumpsite

A.2 Plot of EM conductivity against distance along profile C using a 10, 20 and 40 m coil spacing at Asawase waste dumpsite

A.3 Plot of EM conductivity against distance along profile D using a 10, 20 and 40 m coil spacing at Asawase waste dumpsite

A.4 Plot of EM conductivity against distance along profile E using a 10, 20 and 40 m coil spacing at Asawase waste dumpsite

A.5 Plot of EM conductivity against distance along profile F using a 10, 20 and 40 m coil spacing at Asawase waste dumpsite

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Appendix B

B.1 Used Softwares

- LaTeX : typesetting and layout
- Coral Draw X5 : graphics
- Oasis Montaj (Geosoft): data processing and enhancing
- ArcGIS Desktop 10