GEOENVIRONMENTAL ASSESMENT AND STRATIGRAPHIC CHARACTERISATION OF A CONTAMINATED SITE IN BARUWA, LAGOS STATE.

By

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CERTIFICATION

This is to certify that this thesis project work was carried out by BALOGUN Sola, (Matric No. CVE/99/3282 in the Department of Civil Engineering, Federal University of Technology, Akure for the award of a degree of Master of Engineering in Civil Engineering. To the best of my knowledge, similar work has not been submitted elsewhere for the award of a degree.

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ABSTRACT

Stratigraphic characterization through geotechnical and geophysical exploration were performed for the petroleum hydrocarbon contaminated Baruwa site in Lagos Nigeria. Soil stratigraphy was obtained from borehole data. Interpolation between boreholes was performed by projecting borehole data on cross-sectional planes, by using Computer Aided Drafting (CAD), together with manual interpolation between the boreholes.

Detailed laboratory geotechnical analysis of subsurface soil was employed and twenty seven soil samples (undisturbed and disturbed) were taken altogether. The laboratory tests that were carried out on these soil samples include index properties of soil, chemical analysis, permeability and clay mineralogy. Coefficient of permeability for Baruwa soil samples ranges from 1.72 – 6.36 x10^{-4}cm/s. Soil specific gravity was between 2.64 and 2.66.

The extent of contamination was studied using geophysical survey techniques, to measure the geophysical property of resistivity for the subsurface. Electrical resistivity soundings were also used to study the various stratigraphic units in the Baruwa subsurface.

The determination of the stratigraphy / soil subsurface profile for Baruwa site using geophysical and geotechnical methods has revealed the role of unconsolidated lateritic soils, granular backfill and sand lenses in vertical contaminant migration for the subsurface, especially in the unsaturated soil moisture zone, and this has hastened the pace of the leaked hydrocarbon through the thick surficial aquitard (Average aquitard thickness was 23.65m) in Baruwa.

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The topography, stratigrahpy and hydraulic gradient of the area has aided the movement of the leakage from the source into the surrounding wells at various degrees. The severity of the pollution was also discovered to be based on the heterogeneous nature of the material immediately around the depth of burial of the source (2.0m), the direction of groundwater flow and the topography of the study area.

On a regional basis the groundwater moves from north to south, while on local basis it moves from east to west. From the suspected source of leakage the hydrocarbon product migrates and causes a thickness of 0.72metres on top of groundwater at well 20, 0.65m at well 15, 0.35m at well 41 and 0.12m at well 69. This also explains why contamination in well 30 east of the source is not severe but has a 0.2metres hydrocarbon level.

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CHAPTER ONE

INTRODUCTION

1.1 Preamble

The spilling and leakage of petroleum products within the environment have posed a serious health problem in providing borehole and water wells for consumption within the last few years to the residents of Baruwa Village at Ipaja, Lagos. The occurrence is common in the community due to underground leakage of petroleum pipelines. The contamination in both soil and groundwater require a great deal of geotechnical investigation, field experience as well as laboratory work to unravel.

Contaminated subsurface due to the spill and leakage of non- aquiferous phase liquids such as gasoline, fuel oil chlorinated solvents has emerged lately as a major environmental problem in many developing nations like Nigeria.

Generally, among many contaminants found in the soil and groundwater, organic contaminants are more difficult to remediate due to their low solubilities and high interfacial tensions. The cleaning up of the contamination in both soil and ground water is a complex process and the cost effectiveness of such remediation is achievable through proper planning. Many of these contaminants are slightly water soluble and highly volatile fluids thus the infiltration and migration of these non-aqueous phase liquids in the subsurface is a difficult and complex process. After release on the surface, non-aqueous phase liquids move through the unsaturated zone under the force of gravity as only a small amount of non-aqueous is released.

All of the mobile petroleum products are eventually trapped in pores and fracture in the unsaturated zone, infiltration through vadoze zone dissolves some of the soluble organic constituents in the non-aqueous phase liquids carrying organics to the water table and forming a dissolved organic plume in the acquifer.

In the unsaturated zone the liquid petroleum products dissolve in the water phase and equally volatize into the soil-gas phase hence the remaining petroleum products may persist for long periods of time; slowly dissolving into groundwater and moving in the water phase via advection and dispersion processes. When the product is lighter than water it forms petroleum hydrocarbons such as Benzene, toluene, Ethylbenzene etc and similarly when it is denser than water it forms chlorinated hydrocarbon. Thus, if enough dense non-aqueous phase liquid is released at the surface it can migrate all the way through the unsaturated zone and reach water bearing unit.

Furthermore, it is acknowledged that groundwater represents more than 50% of the world's drinking water supply. Its contamination needs immediate attention, although the amount of groundwater use in Nigeria is still small but with time its future demand is expected to grow especially in water scarce/prone environment like northern part of Nigeria (Akanbi, 2006).

1.2 Background to Study

In Nigeria cases of petroleum product spills have been reported, many of which were detected in wells. These include the pollution of surface and ground water at the Kaduna Refinery and adjoining Rivers Romi and Rido, diesel pollution at Sherada Industrial area in Kano and diesel pollution at Shogunle area of Lagos adjacent to Plasco Sheets Company Ltd. Some of the other cases reported include those at Rigassa and Sarkin Pawa in Kaduna State, Ogbomosho in Oyo State, Orogun in Delta State and Oguta in Imo State. Also not to be forgotten is the spate of spillages from crude and product pipelines in the country, majority of which are attributed to vandalization. Oil spills of crude and refined petroleum products are a major source of contamination of fresh water resources in both surface and groundwater. Between 1976 and 1986, about 2005 crude oil spill incidents were reported by oil producing companies in Nigeria with the estimated quantity of oil spilled being put at about 2 billion barrels (Oteri, 2000). During a period of about 2 ½ years, geologists from the Groundwater Section of the Pennsylvania Department of Environmental Resources, United States of America investigated over 200 hydrocarbon products spills as part of their normal prevention – abatement program activities (Osgood,1974). In dealing with cases of hydrocarbon spillages, prompt action in determining the extent of contamination of soil and groundwater, and developing a recovery/remediation programme is necessary after confirming that soil and groundwater pollution has occurred.

Petroleum product pipelines lie between Baruwa and Jakande Housing Estate on one side and Gowon and Shagari Estates on the other in the Ipaja area of Alimosho Local Government Area of Lagos State. While one of the pipelines runs from Atlas Cove(Ejigbo) to Mosimi (see figure 1.1) carrying various petroleum products (multi-purpose pipeline), the others are dedicated pipelines, carrying various products from Mosimi depot to the Satellite depot at Ejigbo.

Sometime, spillage of petroleum products occurred at the valve pit about 120 metres south of Iyana Ipaja at Baruwa as a result of vandalization; (see figure 1.2). Another spillage was said to have occurred at the same valve pit in January 1996. Petroleum products were first discovered in a well at the Niger Pre-Age School Baruwa adjacent to the pipeline some time after the 1994 spillage. The pollution plume of petroleum product started spreading from one well to the other until large areas were now affected in Baruwa, Jakande, Gowon and Shagari Housing Estates. Many of the people in the affected areas could no longer drink water from these wells or utilize the water for other purposes. The Baruwa Community arrested a man who confessed to be bunkering from a borehole at the premises of the Niger Pre-Age School. He confessed to being a member of an organized ring carrying out bunkering activities in the area. He was detained by the Nigerian police and later released. The groundwater pollution in Baruwa and adjoining areas has received very massive press coverage over the years. The first report in the Press was that in the Guardian Newspaper of 8th September 1997.

