Detection and Delineation of Contaminant Migration using the Terrain Conductivity Technique outside the Perimeters of the Dompoase Landfill Facility in Kumasi – Ghana.

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Abstract

Electromagnetic conductivity survey was conducted outside the perimeters of an active municipal landfill facility located at Dompase, a suburb of Kumasi, Ghana. The study was undertaken to identify potential conductive layers probably connected with leachate communication from the landfill. The Geonics EM 34-3 terrain conductivity equipment was used as the geophysical tool for the survey. Operating in the low induction number regime, three intercoil separations of 10, 20 and 40 m were used in both the horizontal and vertical dipole configurations. The specific area of interest was the two sides of a discharge stream which carries treated effluent from the treatment ponds. Data were acquired at 10 m meter interval along sixteen east–west profiles, each of length 100 m, running approximately perpendicular to the discharge stream. There were seven and nine profiles respectively on the right and left sides of the discharge stream. The high conductivity found within the depths 30 to 60 m close to the southern boundary of the landfill might suggest leachate communication from the landfill. The linear pattern of the contour lines in that anomalous zone probably indicate the presence of zones of weakness trending approximately perpendicular to the direction of flow of the discharge stream. This weak zone could account for the lateral spread of leachate within those depths, where leachate plume has so far migrated.

Keywords: Aquifer, Contamination, Leachate, Electromagnetic conductivity, Geonics EM-34-3, Horizontal dipole, Landfill, Monitoring well, Vertical dipole.

1. INTRODUCTION

Groundwater is water that exists within soils and fractured rocks underneath the ground. Groundwater is usually replenished by rain water. The soils and rocks that hold the water underneath the ground are known as aquifers. When groundwater is being replenished, the aquifer usually gets saturated with water. The top of this saturated zone is called the water table. By reason of its location, groundwater is often cleaner than surface water. Groundwater is usually protected against contamination from the surface by soils and covering rock layers. In Ghana, a lot of households in the urban and peri-urban areas rely on groundwater abstracted from boreholes and hand-dug wells for domestic uses. However, rising population, changes in land use and rapid industrialization is increasingly placing soil and groundwater at risk of contamination. Contamination of the subsurface can take place in many ways: pollution of groundwater or soil through direct contamination, saltwater intrusion, or leakage from buried waste, landfills and even cemeteries (Bastianon et. al., 2000).

Land use such as landfilling, which produces leachate has been found to be one of the major sources of contamination of groundwater (Bjerg et al, 2003), Chofqi et al. 2004; and Christensen et al. 1994; have reported the contamination of groundwater by landfill leachate. Contamination of groundwater by nonorganic landfill leachate may even eventually lead to surface water contamination because groundwater usually discharges to surface water bodies such as lakes and rivers (Freeze & Cherry 1979). Non-organic (ionic) groundwater contamination from leachate usually results in an increase in the conductivity of the groundwater. For example, in a sandy soil, the addition of 25 ppm of ionic material to groundwater increases ground conductivity by approximately 1 mS/m (US EPA, 2006).

According to WHO usage (WHO, 2006), groundwater contamination is defined as the introduction into water of any substance in undesirable concentration not normally present in water, e.g. microorganisms, chemicals, waste or sewage, which renders the water unfit for its intended use.

The soil filters the water and absorbs and removes many contaminants though some will pass through

unimpeded. But if the soil layer is thin, has high permeability, or if the water table is close to the land surface, then the soil is less likely to adequately treat contamination. The excess contaminants may pass through the zone of aeration and enter the groundwater in the zone of saturation. If this happens, a plume forms. A plume is an underground pattern of contaminant concentration created by the movement of groundwater beneath a contaminant source. The contaminant spreads mostly laterally in the direction of groundwater movement. The site of original contamination has the highest concentration of contaminant and the concentration decreases as it moves further away from the source.

Groundwater contamination can be from natural sources or from man-made activities or both (Duah, 2006). Groundwater gets naturally contaminated as a result of their interaction with soils and rocks in which they are found. A monitory programme undertaken by the regional Ghana Water and Sewage Cooperation Laboratory in Tamale on 93 boreholes and shallow well water supply sources in the region indicated that about 63.5 percent of the wells had fluoride concentrations in excess of 1.0 mg/l. The problem has been attributed to the geology of the area i.e. Bongo granite (Smedley et al, 1994).

Man-made sources of groundwater contamination include, poorly designed hazardous waste disposal facilities e.g. unlined landfills or open dumps, leakages from underground storage tanks, liquid spills and discharges from mining activities and excessive use of pesticides and fertilizers in agriculture. In Ghana the main man-made source of groundwater contamination is due to agricultural practices and mining activities (Duah, 2006

Surveys conducted in the Upper East region of Ghana in 1969, 1977 and 1980 revealed a significant increase of nitrate levels in groundwater between 1977 and 1980. Between 1959 and 1977, where there was not much agricultural activity in the area no appreciable increase in nitrate levels was recorded (Akiti, 1982).

