A CASE HISTORY OF SHALLOW AQUIFER CONTAMINATION STUDIES

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ABSTRACT

Degradation of the quality of groundwater resources as a result of contamination from hazardous industrial landfill sites, mining operations, agricultural chemicals and pesticides and solid and liquid waste constitutes one of the major environmental concerns in both developed and developing countries today. The paper presents a case history of an integrated environmental geotechnological study involving the application of geoelectric sounding techniques, drilling and water quality monitoring in the assessment of the extent of groundwater contamination in the vicinity of an industrial hazardous waste landfill site in Tema, Ghana. The findings of the study confirmed the conclusions of other investigators that geoelectric sounding techniques may not yield conclusive results in groundwater contamination studies in situations of complex geology.

KEYWORDS: *Toxic Waste, Leachates, Groundwater Contamination, Geoelectric Sounding, Landfill.*

INTRODUCTION

Given the current global concerns for the quality of the environment, the issue of degradation of groundwater quality as a result of contact with human waste, agricultural chemicals and pesticides and hazardous waste from industrial landfill sites and mining operations is likely to assume increasing importance in the future as will the need for more precise methods of geotechnical characterisation of such sites.

Hamil and Bell [1] provide an excellent review of the factors which influence contaminant transport in groundwater. Depending on whether it is miscible in or immiscible with water, leachate from a polluting source may either remain intact within or mix with and be diluted by the groundwater. In either case, the leachate tends to form a plume, the determination of the spatial extent of which constitutes one of the major tasks in a hazardous waste landfill site characterisation programme.

The traditional approach to leachate migration studies is the drilling of boreholes for monitoring changes in groundwater quality over a period. This approach is not only relatively expensive but is also time-consuming. Consequently, in recent years, increasing use is being made of geophysical techniques including those based on contrasts in electrical conductivities between the contaminant plume and the groundwater in the preliminary screening of hazardous waste disposal sites, [2,3,4] and as a guide to the siting of groundwater quality monitoring boreholes. Geoelectric sounding techniques are, however, only effective in groundwater pollution studies in situations where the solid geology is reasonably simple, the aquifer level is relatively shallow and there exists good electrical contrast between the contaminant plume and the groundwater. In particular, a high concentration of chlorides in either the leachate or the uncontaminated groundwater facilitates the delineation of the resulting contaminant plumes using geophysical techniques.

Following concerns expressed about the possibility of potentially toxic substances in the leachate from an industrial landfill site of "spent" potlining material contaminating groundwater resources in the area, a detailed environmental geotechnological study was commissioned to address the problem. The potential contaminants in the "spent" potlining material are cyanides and fluorides both of which are miscible in water. While small quantities of cyanides and fluorides are probably taken in daily from consumption of certain types of foodstuff, both constituents are classified as toxic, with the World Health Organisation specifying guideline concentrations of 0.1mg/l for cyanide and 1.5mg/l for fluoride in drinking water, as reasonable levels for protection of public health [5]. This study, which involved geological, hydrogeological and geophysical investigations in the project area, in addition to an extensive groundwater quality monitoring programme, afforded an opportunity to investigate the effectiveness of geoelectric sounding techniques in the geotechnical characterisation of hazardous waste disposal sites.

Location and Geomorphology of the Study Area

The study area, which is located in the industrial city of Tema, some 20km to the east of the capital city of Accra, measures approximately 1160m long by 730m wide and is generally low-lying, with topographical heights across the site varying between 10m and 20m above mean sea level. The site slopes gently in the south-westerly direction towards a creek which discharges into isolated surface water bodies to the south of the project site. The area has been used as an industrial landfill site for over two decades, and the extent of waste deposition covering approximately the northern half of the site at the time of this investigation is shown in Fig. 1.