There have been studies whether the pollution is from the Texaco Petrol Station along Ipaja road which was established and became operational around year 2000. It is obviously not the source of leakage of the petroleum product in Baruwa community since it lies in the boundary area where water with dissolved hydrocarbon gives way to unpolluted water.

The First Royal Oil Petrol Station, Jakande Estate was also suspected but said to have been established around 1998 though some people felt it was slightly earlier than that. All agree that it became operational after the area had been polluted. It occurs within an area where petroleum product floats on the water table, and the wells around it have floating product. The well in the premises of the station had a very thin film of oil in 2000/2001 but has since cleared. Analysis showed the water had dissolved hydrocarbon concentration of 2.15 mg/l.

The pipeline traverses the area and it was after the vandalization of the valve pit and the resultant spillage of petroleum products in 1994 and again in 1996 that the first oil polluted well was first discovered in the compound of Niger pre-age school. It is noteworthy that the wells immediately adjacent to the valve pit in the valley and adjoining areas of Jakande and Shagari Estates are polluted with dissolved hydrocarbon, but not floating hydrocarbon. The spillage from the valve pit is a source of pollution.

1.3 Justification for the Study

The residents of Baruwa Community located at North Western part of Lagos State had been enjoying good water since its inception until about 15 years ago (i.e, 1994) when the residents of the community found out that the water abstracted from their wells and boreholes were contaminated. There were changes in colour and odour. Consequently, there was need to assess the level of the contaminant in that community, and determine the extent to which the contamination had spread.

1.4 Aim and Objectives of the Study

The aim of the study was to determine the effect of subsurface soil stratigraphy, drainage and engineering properties of soil on the migration of leaking petroleum hydrocarbon at the contaminated Baruwa site.

The objectives of the study were to:

- determine the stratigraphy/soil subsurface profile for Baruwa site using geophysical and geotechnical methods.
- determine the chemical and geotechnical properties of the soil in the study area,
- monitor the water level in correlation with the lithology of the area at which the contaminant spread.

1.5 Contribution to Knowledge

The research was expected to result in the:

(i) Geotechnical and geochemical characterization of the lateritic subsurface soil at the hydrocarbon contaminated Baruwa site.

(ii) Determination of the vertical pathways of contaminant migration especially in upper unsaturated soil moisture zone around the leaking hydrocarbon source at the case study site.

1.6 Scope of Work

The scope of the study work involved the following:

a. Confirmation of the source of the contamination.
b. Determination of the impact of the spill on the environment.
c. Determination of the rate at which the contamination is spreading.
d. Establishment of the extent of the damages caused by the spillage to the environment.
e. Carry out the required Geophysical and hydrogeology survey to study the contamination.

State Boundary Atlantic Ocean Town Study Area (Baruwa)

Figure 1.1 Map of Lagos State Showing the Study Area (Baruwa)

CHAPTER TWO

GEOLOGY OF THE STUDY AREA.

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2.1 Description of the Study Area

The study area is located in Baruwa Village, Ipaja, Lagos State of Nigeria. Baruwa Village (N06º 36.276" and E003º 16.311") is in the North Western Part of Lagos State and is bounded by Yakubu Gowon Estate and Boys Town Communities. It is accessible by a network of roads through Iyana Ipaja–Ayobo. It is a densely populated residential area with about 25,000 inhabitants and about 10,000 of them live in the area already contaminated. During this investigation, soil samples were taken from three locations situated within the Baruwa Village Community. Fig 1.1 shows the map of Lagos State indicating the study area (Baruwa), while Fig.1.2 shows the map of the study Area (Baruwa Village) indicating the three locations where samples were taken.

2.2 Geology and Well Records of Study Area

The community is situated majorly on a sedimentary layer with some of it lateritic in nature up to about 3metres.The soil type has an aquifer layer of about 23metres in depth. Lagos State lies solely within the extensive Dahomey Basin, which extends from Volta Delta in Southwestern Ghana through the Republics of Togo and Benin to Nigeria. The basin is believed to terminate at the Benin hinge line (also called the Okitipupa ridge of Ilesha spur) in the western part of the Niger Delta.

The geological sequence in the Dahomey Basin extends from the Precambrian to recent. Jones and Hockey (1964) grouped all the cretaceous sediments under the Abeokuta formation, while Akanbi (2006) subdivided the cretaceous sequence into three: Ise, Afowo and Araromi formation under the Abeokuta group. Lithologically, Akinbo and Oshosun formations are similar, being greenish grey shales. The boundary between the Coastal Plain Sand and the Ilaro formation was taken as the base of the last continuous sand (Oteri, 2000) in most of the wells corresponding to the boundary between high resistivity sand formations and the low resistivity clays.

Kampsax and Kruger (1977) subdivided the aquifers in Lagos State into four, with the first representing the recent sediments and the second and third aquifer being the Coastal Plains aquifer. The fourth aquifer represents the Abeokuta formation. The Hydrogeological Investigation of Lagos State (Coode Blizard et al 1997) team confirms that there are three (3) main aquifers separated by clay layers (see Fig. 2.1). Sands and gravels constitute the materials in the aquifer of recent sediments, coastal plains sands and Abeokuta formation. Limestone forms the aquifer material in the Ewekoro formation. In the northern part of the State, the Abeokuta formation is made up of very thick sands, majority of which consist of coarse to very coarse-grain clean quartz.

2.3 Regional Geology and Hydrogeology

Lagos State lies within the Benin sedimentary basin where rocks consisting of a series of shallow marine and estuarine deposits ranging in age from cretaceous to recent occur. These sedimentary rocks rest uncomfortably upon the basement complex rocks of the African shield. The sedimentary rocks which are mainly sands and clays with some limestones thicken towards the west and the coast and downdips towards the coast. They are subdivided into geologic formations which are: Recent Sediments (Alluvium), Coastal Plain Sands, Ilaro-Ewekoro and Abeokuta Formations (Kampsax and Kruger, 1977).

The water-bearing (aquifers) in this basin are the sands in the Abeokuta Formation, limestones in the Ewekoro Formation and sands in both the Coastal Plains Sands and the Recent Sediments. Baruwa and surrounding areas lie on outcrops of the coastal plains sands which consist of soft, very poorly sorted clayey sands, sands, pebbly sands, clays and in some instances lignite. The main aquifer developed for water supply is sands in the coastal plain sands. There is a lot of lateral variation in lithology of this formation from one place to the other. The geology of Lagos State is presented as Figure 2.1. The coastal plains sands in gross lithology is subdivided into three (3) aquifer units – the first, second and third aquifer units. Each unit consists of sands and clay layers separated from the underlying unit by a thick continous clay layer. The first aquifer unit which is the water table aquifer is the target horizon for pollution from spillages from pipelines, overhead and underground storage tanks, soak-always and refuse dumps/landfills. This aquifer is overlain by a thick red lateritic soil. In Baruwa area, the depth to the water table is about 24metres. This is a major aquifer of interest in this study and the lithology of the unsaturated zone, the depth to the water table and hydrogeologic characteristics of the unsaturated zone and the aquifer horizon are of interest to this investigation.