Landfills are another major source of soil and groundwater contamination. Landfills are places where garbage is taken to be buried. Landfills are supposed to have protective bottom layers to prevent contaminants from getting into the groundwater system. However, if there are no preventive layers or these layers are breached, contaminants in the form of leachate from deposited waste materials like car battery acid, paint, household cleaners, etc. can make their way down into the groundwater. Landfills in Ghana are primarily open dumps without leachate or gas recovery systems (Mensah et. al, 2005).

To contain the above potential hazards, Sanitary Engineered Landfills are employed as alternative means of disposing and managing municipal solid waste. Sanitary Engineered Landfills have highly engineered containment systems designed to minimize the impact of solid waste disposal on the environment and ultimately on human health (Kerry et al, 2005). This highly controlled containment systems are achieved by the use of liners and other containment mechanisms.

Landfill liners are applied on landfills to provide barriers to minimize migration of leachate from the containments site to the groundwater in the adjoining regions. This is normally achieved by installing a liner system at the base and sides of the landfill. Kerry et. al. (2005) describe three hierarchies of landfill types and liner systems; the single, composite and double liner systems. Single liners consist of a clay liner, a geosynthetic clay liner, or a geomembrane (specialized plastic sheeting). The second is the composite liner which consists of a geomembrane in combination with a clay liner. Composite liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. The third in the hierarchy is the double liner which consists of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills

Sanitary landfills however, may not be without flaws; the containment systems may not absolutely eliminate leaching and could also suffer from some form of structural failure which may not readily be detected. For these and other reasons, engineered landfills have groundwater monitoring wells to assess the state of groundwater in the area from time to time.

These monitoring wells are sometimes not enough or widely spread around the periphery of the facility and within the contiguous lands to assess the potential impact of the landfill leachate on the surrounding groundwater. Again, sampling wells may not be able to indicate possible lateral and vertical spread of contaminants and finally the cost involved in conducting laboratory analyses may be prohibitive and may prevent landfill operators from conducting regular and periodic groundwater assessment.

The traditional way of monitoring groundwater using wells has been found to be expensive, not widely distributed and occasionally fail to define the full extent of any contamination (Hutchinson et al, 2002). In this

respect, geophysical Electromagnetic Induction (EMI) survey methods have emerged as useful tools to characterize both the horizontal and vertical extent of groundwater contamination. The geophysical method offers innovative and noninvasive tool for identifying subsurface contamination in these situations. Electromagnetic induction has been used by researchers to infer the relative concentration, extent, and movement of animal waste products in soils, because of its sensitivity to soluble salts (Brune and Doolittle, 1990; Drommerhausen et al., 1995; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; Stierman and Ruedisili, 1988). Electromagnetic surveys have been also used for landfill boundary detection (Mack and Maus, 1986; Scaife, 1990.

In this study, Electromagnetic Induction Terrain Conductivity measurements were taken with the Geonics EM34-3 equipment to assess any possible contaminants migration into the lands contiguous to one of the major engineered sanitary landfill facilities in Kumasi, Ghana – The Kumasi Sanitary Landfill and Septic waste treatment facility located at Dompoase, a suburb in Kumasi.

The facility was commissioned seven years ago and it covers an overall area of 40 hectares. The facility admits industrial waste, domestic waste, and septage waste for treatment. The challenge, however, is that the site has only two wells for groundwater monitoring, which is inadequate and cannot completely characterize the state of the underground water in the area.

Reconnaissance at the facility and interaction with the facility supervisors revealed that high volumes of leachate are generated daily. The landfill has a network of pipes and trenches to collect the leachates for treatment. Though the facility has not caused any environmental problems, particularly from the leachate seeping out of the refuse pile into the adjoining groundwater system, the high volumes of waste admitted daily and the seasonal heavy downpour make it imperative to study possible leachate communication from the landfill to the adjoining region. Any potential contamination, if not addressed will put the life of those neighbouring residents who depend on groundwater in danger of contracting water related diseases.

2 METHODOLOGY
2.1 Location and Description of Study Site
The Kumasi Sanitary Landfill and Septage treatment facility is located at Dompoase a suburb in Kumasi. The facility was established under the World Bank financed Urban Environmental Sanitation Project (Urban IV), and the Government of Ghana, under the Ministry of Local Government's Urban Environmental Sanitation Project. It commenced in January 2004 and was designed to handle both solid waste and seepage produced in the city of Kumasi. The site is bordered on the south by the Oda River. The site has an overall area of 40 hectares (Fig. 1).

