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LANDFILL SITE INVESTIGATION IN THE TEMA METROPOLIS USING 2-DIMENSIONAL RESISTIVITY TECHNIQUE

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Abstract

Two-dimensional (2-D) resistivity survey was conducted at a site near Kpone in the Tema metropolis to investigate its suitability for a proposed solid waste disposal site. The resulting sub-surface resistivity pseudo-sections provided information about the overburden thickness, degree of rock fracturing, depth to fresh bedrock and an estimate of the excavation depth. Even though the hardness of the underlying geological formation was observed to increase with depth, the upper 25 m comprised stable argillaceous overburden mixed with isolated pockets of lateritic hardpan or iron stone of resistivity values ranging from 12-1,500 Ω-m. This layer was underlain by east-west gently-dipping massive bedrock with little or no discontinuities with resistivity values ranging from 2,000-4,200 Ω-m. The total excavation depth was estimated to be 30 m below ground level. The site is considered geologically suitable for the intended purpose due to the absence of bedrock discontinuities to enhance contaminant transport to pollute the groundwater resources.

Introduction

Waste disposal has been a major problem in Ghana beause waste is not treated before disposing it. Waste comes in many forms, and may comprise mixed metals, food scraps, kitchen waste, paper, plastics and glass. A greater percentage of these wastes decompose with time and have varying odour and leachate levels. For the purposes of land reclamation, odour and health hazard control, landfill sites are selected with great care. Contaminant flow from decomposed waste has the tendency to infiltrate porous rock to pollute groundwater resources, and this has been a major concern to many hydrogeologists and environmentalists. The problem of waste disposal could either be minimised or avoided if adequate geotechnical investigation is conducted on such proposed sites to ascertain their suitability.

Municipal Development Collaborative Limited (MDCL), a private civil and geotechnical engineering firm in Ghana, was awarded the contract to provide geotechnical services for the development of a proposed Tema solid waste disposal site at Kpone in the Greater Accra Region. As part of the services to be rendered under the contract, the MDCL was to carry out 2-dimensional (2-D) resistivity sub-surface pseudo-sections on the proposed site to provide in-depth information about the geological conditions to inform constructional and geo-technical management decisions. Owing to logistical constraints, MDLC requested the services of CSIR-Water Research Institute (CSIR-WRI) to assist in providing the resistivity pseudo-sections to enable them determine the depth of excavation to encounter impervious rock. The primary objective of the 2-D resistivity survey was to provide resistivity pseudo-section of the sub-surface to form the basis for assessing the suitability of the site for the proposed solid waste disposal ground. Other information required included weathering thickness, nature and

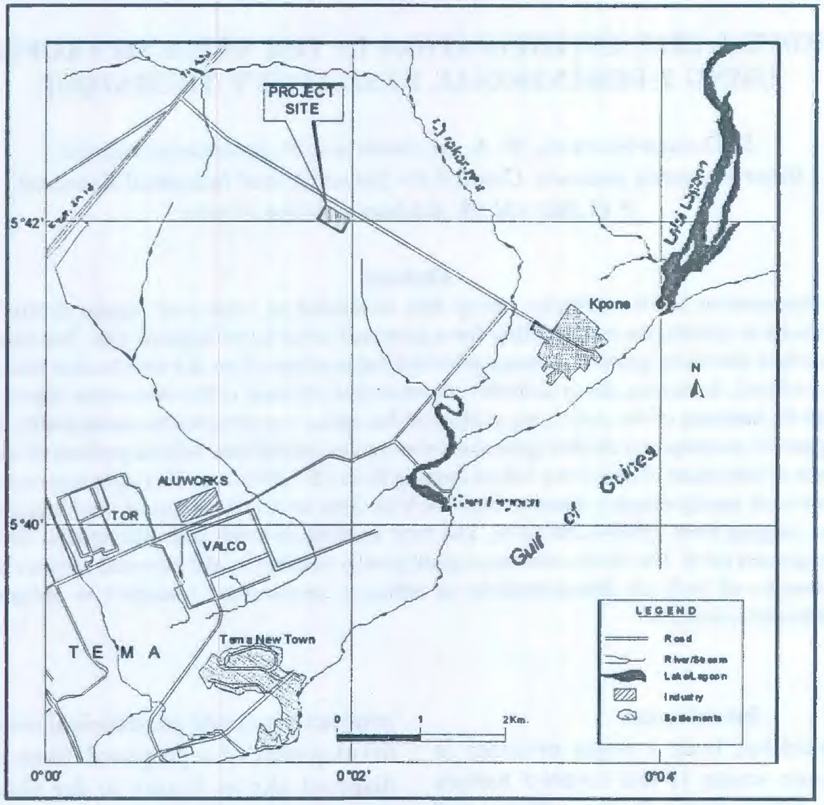

Fig. 1. Map showing the location of the study area

structure of the sub-surface rocks, rock inclination, and degree of rock fracturing.