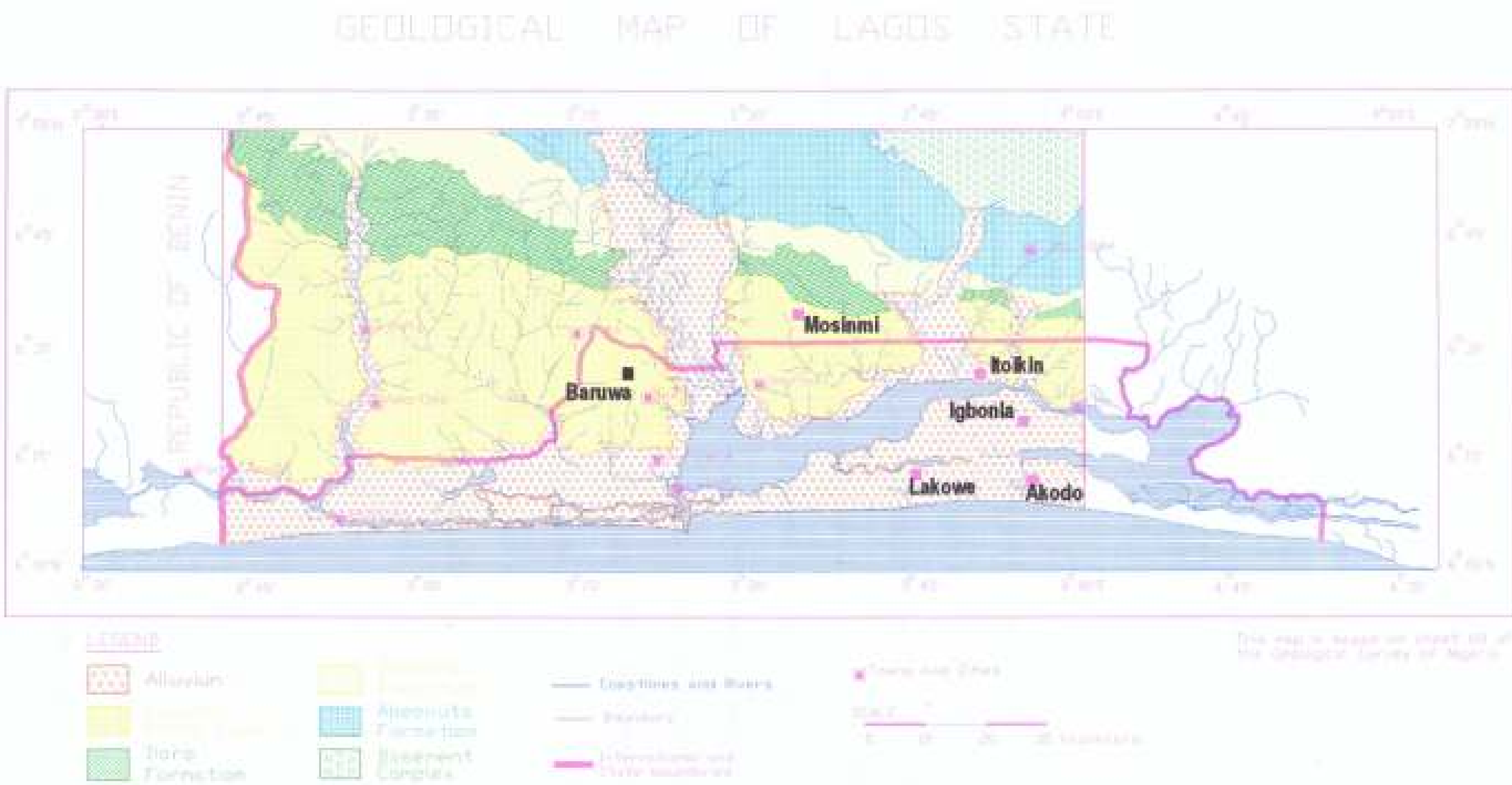

Figure 2.1 GEOLOGICAL MAP OF THE STUDY AREA, LAGOS STATE, NIGERIA

In Lagos State, ground water occurs at all locations such that quantity is not a constraint but its quality resulting from either salt or high iron, silica or phosphate content. The Baruwa area is poorly served by public water supply. Though there is a Lagos State Water Corporation, water mains pipeline traversing the area, over 90 percent of the water used is from large diameter dug wells into the unconfined aquifer. A number of individuals have drilled shallow boreholes. Many wells exist but there is a culture of water sellers in Lagos Metropolis such that residents with no wells in their compounds buy water from vendors either in buckets or tankers.

2.3.1 Abeokuta Formation

The Abeokuta formation is a much more prolific aquifer than the coastal plains sands in the northern part of the State. Fresh water occurs in outcrop areas of the Abeokuta formation in Ogun State. In Lagos State the aquifer is confined beneath younger sediments. At Itoikin and Igbonla (see figure 2.1), artesian conditions exit with free flowing water. The initial piezometric head at the Itoikin well was measured, wit a pressure gauge, at 1.5 bars, which is equivalent to +15metres. Artesian seeps from the ground surface are reported in riverbanks where rivers have down cut through younger sediments to the Abeokuta formation (Tahal, 1995). It was also reported that the magnitude of the artesian head in the aquifer is greater than that expected in a conventional artesian basin. The groundwater is also hot, reported to be at 80^{0}C at the Guinness site in Ikeja and 43^{0}C at the project borehole in Itoikin.

2.3.2 Ilaro and Ewekoro Formation

The formation is not considered as an aquifer in Lagos State as it is predominantly composed of shaly clay. At Lakowe, in the southeastern part of the State (see figure 2.1), a borehole completed in the Ilaro formation resulted in saline water. This was the only source of hydraulic information on the Ilaro formation. In this locality some high energy deposits of fossils and associated gravels were encountered as thin bands in what was otherwise a shaly clay sequence. It was not possible to differentiate the Ewekoro as a target aquifer in any of the project boreholes or existing wells in Lagos State. The formation represents a minor resource in Lagos State (see figure 2.1).

2.3.3 Coastal Plains Sands

Over 95% of all boreholes in Lagos State obtain their water from the coastal plains sands. There is a lot of lateral variation in lithology and water qualities in this aquifer. The aquifer thickens from its outcrop area in the north to the coast in the south and the sand percentage in the formation also changes from north to south. Salt-water occurs in this aquifer with the second aquifer being fresh water bearing in the northern and central parts of the State but salt water bearing in the southern coastal belt (Coode Blizard et al, 1997).

As the salt water in the upper coastal plains sands aquifers overlies fresh water in the lower coastal plains sands aquifer, there is always a clay layer that separates the salt water above from the fresh water below (see figure 2.1). The transition from salt water to fresh water is not abrupt; there is an interface of intermediate salinities. The fresh water interval at Akodo in the lower coastal plains sands aquifer is sandwiched between salt water above and below. While a clay layer separates the salt water from the fresh water above the lower coastal plains sands aquifer, an interface exists between fresh water and saline water in the lower coastal plains sands aquifer. The transition from the fresh water to saline water at the base is gradual (Coode Blizard et al, 1997).

2.3.4 Alluvium

This aquifer is exploited through shallow hand dug wells and boreholes. In the coastal area covering Apapa, Victoria Island and Lekki Peninsula where salt water occurs in the upper coastal plains sands, aquifers within the lower coastal plains sands and the shallow aquifers in the recent sediments constitute a source of water supply for domestic usage. However, due to salt-water intrusion, only a thin layer of fresh water sands occurs in this aquifer at some localities while in others the whole of the water table aquifer is salty (Coode Blizard et al, 1997).

At other places, the fresh water lens is as thick as 20 to 40 meters and is exploited by shallow boreholes. Due to the shallow water table and the very porous permeable sands in the area, contamination of the water from sewage and waste disposal is common especially in Apapa.

2.4 Soil/Groundwater Characterization

The investigation stage of the soil/groundwater characterization process provided a substantial information that can be used to assess the movement and fate of the soil/groundwater contaminants. However, knowledge of the type of contaminants, subsurface characterization and contaminant locations in the subsurface is needed for assessing the transport and information processes in the subsurface. The grouping of contaminants based on mobility is necessary because contaminants in the immobile phase (i.e in non-aqueous phase liquid (NAPL) such as gasoline and fuel oil) can contaminate subsurface water and vapour and similarly contaminants in the mobile phase such as subsurface vapour water and gasoline have the potential to migrate.