A 1.5 km long access road to the landfill links the Dompoase road through the industrial township to the north-western corner of the site. There is a security fence around the perimeter of the site. The landfill area is a valley, with a mound located in the north – eastern half forming a smaller separate catchment area.

The septage ponds are located at the lowest elevation of the site and are situated in the valley that is present on the site (Kumasi Landfill and Septage Facility General Operation and Maintenance Guidelines). The septage ponds are designed to treat both municipal septage and leachate from the landfill. These effluents after treatment are discharged into the Oda river through a nearby stream (Fig. 1).

The facility has a 15-year design life to cater for the current daily generations rates of 860 tons solid waste and 500 cubic metres fecal sludge including the projected future increases after which new facilities would be required (Mensah et al., 2003).
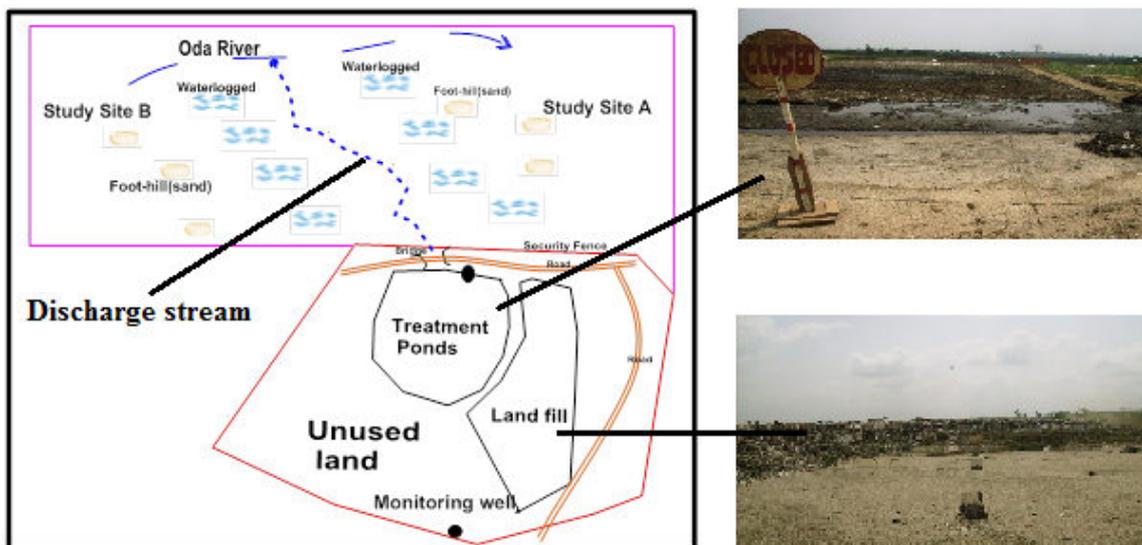
Fig. 1 Location and Layout of the Kumasi Landfill and Septic waste Treatment Facility

2.2 Geology

Kumasi area is underlain by rocks of the Lower Birimian System, consisting principally of phyllites, greywackes and schist, intruded in places by quartz veins and stringers and massive granitic batholiths which are in turn often cut by pegmatite veins. A substantial part of the city of Kumasi is underlain by the so called Kumasi granitic batholiths (Kessie, 1985). Geology at and around the Kumasi Landfill and Septage Facility is described as lying within the Kumasi granitic batholiths, which is a post-Birimian intrusive of Precambrian age. The project site is covered by lateritic soil which is essentially a product of intense chemical weathering of the underlying granitic bedrock. These consist mainly of sand to silt sized quartz particles in a matrix of clay formed from the weathering of the feldspar constituents of the granitic rock.

2.3 Layout of site for data acquisition

A topographical study of the area was undertaken to identify drainage pattern outside the perimeter of the landfill. An area lying on the south eastern part of the landfill boundary was selected for the survey (Figs.1 and Fig. 2). The area was chosen because it contains the discharge stream which carries all the treated effluent from the landfill to join the Oda River about one kilometre away. At the time of the investigation the area was being used for small scale farming and sand winning.

Profiles of length 100 m were demarcated on both sides of the discharge stream. These profiles run approximately perpendicular to the stream in the east-west direction. The distance between adjacent profiles was 10 m. The distance between measurement points on each profile was also 10 m. On each profile line 10 observation points, 10 m apart were recorded. Data were therefore obtained in grid form.