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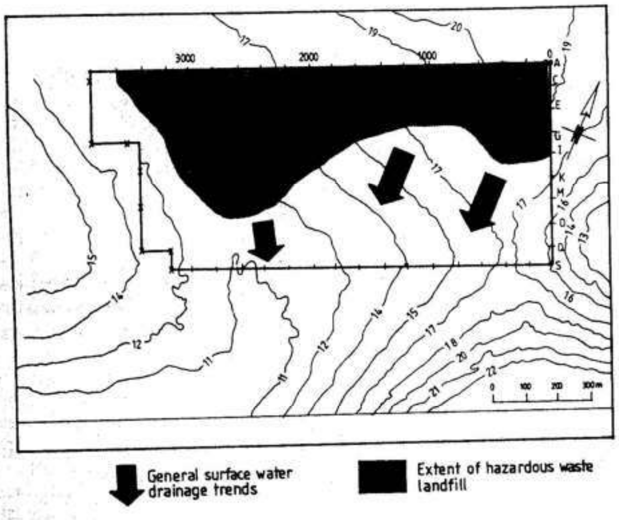


Fig. 1: Plan of Study Area Showing Saltent Surface Drainage Features

Geology and Hydrogeology of the Study Area

Tema is underlain by rocks of the Dahomeyan System of middle Pre-Cambrian age, forming the basement complex of Ghana, and consisting mainly of felsic and mafic gneisses and schists. Previous geological investigations have established that the project area is underlain by hornblende gneisses, cut by numerous quartz veins, and dipping at between 10 and 30 to the south-east.

In general, the gneisses are poorly exposed and are usually mantled by substantial thicknesses of residual soil whose nature and engineering properties have been exhaustively discussed in the literature [6,7,8]

Comprehensive studies of groundwater occurrence in Ghanaian rock types [9,10,11] led to the conclusion that the water-bearing and yielding potential of the Dahomeyan rocks may be rated as negligible on account of the fact that these rocks are generally not intensely jointed or fractured, although decomposed Dahomeyan rocks may yield water to relatively shallow wells as a result of the formation of perched water tables. A detailed study of aerial photographs of the Tema area (Fig.2) however, showed the occurrence, in the vicinity of the project site, of distinctive geologic features such as quartz veins and lineations, which are conducive to the formation of aquifers. Indeed, previous site-specific hydrogeological investigations established the existence of two aquifer horizons within the depth ranges of 5m-7m and 55m-60m respectively. Since the risk of pollution by leachates from the landfill is clearly greater in the upper aquifer horizon, the study was concentrated on this aquifer horizon.

Investigation Methodology

The approach adopted in these studies was essentially the same as employed in similar investigations elsewhere [2,13] and consisted of geodetic surveying to establish a working grid of about 60m by 80m side over the study area, geoelectric sounding surveys, drilling and groundwater quality monitoring. These activities were carried out in a sequential manner with the findings of one phase providing an input into the next activity. The final locations of the various investigation points are shown in Fig. 3 while details of these activities are given in the following sections.

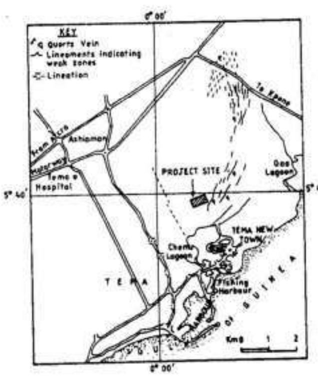


Fig. 2: Aerial Map of Section of Tema Showing Main Geologic FEatures

Geoelectric Sounding Surveys

Geoelectric sounding surveys were carried out in the sixteen locations shown in Fig.3 using the Schlumberger electrode array with a maximum electrode separation of 430m. Preliminary interpretation of the resistivity sounding results was carried out by the technique of curve-matching based on Master Curves evolved for vertical electrical sounding [14] while the final interpretation was done by the method of automatic curve-matching utilising a computer programme developed by Ramachandra [15], using information about layer parameters derived from the preliminary curve-matching.