The purpose of soil sampling is to determine the subsurface distribution of hydro-stratographic units and the distribution of mobile and residual NAPL. These objectives can be achieved through the use of convectional soil bearing or direct push method (e.g Geoprobe or Cone Penetrometer testing). All soil samples should be collected, described and analyzed.

Furthermore, knowledge of the site location, distribution, concentration and total mass of contaminants of regulatory concern subbed to the soils or present as residual and or mobile NAPL is required to calculate contaminant partitioning from NAPL into groundwater, in the same vein, knowledge of the distribution of contaminants in soil can be used as a cost-effective way to estimate the extent of soil contamination.

Groundwater characterization is needed to adequately determine the amount and three-dimensional distribution of contaminants thus, groundwater samples must be collected and analysed. Bio-degradation of organic compounds, whether natural or anthropogenic brings about the measurable changes in the chemistry of groundwater in the affected areas. Groundwater sampling is conducted to determine the concentration and distribution of contaminants and the samples may be obtained from monitoring wells with point source sampling devices such as Geoprobe, Hydropunch, or Cone penetrometer.

2.5 Historical Record of Leakage Assesment and Depth of Pipeline Burial

The residents of Baruwa Village in North Western part of Lagos State can no longer drink water running from their long existing boreholes and wells because of the widespread pollution of natural and underground water resources. The spreading pollution is widely believed to have resulted from leakages in petroleum products supply lines. The various field tests carried out by Federal and State Environmental Protection Agencies confirmed that the contaminated water is not good for human consumption.

The residents of this community noticed that the water from their boreholes and wells appeared to have been contaminated about fifteen years ago (i.e., 1994) when one of the residents whose house is about 200m from the NNPC pipelines right of way, observed a spillage which went on for days and he did not raise alarm until the pollution spread to other areas in Fatade Street, Gowon Estate and nearby Jakande Estate a year later. In 1996, the entire community then noticed that the water from their wells became tasty, the head of their community development Association then discovered that flowers and animals in his compound started dying as a result, the officials of Nigerian National Petroleum Corporation (NNPC) was contacted through their subsidiary, Pipeline Products Marketing Co Ltd. (PPMC), the NNPC officials stated that the pollution was caused by vandalisation of its underground facilities, A valve pit positioned at Baruwa had been vandalised resulting in leakage of fuel into the water table. Furthermore, the PPMC stated that the findings of the engineers in their pipeline maintenance department revealed that some residential buildings in the Estate were built on the pipeline right of way which constitute a hindrance to the proper investigation and identifying the exact damaged supply lines.

In May 2001, the affected residents of Baruwa reeling under the economic, social and health implications of the pollution made a move to sue Nigerian National Petroleum Corporation and its subsidiary Pipeline Products and Marketing Company Limited to court for not addressing the problem of water pollution in their community. The court decided that the Pipeline Products Marketing Company [a Subsidiary of NNPC] should unravel the immediate cause of the pipeline leakage and subsequently provide a potable drinking water for the entire community, The Nigeria National Petroleum Corporation (NNPC) complied with court decision and four new boreholes were drilled at the "Water Project Borehole" within the community, but up till the time of this study, no potable drinking water comes out from all the boreholes drilled in the Baruwa community (Guardian Newspaper, Oct.21st, 2002). According to the Nigerian National Petroleum Corporation officials, the depth of the underground supply pipelines is 2.0meters from the surface.

2.6 Nature of Ground Water Contamination

2.6.1 Movement of oil in soil

After crude or petroleum product is spilled, it migrates down-wards under the force of gravity. The mobility of the oil in the soil depends on its viscosity, quantity of oil spilled, the physical nature of the strata, the amount of moisture present, and the thickness of the unsaturated zone. There is absorption and reactions between the oil and the rock matrix tending to immobilize and attenuate the oil. If the water table is far enough below the ground surface, the oil may be immobilized in the unsaturated zone before it reaches the water table. In the case of shallow water table aquifers, where the oil is not immobilized in the unsaturated zone, the spill will reach the water table. The oil is forced to spread laterally in form of a thin pancake due to its lower specific gravity. Soluble components will dissolve in the water and vapours will be released which may collect forming potential fire or explosion hazards. The pollution plume of crude and dissolved phases will move in the direction of ground water flow in the aquifer. Spills to the ground water are significant and dangerous. Spills which are immobilized in the unsaturated zone can still pollute ground water because rain percolating through the contaminated soil will dissolve the soluble components of the hydrocarbon and carry them into the ground water. This is also the reason why, once spillage has occurred, it takes a long time to clean up as every recharge by percolating rain or a fluctuating water table regenerates the contamination.

2.6.2 Groundwater contamination from oil spills:

Oil spills of crude and refined petroleum products are a major source of contamination of fresh water resources (i.e surface and groundwater). Between 1976 and 1986, a total number of 2005 crude oil spills incidents were reported by oil producing companies in Nigeria with the estimated quantity of oil spilled being put at about 2 billion barrels. Spills of petroleum products are also very rampant. During a period of about 2.5 years, geologists from the groundwater section of the Pennsylvania Department of Environmental Resources investigated over 200 hydrocarbon products spills as part of their normal prevention – abatement program activities (Osgood,1974). In dealing with cases of hydrocarbon spillages, prompt action involving the determining the extent of contamination of soil and groundwater and developing a recovery/remediation programme is necessary after confirming that soil and ground water pollution has occurred.

2.6.3 Hydrogeology

Two hydrogeologic regimes occur in the Baruwa project area. In most of the area, the shallow unconfined aquifer is the sand occurring from a depth of about 20 to 27m. It is a white medium to coarse grained sand, occasional silty and slightly clayey. The water table in this aquifer occurs at depth of 19.3 to 30.07m. The aquifer is underlain by a clay layer that the saturated thickness of the aquifer varies from 2.5 to 5m, while an upper clay layer separates the aquifer from ground surface. Within the valley, surrounded on all four sides by higher ground that trend between Gowon Estate, Jakande Estate and Ipaja Road in the northeast (see Fig 1.2), the unconfined aquifer is sandy clay with the water table varying 1.4 to 7.2m. The sandy clays and sands below this horizon are all saturated and confined. The aquifer from 20 to 26.7m corresponding to the main unconfined aquifer in the other parts of Baruwa area is confined within this area with the two being in hydraulic continuity. While the aquifer between 20 and 27m yields enough water to dug wells, the yield in drilled boreholes is very low. Shallow boreholes are drilled to lower aquifers which occur from about 30 to 45m and yield enough water for the boreholes.

2.6.4 Source of Contamination and Liquid Hydrocarbon Leakage in the Study Area.

2.6.4.1 Possible sources of petroleum product leakage in Baruwa Area.

(a). The Petrol Stations: There exists three (3) petrol stations within and at the periphery of the contaminated area in Baruwa at adjourning areas. These are the Texaco Petrol Station along Ipaja road which was established and became operational around year 2000. It also lies at the boundary area where water with dissolved hydrocarbon gives way to unpolluted water. It is obviously not the source of leakage of the petroleum product in Baruwa community.

The first Royal Oil Petrol Station, Jakande Estate was said to have been established around 1998 though some people felt it was slightly earlier than that. All agree that it became operational after the area had been polluted. It occurs within an area where petroleum product floats on the water table and the well around it have floating product. The well in the premises of the station had a very thin film of oil in 2000/2001 but has since cleared. Analysis showed the water had dissolved hydrocarbon concentration of 2.15mg/l. The Conoil Petrol Station became operational in 2006 and therefore could not have been the source of leakage.