Experimental

The study area

The proposed solid waste disposal site is located between Tema and Kpone in the Tema metropolis. It is located at about 2 km off Kpone Police barrier on the main Accra-Aflao trunk road, and has good all-weather accessibility. The topography of the site is slightly undulating and generally does not rise above 20 m above mean sea level (Dickson & Benneh, 1980).

The site lies within 2 km of the ephemeral Gyrokorgyor stream, which flows into the nearby Gao lagoon (Fig. 1). Physical observation of the study area showed that the proposed site had been seriously disturbed through sand-winning and stone quarrying, leading to the creation of numerous long-stretched quarry pits and manholes. The soil profile through existing quarry pits indicated that the site has thick earth cover or weathered overburden material for easy excavation and handling.

Dahomeyan rock system (basic and acidic components) generally underlies the entire south-eastern corner of Ghana and stretches through the entire Accra plains (Bates, 1985) of which the study area forms a part. The rock system is characterised by low-lying plain, broken by isolated inselbergs and ridges of ultra-basic intrusives and hills (Kesse, 1985). The study area

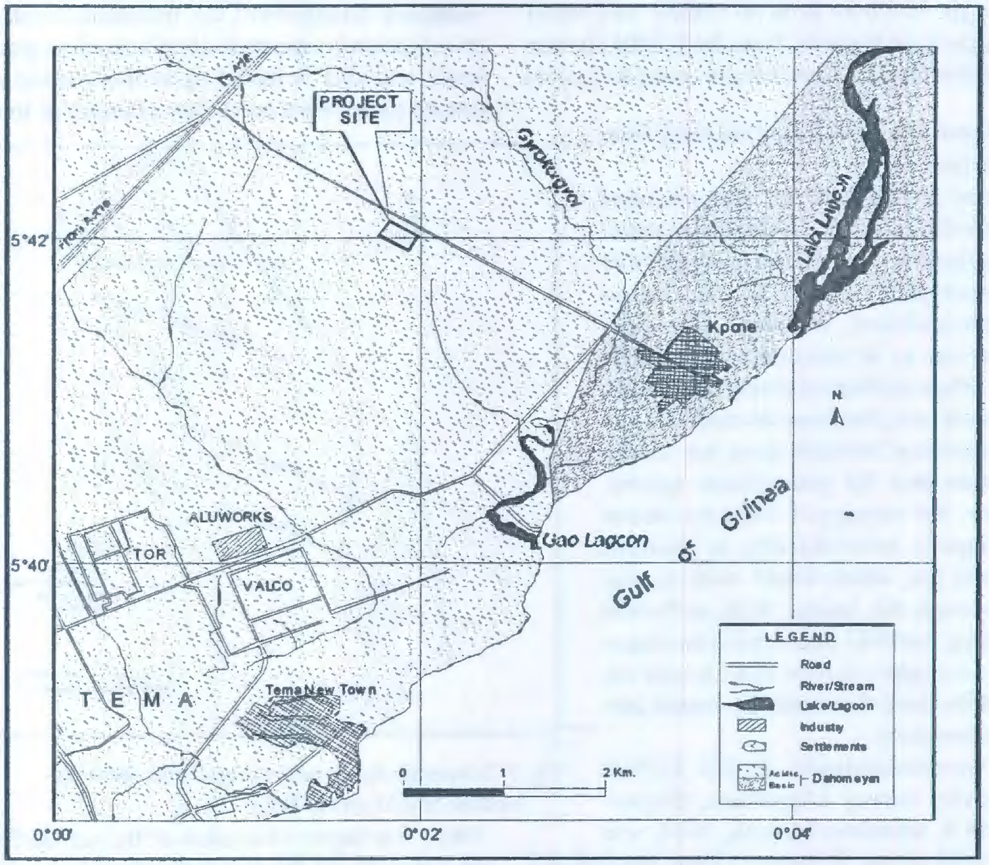

Fig. 2. Geological map of the study area

is underlain by acidic component of the Dahomeyan rock system, with ortho and para-gneisses, quartz, feldspar, schist and migmatite as the major rock types (Fig. 2). The acidic Dahomeyan rocks are characterised by intense folding and fold axes, which strikes south-southwest to north-northeast direction. Recumbent folding, associated with numerous over-thrusts, minor folds and flexures are common structures of the acidic Dahomeyan system (Kesse, 1985).