While iso-resistivity contours for the first layer within which the upper aquifer horizon occurs (Fig.5a) show a consistent pattern which may be taken as indicative of the direction of flow of contaminated groundwater, the bedrock iso-resistivity contours (Fig.5b) showed isolated zones of relatively low apparent resistivities in the landfill areas and also along the natural drainage channels across the site.

There was also a general north-east to south-west linear trend to the bedrock iso-resistivity contours, which could be attributed to the existence of a geologic discontinuity or a fracture zone. On the other hand, the fact that this linear trend also almost coincides with a major drainage artery from the project

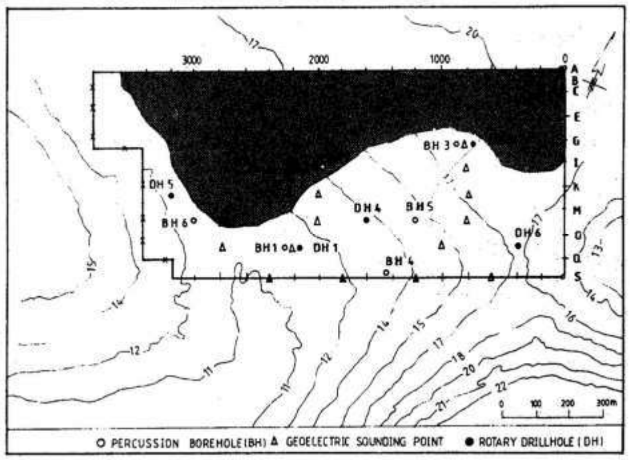


Fig. 3: Location of Investigation Points

The resulting geoelectric sounding curves were mostly of the double ascending type, suggesting the existence of a three-layer geoelectric structure at the site. These consisted of an upper layer which varied in thickness from 1.5m to 6m over the site with apparent resistivities ranging between 2.6ohm-m and 10ohm-m, underlain by a second layer with apparent resistivities of between 15ohm-m and 90ohm-m. The third layer which clearly corresponded to bedrock, had apparent resistivities in excess of 150ohm-m. Typical resistivity sounding curves along gridline S are given in Fig 4.

The total depth explored during the survey was, however, relatively shallow, ranging from 5m to 27m, probably on account of the highly conductive nature of the overburden. This was, however, not considered a serious draw-back since the upper aquifer horizon which is particularly vulnerable to pollution by leachate from the landfill, occurs within this depth range.

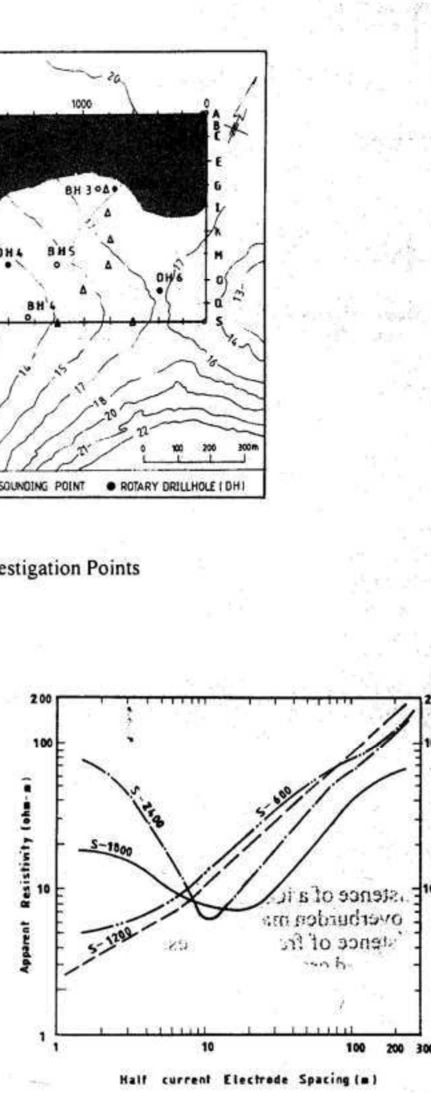
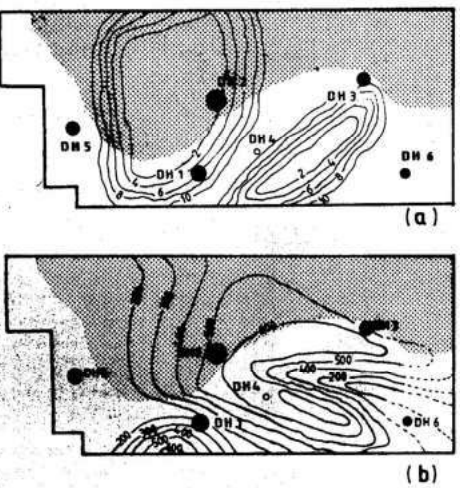