(b). PPMC Pipeline (I–valve pit): The pipeline traverses the area and it was vandalized in 1994 and 1996. The first oil polluted well in a compound adjacent to the valve pit in the valley and adjourning areas of Jakande and Gowon Estates were polluted with dissolved hydrocarbon after the spillage resulting from the vandalization, but not floating hydrocarbon. The spillage from the valve pit gave it a source of pollution.

The zone with the thickest floating hydrocarbon in Baruwa area of Ipaja road cuts across the pipeline right of way with the lines carrying products to and from Mosimi depot. Could there be an undetected leakage on the pipeline? Since 1994 till date, there has been no known surface evidence of petroleum leakage along the "Right Of Way" usually associated with pipeline leakage such as smell or liquid product on the soil either in the low lying areas or along the line.

(c). Other Unknown Sources: Could there be other sources like people who were carrying out illegal "bunkering" in the area which combined with that from the valve pit? It is instructive that a man was caught in 2004 who confessed to being a part of an organized ring carrying out bunkering activities at the Niger Pre-Age School (the site of the first discovery of the pollution). During the excavation exercise undertaken, a number of artisans along the pipeline "Right Of Way" informed the crew that a lot of bunkering activities used to take place in the areas in times past. It is noteworthy that in the area between Niger Pre-Age school and the adjoining plot, the dedicated pipelines to satellite depot have been seriously encroached upon.

2.6.4.2 Leakage of petroleum product in Baruwa from the Valve Pit

When the leakage of petroleum products from the valve pit first occurred in 1994, the products flowed southwards. As the products flowed southwards, a proportion of it infiltrated into the subsurface while some evaporated. The portion that infiltrated moved down in the vadose zone some of which reached the water table which at about 23m below ground level. No free product could penetrate the water table as the water table formed a barrier to downward migration of the spilled free hydrocarbons. If the volume of products reaching the water table was large, a pancake of free hydrocarbon would form on the water table.

Both soil samples and the water from the boreholes indicated hydrocarbon contamination. All topographic and hydrogeologic evidence point to the fact that the spillage at the valve pit in 1994 and 1996 gave rise to ground water pollution in form of dissolved oil only (Oteri, 1998).

2.6.4.3 Source of floating hydrocarbon in the study area

From previous discussions in 2.4.1 above (see figure 1.2), there are two likely sources of the petroleum product floating on water in the aquifer in Baruwa area. These are leakages of any of the pipelines within the topographic high area by the junction of Oladipo Ajulo street and NNPC pipeline road (see figure 1.2), Niger Pre-Age School area as a result of corrosion of the pipeline; and vandalization of the pipelines and bunkering in the area between the junction of Ipaja road and NNPC pipeline road.

(a) Corroded Pipeline: A leaking pipeline due to corrosion as the source of the floating hydrocarbon appeared improbable from the beginning for a number of reasons:

- There has never been any smell of hydrocarbon or other surface evidence of liquid product on the soil usually associated with pipeline leakage along the area since 1994 to date.
- The volume of spilled oil required to reach the water table at this site (if at all) should have been very high. The tendency for evidence of the oil to show at the ground surface should have been high but none is seen. While soil gas from the

wells containing floating hydrocarbon is found, no sign of soil gas is evident along the pipeline route in the area suspected to be the source of spillage.

- The unconfined aquifer has a low permeability, low yield and low velocity. Based on natural groundwater flow rates, the extent of the pollution plume should have been much smaller than is observed. However, as individuals were pumping their wells, this would have resulted in faster rate of flow of ground water in the area.
- The size of the pollution plume has been decreasing since 2001 and this is not consistent with leakage of a corroded pipeline as there has been no pipeline repair in the area.

A search of the literature showed that while pipeline breaks leading to spillage of petroleum contamination of groundwater usually showed some evidence at the ground surface, a number of instances occurred with no surface evidence found. These were instances where the leak was due to a crack or very small hole on the under side of the pipeline resulting in a very slow rate of leakage.

2.6.5 Water levels and groundwater flow direction

Measurement of depth to water levels was carried out in many of the wells in the project area using an electric water level indicator (sounder). From the measurement of elevation at some of the wells, the sub sea water level elevation was determined and a ground water contour map was drawn for the main shallow aquifer horizons that occur between depths of 20 and 27m. A regional groundwater flow direction was found to be in the southwest direction but flow radiates from the valley between Jakande Estate and Gowon Estate.

CHAPTER THREE

LITERATURE REVIEW

3.1 Laterites and their Formation

Laterite is a reddish brown residual sandy or gravelly soil, often hard and compact, formed by leaching and weathering; under tropical conditions the resultant material is rich in aluminum and iron and primarily composed of the oxides of these metals (Gidigasu, 1976).

Ola (1983) proposed the local terminology which regards as literite soils all products of tropical weathering with reddish brown or dark brown colur, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crusts or hard pan.

Lateritic soils (which are also called residual or topsoil) are formed by chemical weathering and may be found where the action of the elements has produced a soil with little tendency to move. Residual soils can also occur whenever the rate of break-up of the rock exceeds he rate of removal. If the parent rock is igneous or metamorphic the resulting soil sizes range from silt to gravel (Smith1995).

Laterite soils are essentially products of tropical or sub tropical weathering, the chemical composition and morphological characteristics of these products are influenced by the degree of weathering which the parent material has been subjected, Russell (1889) of the U.S.A Geological survey in the discussion of the aerial survey of rocks and the origin of the red colour of certain formations in the United States of America was probably the first to emphasize that in warm moist temperate and tropical climates the water percolating through rock has a strong solvent power and that weathering is more rapid in warm than in cold region and greater in humid than in acid climates. Holland (1903) also suggested that during the weathering of aluminous silicates in the tropics, the silica, alkalis and alkaline earths are removed in solution while the alumini and ferric oxide became dehydrated and remain behind.

3.2 Chemical Definitions

Mallet (1883) was perhaps the first to introduce the chemical concept by establishing the ferruginous nature of laterite. Bauer (1898) also established the relatively insignificant content of silica and high contents of aluminum in a hydroxide form comparable to the composition of bauxite. Warth and Warth (1903) established that some Indian laterites contained small amounts of alumina, but were relatively poor in iron. The great interest developed in laterites as a possible source of aluminum is intensified research on the material.

Fermor (1911) abandoned the criterion of physical hardness of laterite in its natural state or on exposure, and developed a comprehensive system of nomenclature of laterite soils on the basis of their chemical composition. Various forms of laterite on the basis of the relative contents of the so-called laterite constituents (Fe, Al, Ti and Mn) in relation to silica were defined. A similar and more comprehensive chemical classification system was proposed by Lacroix (1913) who divided laterites into:

(a) True laterites

(b) Silicate laterites and

(c) Laterite clays depending on the relative contents of the hydroxides.

There have been definitions given by various researchers; an approach on chemical classification was given by Ola (1983) on the basis of silica aluminum ratio. It was that, generally ratios of silica to sequioxide represented by $SiO_2/(Fe_2O_3+Al_2O_3)$ which are less than 1.33 are indicative of true laterites, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non-lateritic types.

Winterkon et al (1972) questioned the use of silica – alumina ratio since the original definition of lateritic by Buchanan (1807) attached special importance to the role iron oxides play in the laterite rock. Moreover the presence of iron in lateritic soils is also considered the most important factor influencing their engineering properties (Winterkorn et al, 1972). The use of the silica – sesquioxide ratio (SiO_2 / Al_2O_3+ Fe_2O_3) after Joachin in and Kandiah (1941) with the same limiting values as those prepared by

Martin and Doyne was adopted. The chemical definitions later gave way to morphological definitions

3.3 Morphological Definitions

Walther (1916) proposed the morphological definition to cover all red-coloured, brick like alluvial and tropical red earths, Later Harassowitz(1926) proposed a typical laterite profile which agrees with the descriptions of Fox (1939) and Lacroix (1913). Pendelton and Sharasurana(1946) also emphasized that although the silica- alumina or the silica-sesquioxide ratio are useful parameter, they do not conclusively define laterites.