Landfill sites and hydrogeologic characteristics

With increasing environmental awareness, Ball (2004) has indicated that the location of proposed refuse dump sites and their operations should not detrimentally affect environmentally-sensitive resources such as aquifers, groundwater reservoir or watersheds. He recommended that proposed landfill sites should be located at a distance not less than 1 km away from surface and underground water supply intake points. Fountoulis *et al.* (2003) also have the view that proposed landfill sites should not be located within flood plains, or areas characterised by shallow, sandy and unconsolidated aquifers or within highly-porous basement rocks, as such areas are highly vulnerable to contaminant pollution. They maintain that the geology of proposed landfill sites should be investigated for geologic hazards such as faults and other hydrogeologic features. Thus, Ball (2005) further noted that proposed landfill sites must be located at a distance not less than 75 m away from active fault zones.

Kesse (1985), however, recommended that combined stable overburden material of argillaceous-rich soil overlying massive or impervious bedrock (rock with no discontinuities) is ideal geologic formations to be considered as landfill sites. When sited on relatively impervious basement rock, the waste decomposes and the resulting leachate does not easily penetrate into the groundwater system. Rather, the entrapped leachate would decompose anaerobically to produce methane gas, which would work its way up through the waste. With sufficient draining, aerobic decomposition takes place to produce carbon dioxide near the top of the heap that could be vented into the atmosphere.

Two-dimensional (2-D) LUND resistivity survey (Agyekum, Dapaa-Siakwa & Amankwa-Mainoo, 2004) was conducted along 10 traverse lines labelled A-J within the 20-acre project site (Fig. 3), each measuring 400 m. The traverse directions were selected in order to obtain cable spread of 400 m, and good ground contact to ensure maximum current penetration for good resolution. The 2-D resistivity survey technique runs both profiling and sounding measurements concurrently to produce 2-D high resolution pseudo-sections of the sub-surface. The technique uses the standard ABEM terrameter SAS1000/4000C, ABEM electrode selector ES 464 equipment, four electrical cables of 100 m each, and a total of 64 electrodes.

To ensure deeper depth of investigation, all four electrical cables were stretched along each traverse line to give a total cable spread of 400 m. With this arrangement the maximum depth of investigation is expected to be 65 m below ground level, and this is based upon the ground and current penetration conditions (Beeson & Jones, 1988). For higher resolution of the sub-surface, all take-outs on the two inner electrical cables were connected to electrodes at 5 m intervals, whilst take-outs on the two outer cables were connected to the electrodes at 10 m intervals. The SAS 1000C terrameter and the electrode selector ES464 were linked by a reference cable, and the two connected to external power supply source. Electrical current was passed through the electrodes for sub-surface resistivity measurements. The layout of the site showing the location and directions of each of the 10 survey lines are shown in Fig. 3.

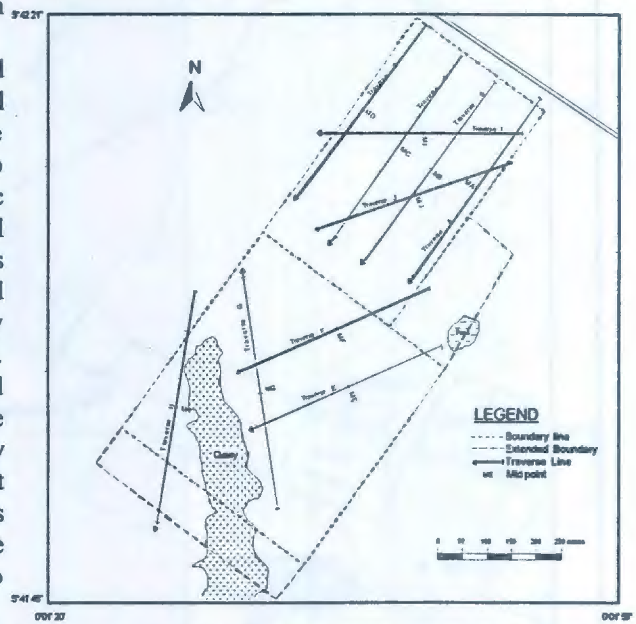

Fig. 3. Schematic layout of the project site, showing location of 2-D survey lines