Fig. 2 Sections of study site showing the discharge stream

2.4 Geophysical Measurements

In this investigation the EM ground conductivity survey was done using the Geonics EM34-3 instrument. This instrument is designed and manufactured by GEONICS Limited Ontario, Canada. It consists of insulated transmitter and receiver coils with equal internal diameters of 63 cm. The EM34-3 uses three intercoil spacings -10, 20 and 40 m to provide variable depths of exploration down to 60 metres (Table 1). There are two main modes of operation: the horizontal dipole mode (HD) where the transmitter and receiver coils are positioned vertically and the vertical dipole mode (VD), where the coils lie horizontally on the surface.

Table 1 Exploration depth for EM 34-3 at various intercoil spacing (McNeil, 1980).

At

Intercoil Spacing (meters)	Exploration Depth (m)		Frequency (kHz)
	Horizontal Dipoles	Vertical Dipoles	
10	7.5	15	6.4
20	15	30	1.6
40	30	60	0.4

each

observation point the horizontal dipole (HD) mode reading is taken first, followed by the vertical dipole (VD) mode, to probe different depths based on the respective intercoil spacing (10 m, 20 m and 40 m). All the three intercoil spacing were used and data were acquired for both the vertical and horizontal dipole mode in order to characterize the conductivity anomalies that may exist within the chosen site.

The approximation upon which the instrument works is technically defined as operation at low values of induction numbers. This condition is incorporated in the design of the Geonics EM34-3 equipment (Mc Neil, 1980). This makes it possible to construct linear terrain conductivity meter to give a direct reading by simply measuring the ratio H_S/H_P. this ration is given as

$$\frac{H_S}{H_P} \cong \frac{i\omega\mu_o\sigma s^2}{4} \qquad (1)$$

Given this ratio, the apparent conductivity indicated by the instrument is defined from the equation (1) as

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

Equation (2) gives the apparent conductivity σ_a in terms of the frequency f, and intercoil spacing, s. The ratio of the secondary magnetic field to the primary magnetic field is linearly proportional to the apparent conductivity. Measurements taken under the condition of low induction numbers provide apparent terrain conductivity, σ_a which the EM34-3 equipment reads directly in millisimens per meter (mSm^{-1}).

3 RESULTS

Data were acquired along sixteen east–west profiles, each of length 100 m, and run approximately perpendicular to the discharge stream. The distance between measurement points was 10 m and all three intercoil separations of 10 m, 20 m and 40 m were used. At each location, six apparent conductivity values were obtained by making measurements in both the horizontal and vertical dipole modes with all the three intercoil separations. The data acquired therefore represent lateral variations in apparent EM conductivity at various depths on each side of the discharge stream. These nominal exploration depths as dictated by the selected frequencies and intercoil separations are 7.5 m, 15.0 m and 30.0 m respectively for the horizontal dipole mode. For the vertical dipole mode, the respective depths are 15.0 m, 30.0 m and 60.0 m. For each of these exploration depths, the EM field data are represented in the form of conductivity contours to identify any significant spatial trend that might exist in the EM dataset at the indicated depths.

These contour maps were generated with Surfer (Version 10) using the kriging gridding method. The kriging gridding weighs the surrounding measured values to derive the prediction for each location. The weights are based on the prediction location and on the overall spacial arrangement among the measured points (Geoff Bohling, 2005). The advanced colour scheme was adopted with custom colours. Ten colours were assigned to the apparent conductivity range of values. Table 2 shows the colour scheme with the corresponding apparent conductivity range. As defined in the colour scheme, areas of high conductivity are shown in Red, while areas of low conductivity are in Yellow.

Table 2 Colour scheme with apparent conductivity range

Colour		Apparent Conductivity Range σ (mSm^{-1})
	Red	90 – 100
	Magenta	80 – 89
	Orange	70 – 79
	Pink	60 – 69
	Brown	50 – 59
	Purple	40 – 49
	Cyan	30 – 39
	Blue	20 – 29
	Green	10 – 19
	Yellow	0 – 9

2 -D representation of results (Surfer conductivity maps)

Horizontal Dipole (HD)

In Fig. 4, lateral apparent conductivity variations are shown at the depths of 7.5 m 15.0 m and 30.0 m respectively from the ground surface.

In Fig. 4(a), where the contour interval is 2 mSm^{-1}, conductivity exhibits laterally uniform decrease away from the stream and this is most evident at the right side of the stream.

On the right of the discharge stream, Analysis on the data indicates that 56.52 % of the profile points had apparent terrain conductivity values in the range of 10 mSm^{-1} to 19 mSm^{-1}. The locations of these points are joined by green coloured contour lines.

On the left side of the discharge stream, apparent conductivity data recorded fell within six apparent conductivity ranges. This is indicated by the six different coloured contoured lines displayed on the map. Analysis on the data indicates that 65.66 % of the profile points had apparent terrain conductivity values in the range of 0 to 9 mSm^{-1} (yellow coloured contour surfaces).