Consequently, Pendelton and Sharasurana (1946) defined laterites soils as profiles in which a laterite horizon is found, and lateritic soils as profile in which there is an immature laterite horizon from which a true laterite horizon will develop if appropriate conditions prevail long enough. A criterion combining both the chemical and physical concepts was proposed by Femor (1911) who classified laterites into four principal forms of sesquioxide – rich materials that are either hard in–situ or capable of hardening on exposure to air. The morphological, physical and chemical concepts proposed have been summarized by Alexander and Cady (1962) as follows:

"Laterite is a highly weathered material, rich in secondary oxides of iron, aluminum ,or both, it is nearly void of bases and primarily silicates but it may contain large amounts of quartz and kaolinite, it is either hard or capable of hardening on exposure to wetting and drying". Peck (1971) refers to all such materials as reddish tropically weathered materials irrespective of the details of the degree of their weathering and irrespective of the presence or absence of crusts.

3.4 Laterization

Gidigasau (1976) identified three stages in the process of laterization – decomposition, laterization proper and hydration and desiccation.

3.4.1 Decomposition

This is characterized by the physio-chemical breakdown of primary minerals and the release of constituent's elements. It involves the physical disintegration and chemical decomposition. Physical distingeration involves the physical breakdown of the parent rock due to differential expansion and contraction of the rock forming mineral as a result of temperature variation.

Chemical decomposition is the breakdown of the unstable primary minerals and the formation of new minerals. This is where the leaching of dissolved constituents especially combined silica and bases start.

3.4.2 Laterization

This involves the primary and secondary stages. The first stage is the progressive decrease of combined silica and bases and the relative accumulation of insoluble Al, Fe Ti and Mn constituents, the second stage is absolute accumulation of oxides and hydroxides of sesquioxide (mainly Al_2O_3 and Fe_2O_3).

3.4.3 Hydration and desiccation

This involves partial or complete dehydration (sometimes involving hardening) of the sesquioxide – rich minerals and secondary minerals.

3.5 Factor Affecting Formation of Laterite

Laterite formation factors include climate (precipitation) leaching, capillary rise and temperature, topography (drainage), vegetation, parent rock (iron rich rock) and time of these primary factors. Climate is considered the most important (Ola 1983).

Most laterites are composed predominantly of kaolinite and with some quartz. The most significant factor with respect to engineering work are of swelling minerals which reduce the bearing strength of the soil. The proportion of iron and aluminum oxides found in laterites tend to cement the soil particles to form weakly bonded particules. In spite of the bonded nature, the tensile strength is small, occasionally; a slight cohesion reflects an increase in the surface change as a result of finer fundamental particles produced by leaching (Okafor, 1989)

3.6 Hydraulic Head and Fluid Potential in Groundwater Flow

The analysis of the physical processes that involves flow usually requires the recognition of the potential gradient. It is necessary to understand the potential gradient that controls the flow of water through porous media. This concept has been carefully considered by Freeze and Cherry (1979), in their classical treatise on groundwater flow.

Freeze and Cherry (1979) define potential as a physical quantity, capable of measurement at every point in a flow system, whose properties are such that flow always occurs from regions in which the quantity has higher values to those in which it has lower, regardless of the direction in space. Two obvious possibilities for the potential quantity are elevation and fluid pressure.

From the elementary concepts in elementary physics and fluid mechanics, the best way to explain the fluid potential is to examine the energy relationships during the flow process. In fact the classical definition of potential as it is usually presented by mathematicians and physicists is in terms of work done during the flow process; and the work done in moving a unit mass of fluid between any two points in a flow system is a measure of the energy loss of the unit mass.

Fluid flow through porous media is a mechanical process. The forces driving the fluid forward must overcome the frictional forces set up between the moving fluid and the grains of the porous medium. The flow is therefore accompanied by an irreversible transformation of mechanical energy to thermal energy through the mechanism of frictional resistance. The direction of flow in space must therefore be away from regions in which it is lower. Mechanical energy per unit mass at any point in a flow system can be defined as the work required to move a unit mass of fluid from an arbitrary chosen standard state to the point in question. The "fluid potential" for flow through porous media is therefore the mechanical energy per unit mass of fluid.

3.6.1 Mechanical transport of groundwater

The external forces acting on Groundwater are;

(1) Force of Gravity ($F = mg$)

(2) External pressure

  (a) Atmospheric Pressure: (Water Table Aquifers)

  (b) Hydrostatic Pressure: (Pressure exerted by overlying water and overlying rock strata)

(3) Molecular Attraction

  (a) Dipolar nature of water molecule

  (b) Causes water to adhere to solid surfaces

  (c) High surface tension capillarity

3.6.2 Mechanical energy

The mechanical energy consists of the following;

A. Kinetic Energy: energy of motion

$E_k = (0.5)mv^2$ where E = kinetic energy, m = mass, v = velocity

B. Gravitational Potential Energy: energy of position

$E_p = mgz$ where m = mass, g = acceleration due to gravity,

z = elevation of center of gravity of fluid above reference elevation

C. Energy of Fluid Pressures: pressure force exerted on a fluid mass by surrounding fluid acting upon it.

$P = F/A$

P = pressure, F = force, A = area

Total Energy of Fluid Mass System = (Sum of Three Components: kinetic, potential, pressure)

assuming density = mass/volume, then density (ρ) = mass for a unit volume of fluid (i.e. $V = 1$), substituting ϱ for m in above equations...

$$E_{tv} = E_k + E_p + P = 1/2\, \varrho v^2 + \varrho gz + P \quad \text{...(3.1)}$$

where E_{tv} = total energy per unit volume, v = velocity, g = gravity, z = height above reference datum, P = fluid pressure, ϱ = density

*by dividing out by ϱ..

$$E_{tm} = (V^2/2) + gz + (P/\varrho) = \text{"Bernoulli Equation"} \quad \text{......................................(3.2)}$$

where E_{tm} = total energy per unit mass (units = L^2/T)

$$E_{tw} = (E_{tm})/g = \text{total energy per unit weight (units = L)}$$

3.6.3 Derivation of hydraulic head from Bernoulli Equation

Definition of Hydraulic Head

Hydraulic head = total mechanical energy operating on a fluid mass per unit weight.

h = hydraulic head, measured in terms of length

Equation (3.2)

$$E_{tm} = (V^2/2) + gz + (P/\varrho) = h \text{ (hydraulic head)}$$

Since ground water velocity is so slow compared to the other components (avg = 10^{-8} m/s = 30 m/yr), the velocity portion of the equation essentially = 0

hence $h = gz + (P/p) = z + (P/\varrho g)$ by rearranging and substitution of $P = \varrho g \Psi$

** $h = z + \Psi$ (units of measurement in L) ** ....(3.3)

here h = total hydraulic head, z = elevation of a reference point in water column above datum, Ψ = point water pressure head = height of water column above reference point.

** $\Psi = P/(\varrho g)$ ** Rearranging $P = \varrho g \Psi$

where Ψ = point water pressure head (pressure head), P = fluid pressure, ϱ = fluid density, g = gravity

(g = 9.8 m per sec ; density of pure water = 1 gm/cm^3 = 1000 kg/m^3)

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CHAPTER FOUR

MATERIALS AND METHODS

This study work involved collection of sample (field work), preparation of sample and detailed laboratory tests of the geotechnical properties of the collected samples. All the field equipment and the methods used for the preparation of the samples are discussed here.