The recorded 2-D resistivity survey (LUND imaging survey) data were down-loaded from the ABEM SAS 1000C terrameter onto a field laptop computer. Using geotomo software, the recorded resistivity data were initially converted to readable

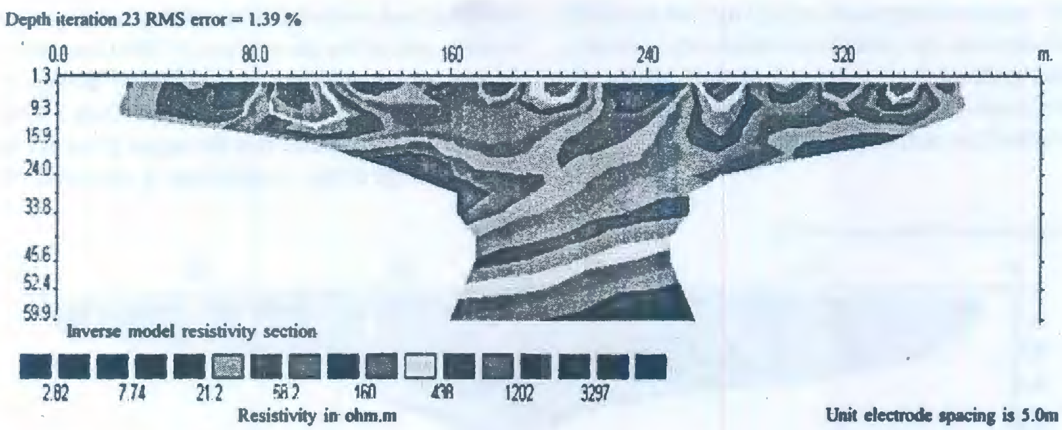

Fig. 4. Two-dimensional (2-D) resistivity pseudo-section along traverse F

files through special data conversion utility software, which were later inverted and finally modelled to produce the 2-D resistivity pseudo-sections of the sub-surface rock formation. The inversion programme uses both finite-difference and finite-element forward modelling technique. A forward modelling subroutine was used to calculate the apparent resistivity values, whilst a non-linear least-squares method, based on a quasi-Newton optimization technique was used for the inversion (ABEM Geotomo Software Manual, 2002).

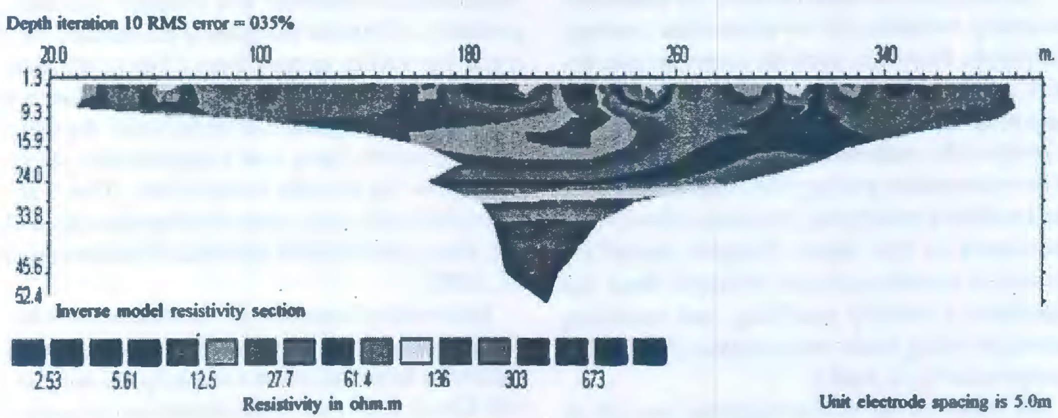

Fig. 5. Two-dimensional (2-D) resistivity pseudo-section along traverse G

Results and discussion

The results along each survey line showed the measured and calculated apparent resistivity pseudo-sections of the sub-surface, together with a modelled apparent resistivity pseudo-section obtained by inversion. Whereas the measured apparent resistivity pseudo-section represents the measured apparent resistivity values of the sub-surface, the calculated resistivity section is the result of the model calculation, whilst the inversion resistivity model pseudo-section is the result of the mathematical estimation.