Fig. 4: Typical Resistivity Sounding Curves for Gridline S



NOTES
1. DRILLHOLE DIAMETERS ARE PROPORTIONAL TO FLUORIDE CONCENTRATION IN GROUND-WATER.
2. ISO-RESISTIVITY CONTOUR INTERVALS ARE IN OHM–M.
3. NO GROUNDWATER QUALITY MONITORING WAS DONE IN DH 4.

Fig. 5: Iso - Resistivity Contours for
(a) The Upper Aquifer Horizon and
(b) Bedrock.

site into a nearby lagoon means that the observed trend in the bedrock iso-resistivity contours could also be due to flow of contaminated groundwater towards the lagoon.

In sam, the observed features of the bedrock iso-resistivity plot could therefore be attributed to one or more of the following causes:

- o the existence of a loose and possibly highly saline overburden material,
- o the existence of fracture zones, and
- o contaminated groundwater plume resulting from highly conductive leachate from the landfill.

The results obtained from the geoelectric sounding programme were, clearly, inconclusive and therefore needed to be supplemented with data acquired from drilling and groundwater quality monitoring programmes.

Drilling Operations

A drilling programme involving the sinking of six rotary drillholes, and six percussion boreholes, was undertaken in order to facilitate:

-a positive identification of the nature, condition and thicknesses of the surficial soils and the country rock for correlation with the results obtained from the geoelectric sounding surveys;

-the performance of in-situ permeability tests at various levels within the overburden material and the country rock; and

-the installation of a groundwater quality monitoring system in selected parts of the project site.

The choice of the locations of the various drillholes and boreholes, shown in Fig 3, was done in such a manner as to facilitate the acquisition of sub-surface information in portions of the study area where the geoelectric survey indicated anomalies. The rotary drillholes extended to sound rockhead at depths in excess of 30m while all six percussion boreholes had to be terminated at depths less than 4m on account of the compact nature of the weathered gneiss. In-situ falling head permeability determinations were also carried out at various levels in all boreholes and drillholes in accordance with recommended practice.

On the completion of the drilling and in situ permeability testing programmes, five of the rotary drillholes were converted into standpipe piezometers to facilitate regular monitoring of groundwater quality while the percussion boreholes were caulked to prevent ingress of contaminated surface water into the boreholes and ultimately into the aquifer.

Subsurface Conditions

The drilling programme revealed sub-surface conditions which are typical of areas underlain by the Dahomeyan hornblende gneisses. At the top of the residual soil profile is a dark-green plastic clay [LL = 70%, PI = 45%] varying in thickness from 1m in most boreholes and drillholes to a maximum of 8m in DH5 which is located close to stream flowing across the site. This clay layer which is capable of considerable volumetric activity, is underlain by a layer of greyish, friable clayey silt with occasional calcareous concretions, fragments of weathered gneiss and quartz vein, and which in turn, graded into fresh hornblende gneiss with typical rock quality designations (RQD) and average core recoveries in excess of 60% and 70% respectively.