4.1 Field Tools

The equipment used for the collection of samples are Cutlass, Digger, Shovel, Sample bag/sack and Measuring tape.

For vertical electrical sounding it included ABEM SAS 300c Terrameter and Booster, Multi-meter, measuring tape, a pair of pre-marked strings, potential and current cables, four (4) steel electrodes and Garmin II GPS Plus

4.2 Sampling

Based on the review of existing borehole data for the study, three locations representative of the major subsurface profiles were chosen. The method used in the collection of sample is the trial pit method. Undisturbed block samples were collected from three (3) different trial pits each at different locations in Baruwa (see Figure 1.2). These locations are listed:

(i) Location 1: Oyewole.

(ii) Location 2: Elegbede

(iii) Location 3: Ladipo Ajulo

4.2.1 Trial pits

This is the method of soil exploration that was used in this study. A test pit is simply a hole dug in the ground that is large enough for a ladder to be inserted, thus permitting a close examination of the sides. With this method, relatively undisturbed samples of soils were collected.

The final depth of each trial pit was 2.0m and about 1.2m x 1.2m wide (i.e. 1.2m x 1.2m x 2.0m pit). The types of samples collected for the laboratory analysis are as follows

(i) Disturbed samples

(ii) Undisturbed samples

The pit was sunk by hand excavation with the aid of spade and digger, with the collection of depth discrete samples at 0.50m (Top level), 1.25m (Middle level) and 2.00m (Bottom level) depth.

4.2.2 Undisturbed sample

Undisturbed samples are required for permeability tests on the soil. Undisturbed block samples were cut by hand from the bottom of the pits at 0.50, 1.25 and 2.00m. During cutting the samples were protected from water, wind and sun to avoid any change in water content. The samples are covered with black polythene bag immediately they are brought to the surface and labelled respectively. The block undisturbed samples collected, had sizes of about 225mm x 225mm x 225mm. Cylindrical samples for the permeability test were trimmed from the block samples.

4.2.3 Disturbed sample

Disturbed samples were used for soil classification, specific gravity and mineralogy tests. These were also collected from thr trial pits. Twenty seven soil samples were taken altogether from these three different locations (location 1, 2 and 3). The laboratory tests that were carried out on these soil samples include both index properties of soil, permeability and clay mineralogy.

4.3 Laboratory Tests

The laboratory tests that were carried out on the soil samples include both the index and mechanical properties of soils. Some of the properties of the soils were carried out in the following laboratories:

- Geotechnical laboratory, Civil Engineering Department of the Federal University of Technology, Akure.
- Chemical Laboratory, Pearls Laboratory, Bolade Oshodi,Lagos
- X-ray unit, Rolab Research and Diagnostic Laboratory, Ibadan Oyo State

4.3.1 Specific gravity

The specific gravity was carried out in accordance with BS1377(1981) and AASHTO(1986) specification and this is expressed as the ratio of the weight of a given volume of the soil in air at a specific temperature to the weight in air of equal volume of water at the same temperature. It is also known as a measure of the density of the soil to that of water at a given temperature.

Lohne and Damirel (1973), suggested that the specific gravity of a soil particle is a very good index property to characterize lateritic soil because it reflects their sesquioxide content and hence the extent of laterisation (Bowles, 1986) gave the following classification for soils with various specific gravity values.

Table 4.1 Classification for soils with specific gravity values.

Type of Soil	Specific Gravity (Gs)
Sand	2.65 - 2.67
Silty sand	2.67- 2.70
Inorganic clay	2.70- 2.80
Soils with micas or iron	2.75- 300
Organic soils	Variable, but may be under 2.00

4.3.2 Grain size distribution

This analysis was carried out in accordance with BS1377 (1981) and AASHTO (1986) specification in an attempt to determine the relative proportion of different grain sizes which make up a given soil mass. It is expressed as a percentage of the total dry weight; it gives the percentage content of the various fractions i.e. boulders, cobbles, graves, sands, silts, clays and colloidal size particles.

There are three stages in the grain size analysis of laterites and these are:

- wet sieving
- mechanical or sieve analysis
- hydrometer analysis

Wet sieving: - the aim was to separate coarse fraction of the soil from the fine ones. The apparatus used are weighing balance, sieves, drying pan, sieves brushes and paper tape.

Procedure:-(i) About 500g of the air dried sample was soaked in water for 24 hours.

(ii) The soaked sample was sieved through 75μm sieve.

(iii) The sample retained was oven-dried for another 24hours.

This is aimed at separating the silt and clay fractions from the coarse fraction (sand and gravel). The fraction retained on the sieve was transferred to a container and oven-dried at temperature of 100-110°C. The two fractions were then subjected to further analysis.

Mechanical or sieve analysis: - The separated coarse fraction were oven-dried for 24hours at temperature of 100°C. This was then subjected to mechanical sieving by using sets of sieve shaker. The sieve shaker was put on for 10minutes. The time of sieving is very crucial and it has to be standardized in order to avoid mechanical instability (Malomo, 1977). Mechanical instability is peculiar to lateritic soils in the tropics and is the susceptibility of grains of soils to breakdown when its level of mechanical energy is increased. This is as a result of increase in time of sieving or during compaction test. The percentage retained on each sieve was then computed by dividing the weight retained on each sieve with the original soil weight. The percentage passing through the sieve was then computed and these were plotted on semi-logarithm chart to obtain the grading curve.

Hydrometer analysis: - this analysis is aimed at estimating the percentage of silt and clay size particle of the soils. It is based on Stoke's law which states that the settling velocity of a spherical particle is directly proportional to particle size (D), the difference in densities of the particles and the fluid through which the particle is falling and inversely proportional to viscosity of the fluid. This analysis has a limitation based on the fact that not all grains are spherical or rounded in shape.

4.3.3 X-Ray analysis

The powdered specimen was mounted on a small pedestal connected with a continuously rotating base. The X-rays were permitted to hit the specimen and be diffracted upon a film. Each line of the pattern represents a refraction from different atomic planes within the mineral (Krynine and Judd, 1957). The clay minerals can be identified further by the temperatures required to extract structural water from their lattices.

4.3.4 Permeability

This test was carried out in accordance with BS1377 (1981) and AASHTO (1986) specifications on the soil samples to determine the coefficient of permeability of the soil. The falling-head permeability method (Bowles, 1986) was used in this study. Also, three tests were conducted on each sample.

4.3.5 Chemical analysis of the soil samples

The samples were taken in polythene bags upon transportation to the laboratory. The soil samples were air-dried and sieved with 2mm mesh (Carter, 1992). The sieved samples were used for the various mineral analyses.

4.3.6 Vertical electrical sounding

The geo electric section is a representation of the sequence of geologic layers in the drilled wells. Six (6) wells were observed for the study. Nine (9) vertical electrical sounding were carried out at the well locations to get the resistivity of the layers. The data and its interpretation are presented as Appendix A. (1-9).

CHAPTER FIVE

RESULT AND DISCUSSION

This chapter presents the results of various geotechnical, chemical and X-ray tests carried out on all the samples. Tables and graphs were also plotted for each test. The following symbols were used to designate soil samples:

TP 1(T) ....Top Soil Sample from Oyewole

TP 1(M)....Medium Soil Sample from Oyewole

TP1 (B)...Bottom Soil Sample from Oyewole

TP 2(T) ....Top Soil Sample from Elegbede

TP 2(M)....Medium Soil Sample from Elegbede

TP2 (B)...Bottom Soil Sample from Elegbede

TP 3(T) ....Top Soil Sample from Ladipo Ajulo

TP 3(M)....Medium Soil Sample from Ladipo Ajulo

TP 3(B)...Bottom Soil Sample from Ladipo Ajulo

5.1 Bulk Density

The results of the bulk density of the studied soil samples are summarized in Table 5.1. For soil samples in location 1, the bulk densities vary from 1.81Mg/m^3 to 1.85Mg/m^3 with increasing depths of 0.47 to 1.65m. The bulk densities also increase from 1.91Mg/m^3 to 1.98Mg/m^3 for soil samples in location 2 and 2.06 to 2.19Mg/m^3 for soil samples in location 3 with increasing depths in both locations. The results show that the bulk density increases with depth.