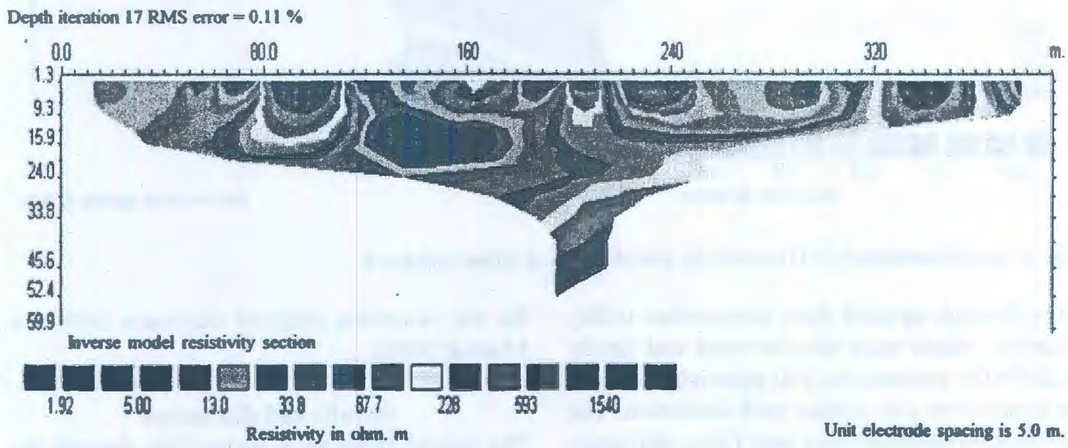

Fig. 6. Two-dimensional (2-D) resistivity pseudo-section along traverse J

The three pseudo-sections show the contoured resistivity variation of the sub-surface geology with depth. However, since the inversion pseudo-section combines the results of both the measured and the calculated resistivity sections to produce the mathematical resistivity estimation of the sub-surface geology, the results from only the modelled resistivity pseudo-sections were presented in the study. Sample modelled resistivity pseudo-sections obtained from the combined resistiviy profiling and sounding technique along three traverse lines (F, G and J) are shown in Fig. 4, 5and 6.

The mean depth of investigation was 56 m (range 52.4 - 58.9 m) below ground level, and was due to the prevailing ground conditions. The different colour codes and apparent resistivity values indicate rocks of different hardness, resulting out of weathering and or rock fracture conditions. The resistivity pseudo-sections have revealed that the bedrock resistivity in the south-western part of the site is lower (< 700 Ω-m.) than in the north-eastern part, whose bedrock resistivity ranges from 1,500-3,200 Ω-m.. The results further indicate that the upper 25 m of the basement geology comprises a mixture of weathered overburden and isolated boulders, probably of lateritic hardpan at the surface with resistivity values varying from 12 to 1,500 Ω-m. Sections showing very low resistivity values are indication of argillaceous (clay) soil deposits. Clays generally have low transmissivity values and poor hydraulic properties. They are characterised by high water-holding capacity, and are, thus, good landfill materials (MacDonald *et al.*, 2008).

Sandwiched between the overburden and the fresh rock is about 5m thick fractured rock with relatively lower apparent resistivity values (30–150 Ω-m.). Such zones have developed secondary porosity and, thus, have the potential to act as conduits for the transport of leachate. As a characteristics of acid Dahomeyan rocks (Kesse, 1985), the fresh bedrock at the site was observed to be layered and trends slightly in the southwest-northeast directions. The bedrock lies at a mean depth of 30 m below ground level with high apparent resistivity values in the range of 2,000 and 4,200 Ω-m.. This indicates that the proposed landfill site is underlain by massive or impervious rock to restrain leachate infiltration to contaminate the available groundwater resources.

Conclusion

The 2-D geophysical survey results produced high resolution resistivity contrast of the sub-surface geology to define weathering thickness, fractured and fresh rock depths at the proposed solid waste dump site. The upper 25 m of the sub-surface comprises varying resistivity values (12–1,500Ω-m.), and probably a mix components of argillaceous soil (clay and shale) isolated pockets of lateritic hardpan (iron stone) at the surface. The thick overburden, as revealed by the resistivity pseudo-sections, indicates that the site would have adequate earth material for after-use surface cover and compaction activities. The site is underlain by relatively higher resistivity rock (2,000 – 4,200 Ω-m.), and probably contains little or no fractures. The depth of excavation at the proposed project site should not be deeper than 30 m below ground level. On the basis of the investigation, the site is considered safe for the intended purpose, as the underlying bedrock is massive, free from geologic hazards, and would, therefore, have minimum or non-existent pathways for contaminant transport to pollute groundwater resources.

Acknowledgement

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