Fig. 4(b) depicts lateral apparent conductivity distribution at 15.0 m from the ground surface showing uniform and relatively low apparent conductivity measurements. On the right side of the stream apparent conductivity is predominantly in the range of 10 – 19 mSm^{-1}. Statistically this conductivity range (10 – 19 mSm^{-1}) has data coverage of 97.14 % of the total number of data acquired. On the left side of the discharge stream, the conductivity range 0 – 9 mSm^{-1} represents the predominant conductivity distribution.

Fig. 4(c) shows the apparent conductivity distribution at the exploration depth of 30.0 m measured with the 40 m coil spacing in the HD mode. Apparent conductivity predominant on right side is in the range of 30 – 39 mSm^{-1}

(cyan coloured contours). The highest values of apparent conductivity measured on this side fell within the range of 80 - 89 mSm^{-1}. The points where these data were recorded are connected with a purple coloured contour line close to the land fill boundary. On the left side of the discharge stream, the apparent conductivity data acquired fell within three different ranges of apparent conductivity values. The majority of data fell within the 30 – 39 mSm^{-1} range (cyan coloured contours). Followed by the 40 – 49 mSm^{-1} range (purple coloured contours) and 50 – 59 mSm^{-1} range (brown coloured contours).

Vertical Dipole (VD)

Fig 5 shows the contour for data acquired with the instrument operated in vertical dipole mode for the various intercoil spacings. They show the apparent conductivity at various depths on both sides of the discharge stream.

In Fig. 5(a), lateral apparent conductivity variations are shown at the depth of 15 m. Both sides of the discharge stream, have predominant conductivity within the range of 0 – 9 mSm^{-1} (yellow coloured contour lines). The highest conductivity values in the range of 20 – 29 mSm^{-1} exist at a relatively small portion of the study area close to the landfill boundary.

Fig. 5(b) depicts lateral apparent conductivity distribution at the 30.0 m depth. The right side of the discharge stream has a predominant conductivity values within the range of 10 – 20 mSm^{-1} (green shades of contour lines).

The left side of the discharge stream exhibits a predominant conductivity value that falls within the range of 0 – 10 mSm^{-1} (yellow shades of contour lines). The highest conductivity values are in the range of 50 – 59 mSm^{-1} exist at points close to the landfill boundary and to the discharge stream.

The apparent conductivity distributions at the exploration depth of 60.0 m measured with the 40 m coil in the VD mode are shown by the contours in Fig. 5(c). The predominant values recorded on the right side of the discharge stream fell within the range of 20 – 29 mSm^{-1} (blue shaded contours). On this side, a relatively high conductivity value in the range of 90 – 100 mSm^{-1} exists along points close to the landfill boundary. These ranges of values gradually decrease to 30 – 40 mSm^{-1} towards profile line 3.