The depth to bedrock was greatest in DH4 which is located in an area where one of the highest apparent resistivities was recorded over the project site. [see Fig.5(b)] Besides, the weathered gneiss encountered in this drillhole contained fragments of shattered quartz, and it was generally very difficult to keep this drillhole open long enough for it to be cased. Consequently, it was neither possible to carry out the in-situ permeability testing in this drillhole nor to convert it into a monitoring well. It has been concluded that DH4 has been located within a fracture zone.

The existence, at the study site, of the upper plastic clay horizon is of particular relevance to the study, because of its potential to act as a natural clay liner which could substantially reduce the rate of infiltration of leachate from the landfill to the aquifer. Field permeability tests in this clay yielded an average in situ permeability of 5×10^{-5}m/s which is comparable to the threshold permeability specified by most regulatory agencies for engineered clay liners for hazardous waste disposal sites [16]

Groundwater Levels

Groundwater which clearly represented the upper aquifer horizon, was struck in all drillholes at a stabilised depth of approximately 6m below existing ground surface. Almost daily monitoring of the groundwater levels in the drillholes over a two-month period showed little change in the stabilised water level in spite of heavy rainfall over the period - an indication of the effectiveness of plastic clay layer in reducing the rate of infiltration of surface water into the upper aquifer.

Groundwater Quality

A programme of chemical analyses of samples of groundwater from the upper aquifer was undertaken over a six-month period for the determination of levels of concentration of flouride and cyanide. Samples of the groundwater was obtained from each monitoring well in clean, sterilised bottles and each sample was later sub-divided to be tested in three independent testing laboratories. Some water samples were also sent to a laboratory outside Ghana in the latter stages of the groundwater quality monitoring programme in order to provide a further independent check on the results obtained from the local laboratories. A close study of the results of the chemical analyses indicated the following trends.

(a) for a given batch of groundwater, the results of fluoride content reported by one local laboratory (Laboratory A) which used gravimetric techniques, were several orders of magnitude higher than those reported by the other two local laboratories and the foreign laboratory all of which used the fluoride electrode technique. The results reported by Laboratory A were therefore discounted in the evaluation of the results of the study.

(b) relatively high initial values of fluoride and cyanide concentration were reported from all laboratories. This is believed to be attributable to the fact that, in spite of the measures taken during the operations to prevent ingress of contaminated surface water into the drillholes, some contamination must have occurred particularly in view of the fact the drilling operations were undertaken during the wet season, and that water flush rather than air flush was used during the rotary drilling operations. Subsequent flushing of the monitoring wells led to the recording of reasonably consistent concentrations of fluoride in each drillhole.

(c) the concentrations of total and free cyanide recorded after the initial set of uncharacteristically high results, were generally low, probably on account of either the existence of a relatively thick vadose zone between the landfill and the upper aquifer, or the relative inpersistence of cyanides in soil and water for various reasons including microbial transformation and photodegradation [17].

The above observations notwithstanding, it may be seen from a study of the maximum concentrations of both constituents recorded for each batch of groundwater sample, presented in Table 1, that:

-In any batch of groundwater sample, the highest concentrations of fluoride and cyanide were recorded in DH2 which was located directly in the landfill area, while only traces of either contaminant were detected

TABLE 1: Results of Chemical Analysis of Groundwater Samples

Elapsed time (days)	FLUORIDE CONTENT (mg/l)					CYANIDE CONTENT(TOTAL/FREE)				
	DH1	DH2	DH3	DH5	DH6	DH1	DH2	DH3	DH5	DH6
0	68	395	-	10	Trace	0.5	72	-	120	Trace
30	28	42	7	-	Trace	0.29 / 0.03	0.49 / 0.05	0.01 / 0	-	Trace
70	34	47	-	6	12	0.10 / 0	0.24 / 0.03	-	0.002 / 0	0.004 / 0
110	36	44	-	5	Trace	0.011 / 0	0.060 / 0	-	0.005 / 0	Trace
145	36	44	-	4	Trace	-	-	-	-	-

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