Two dominant apparent conductivity ranges were recorded on the left side of the discharge stream. They are in the range 30 – 39 mSm^{-1} (cyan shaded contours) and 50 – 59 mSm^{-1} (brown shades contours) respectively. On this side, a relatively high conductivity value in the range of 90 – 100 mSm^{-1} exists at a point 20 m from the discharge stream between the first and the second profiles.
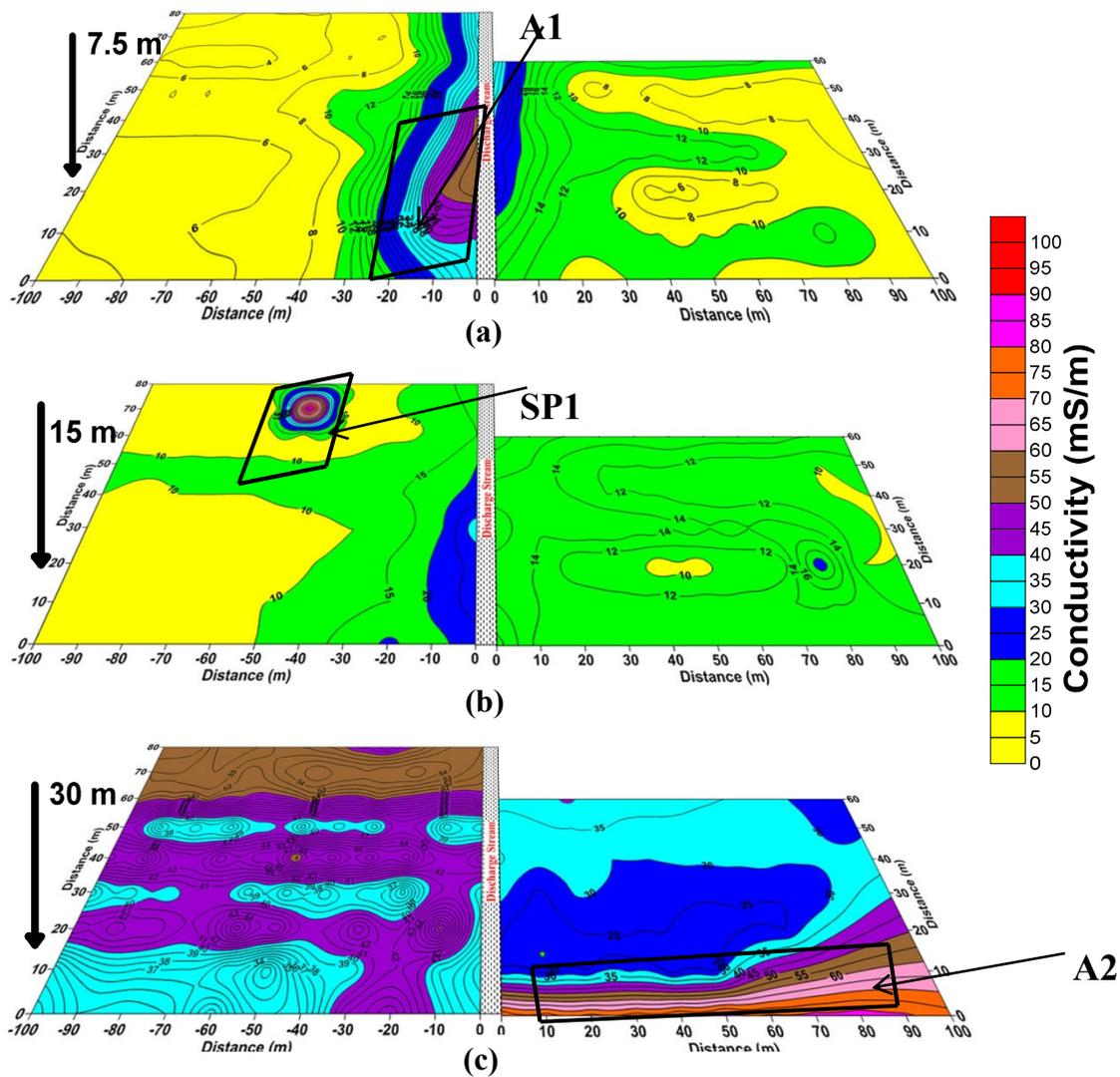
Fig. 4 Contour maps of apparent terrain conductivity acquired with the EM34-3 instrument operated in Horizontal Dipole (HD) mode with coil separation of (a) 10 m, (b) 20 m and (c) 40 m and corresponding depth of 7.5 m 15 m and 30 m respectfully.
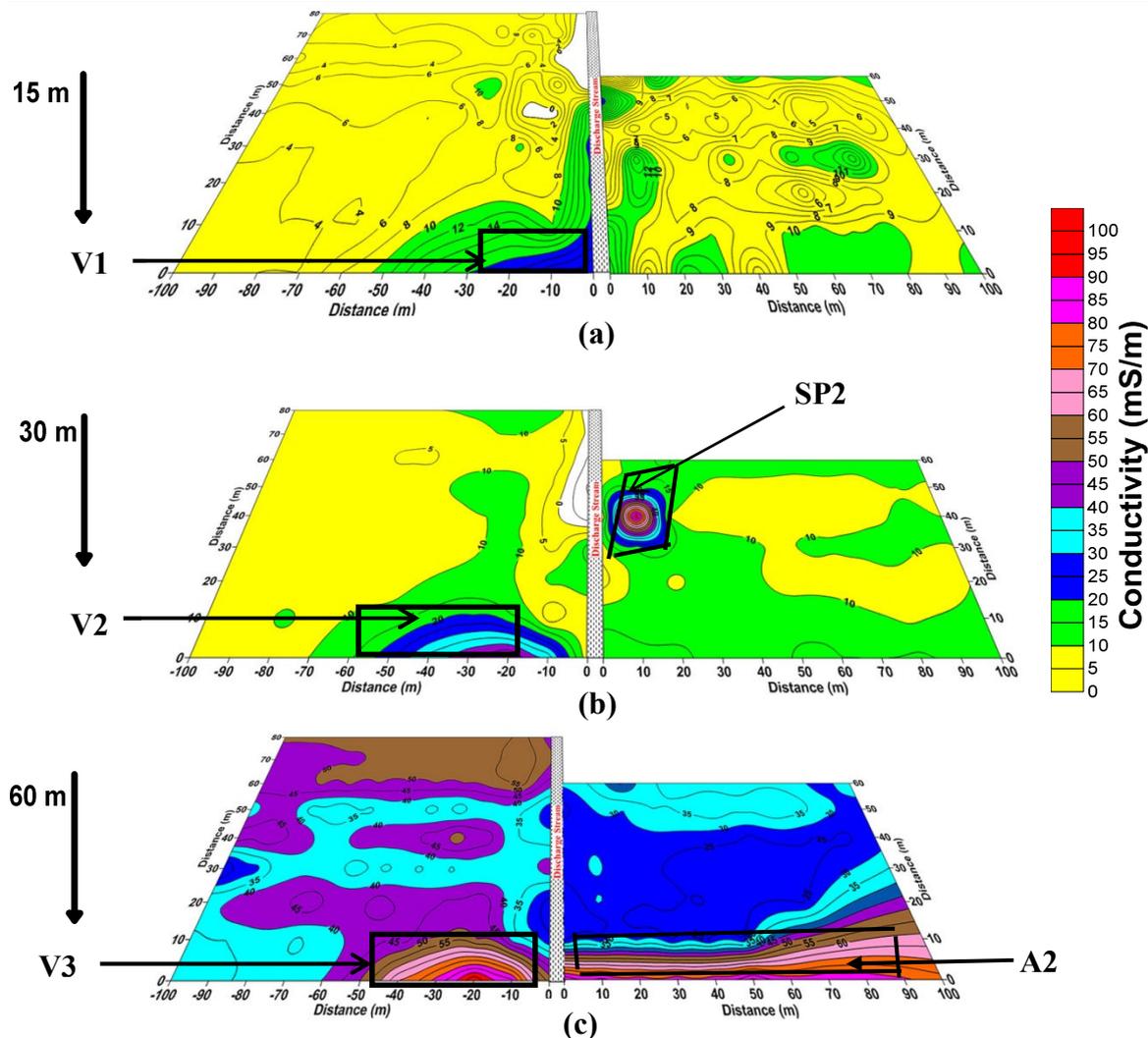
Fig. 5 Contour maps of apparent terrain conductivity acquired with the EM34-3 instrument operated in Vertical Dipole (VD) mode with coil separation of (a) 10 m, (b) 20 m and (c) 40 m and corresponding depth of 7.5 m 15 m and 30 m respectfully.

4 DISCUSSIONS

The Geonics EM 34-3, like all terrain conductivity meters reads directly in apparent conductivity and most surveys using such equipment are done in the profile mode, interpretation is usually qualitative and of the "anomaly finding" nature. The area of interest was surveyed with a series of profiles to produce 2-dimensional apparent conductivity map. In this research, therefore, interpretation is done based upon the lateral distribution of apparent conductivity at the various depths dictated by the coil separation values.

In discussing the causes of the conductivity anomalies, it is understood that non-organic (ionic) contamination of groundwater or soil usually results in an increase in the conductivity of the groundwater. The interpretational problem is to explain the changes in conductivity besides the conductivity variations caused by other parameters such as changing lithology. In this study, lithologic variations are not considered potential contributing factor at this site.

Conductivity is linked to salinity, and soluble salts are more likely to build up in areas where there is less direct communication with surface water. Areas of higher conductivity could be interpreted as zones with more confined systems, where areas with lower conductivity could be interpreted as zones with greater surface-water and groundwater interaction.

Conductivity variation is also linked to the soil moisture variations that themselves are related to the valley slope and other topographic undulations. Substantial topographic variations may affect the EM readings such that an

increase in elevation will correspond to a decrease in conductivity (Duran, 1984). The topographic variations within the survey site is however minimal and considered to have no appreciable effect on the EM data. Cultural effects are also minimal because no metal pipes or power lines were located very close to the survey site, except the landfill perimeter fencing.

In summary, the effects of cultural and natural interferences on the geophysical data collected at the site are interpreted to be minimal. Therefore, anomalies and trends indentified in the data can most likely be attributed to elevated concentrations of ionic contaminants in the leachates.

Distribution of apparent conductivity with depth

In Figs. 4 and 5 depth information are also revealed by the measured conductivity maps for the horizontal and vertical coils respectively. Here emphasis is placed on the relative exploration depths of the three intercoil separations. The background conductivities which are reflections of some sort of an average conductivity at the optimum depths on both sides of the discharge stream are shown in Table 3.

Table 3 Summary of the background conductivities on the right and left sides of the discharge stream

Inter coil space (m)	Depth (m)	Dipole	Right side of discharge stream				Left side of discharge stream			
			No. of data	Apparent Conductivity (mSm^{-1})			No. of data	Apparent Conductivity (mSm^{-1})		
				Min	Max	Mean		Min	Max	Mean
10	7.5	HD	69	5	38	12.3	99	3	54	13.1
10	15	VD	69	1	23	8.6	99	-7	28	6.7
20	15	HD	72	9	22	13.4	98	6	98	12.4
20	30	VD	72	3	99	12.4	99	-11	52	9.7
40	30	HD	65	22	84	38.0	98	30	56	43.7
40	60	VD	65	21	92	37.6	99	19	100	44.9

A comparison of the background conductivities of the top layers indicates one major anomalous zone (A1), at the left side of the discharge stream (Fig. 4(a) – top layer). With a background conductivity range of 12.3 – 13.1 mSm^{-1}, as indicated by the horizontal dipole configuration, this anomalous zone has a conductivity range of 40.0 – 60.0 mSm^{-1}. Since this anomaly is not entirely corroborated by the VD measurements (Fig. 5(a) – top layer), which portrays more uniform terrain conductivity, it implies the anomaly is probably a reflection of more shallow effects.

Moving down further to the depths explored by the 20 m coil separation, measurements by both coil configurations show substantially uniform conductivity. Background conductivities are almost the same on both sides of the discharge stream (13.4 and 12.4 mSm^{-1} respectively). There are however, two anomalous zones of discrete nature, SP1 (Fig. 4(b) – middle layer) and SP2 (Fig. 5(b) – middle layer) at the left and right sides respectively. SP1 is a high conductivity spike which possesses a maximum conductivity within the range 90 – 100 mSm^{-1}. SP2 is also high conductivity spike of maximum conductivity within range of 90 – 100 mSm^{-1} located about 10 m from the discharge stream. These spikes could be due to buried a high conducting material, like metal. They could also be statistical or measurements errors.

A significant anomalous zone, A2 exists close to the boundary of the landfill as indicated in both Figures 4(c) and 5(c) – bottom layers. This anomalous zone is very prominent at the right side of the discharge stream and shown by both dipole configurations. The zone has a maximum conductivity of 100 mSm^{-1}. The background conductivity at this level is within the range 37.6 – 44.9 mSm^{-1}. The size, shape and magnitude of this anomaly suggest that a zone of increased conductivity exists between the exploration depths of 30 and 60 m. This zone could be interpreted to represent lateral migration of a contaminant plume. The plume appears to be extending from the landfill and concentrated between the exploration depths of 30 and 60 m.

There is another anomaly that is apparent in the vertical dipole configuration and almost non-existent in the horizontal dipole (Fig. 5). The anomaly is designated at $V1$, $V2$ and $V3$ respectively on the 10, 20 and 30 m coil separation contours (VD mode). The detection of this anomaly by only the vertical dipole indicates a possible contamination within a vertical dike-like feature (Boniwell, 1987). The exploration depth of 15 m, the EM 34 – 3 indicates a small plume ($V1$) of very limited extent. At an exploration depth of 30 m, the plume has increased in

size and magnitude. The EM data at depth of 60 m shows that the plume has slightly expanded. Generally the maximum conductivity of this anomaly at the depth of 60 m is about two times greater than that at the 30 m depth and a little greater than three times the maximum conductivity at 15 m. The doubling of conductivity between 30 to 60 m in depth, coupled with only a slight expansion in size of the plume, suggest vertical migration of contaminants within a probably fault zone or some form of vertical structural weakness.

5 CONCLUSION

Electromagnetic profiling has been carried out on a section of the lands contiguous to the Dompoase landfill facility, Kumasi, to outline possible conductive layers probably connected with leachate communication. The objectives of the survey basically amounted to examining two hypotheses; that contaminant plumes are migrating laterally away from the discharge stream and from the landfill, and also that the contaminant plumes are seeping down into the groundwater aquifer system. The study was based solely on practical field survey with the terrain electromagnetic equipment – Geonics EM 34-3.

The high conductivity found within the depths 30 to 60 m close to the southern boundary of the landfill might suggest limited leachate communication from the landfill. The linear pattern of the contour lines in that anomalous zone probably indicate the presence of zones of weakness trending approximately perpendicular to the direction of flow of the discharge stream. This weak zone could account for the lateral spread of leachate within those depths, where leachate plume has so far migrated about 30 m from the landfill southern boundary.

The discharge stream carries waste water from the septic and leachate treatment ponds. Anomalously high ionic contaminants escaping into the stream will be a reflection on the level of efficiency of the treatment process. The research does not indicate that any such anomalously high volumes of ionic contaminants are getting into the discharge stream. This is evident on the lack of any significantly high anomalous conductivity zones close to the discharge stream at the surface and at depths.

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