TABLE 5.1: SOIL BULK DENSITY TEST RESULTS

No	Depth (m)	Soil Bulk Density Mg/m3
TP 1 (T)	0.20 - 0.50	1.81
TP 1 (M)	0.85 - 1.25	1.83
TP 1 (B)	1.30 - 2.00	1.85
TP 2 (T)	0.20 - 0.50	1.91
TP 2 (M)	0.85 - 1.25	1.95
TP 2 (B)	1.30 - 2.00	1.98
TP 3 (T)	0.20 - 0.50	2.06
TP 3 (M)	0.85 - 1.25	2.14
TP 3 (B)	1.30 - 2.00	2.19

5.2 Volumetric Moisture Content

The results of the volumetric moisture content are showed in Table 5.2 .The result shows that the values range from 27.4 to 39.40% for soil samples in locations 1, 2, and 3, respectively for increasing depths. The results show the effect of weathering with the moisture content increasing with depth.

TABLE 5.2: VOLUMETRIC MOISTURE CONTENT

No	Depth	Volumetric Moisture Content, %
TP 1 (T)	0.20 - 0.50	27.4
TP 1 (M)	0.85 - 1.25	29.3
TP 1 (B)	1.30 - 2.00	31.08
TP 2 (T)	0.20 - 0.50	31.62
TP 2 (M)	0.85 - 1.25	33.94
TP 2 (B)	1.30 - 2.00	35.10
TP 3 (T)	0.20 - 0.50	36.03
TP 3 (M)	0.85 - 1.25	38.19
TP 3 (B)	1.30 - 2.00	39.40

5.3 Specific Gravity

This is an important index property of soil that is closely linked with mineralogy/ chemical composition. The specific gravity values of the soils shown in Table 5.3. are 2.66, 2.64 and 2.64 for soil samples in locations 1, 2 and 3, respectively when the samples are taken from depths 1.25, 0.85 and 1.65m from the three locations respectively.

TABLE 5.3. SUMMARY OF THE SPECIFIC GRAVITY TEST.

S/No	Depth (m)	Average Specific Gravity (GS)
TP 1	0.20 - 0.50	2.66
TP 2	0.85 - 1.25	2.64
TP 3	1.30 - 2.00	2.64

5.4 Permeability

The coefficient of permeability depends primarily on the average size of the pores which in turn is related to the distribution of particle sizes, shapes and soil structure (Craig, 1979). The results of permeability tests on the soil samples are shown in Table 5.4. It can be deduced that coefficient of permeability for soil samples from locations 1 and 2 increased with depth, while that from location 3 decreased with increase in depth. For soil samples in location 1, the value ranges from 3.11×10^{-4}cm/s to 1.72×10^{-4}cm/s and for location 2, it ranges from 2.22×10^{-4}cm/s to 6.36×10^{-4}cm/s. On the other hand, it decreased from 3.05×10^{-4}cm/s to 2.65×10^{-4}cm/s in soil samples from location 3. The result indicates that the permeability increases with the increase in void ratio.

TABLE 5. 4. PERMEABILITY TEST RESULT

Location 1 Oyewole Close

S/No	Depth	Void Ratio (e)	K cm/sec
TP 1 (T)	0.20 – 0.50	0.846	0.000311
TP 1 (M)	0.85 – 1.25	0.98	0.000492
TP 1 (B)	1.30 – 2.00	0.767	0.000172

Location 2 Elegbede Street

S/No	Depth	Void Ratio (e)	K cm/sec
TP 2 (T)	0.20 – 0.50	0.521	0.000222
TP 2 (M)	0.85 – 1.25	0.581	0.000415
TP 2 (B)	1.30 – 2.00	0.647	0.000636

Location 3 Ladipo Ajulo Street

S/No	Depth	Void Ratio (e)	K cm/sec
Tp 3 (T)	0.25 – 0.50	0.733	0.000305
TP 3 (M)	0.85 – 1.25	0.705	0.000298
TP 3 (B)	1.30 – 2.00	0.643	0.000265

PERMEABILITY TEST RESULTS

Location 1: Oyewole Close

TABLE 5. 4a. PERMEABILITY TEST RESULT FOR OYEWOLE SAMPLES

S/No	Depth (m)	Void Ratio (e)	K (cm/sec)
TP1/T	0.25 – 0.50	0.846	0.000311
TP1/M	0.85 – 1.25	0.98	0.000492
TP1/B	1.30 – 2.00	0.767	0.000172

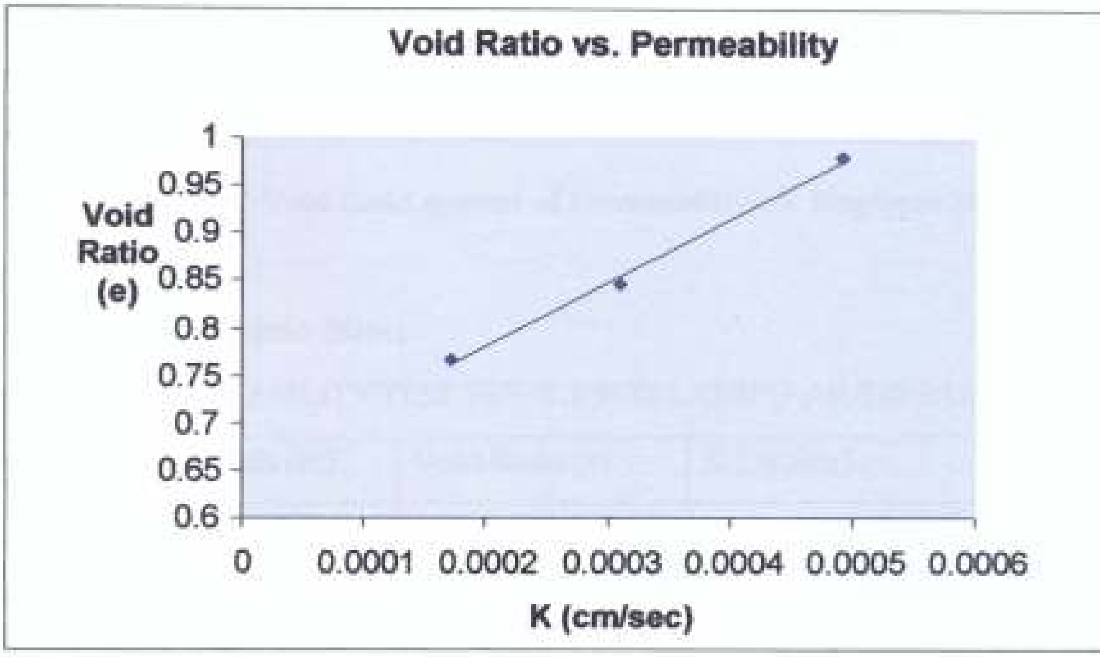

Figure.5.1a: Graph of Void Ratio against of Permeability for Oyewole Site

Location 2: Elegbede Street

TABLE 5.4b PERMEABILITY TEST RESULT FOR ELEGBEDE SAMPLES

S/No	Depth (m)	Void Ratio (e)	K (cm/sec)
Tp1/T	0.25 – 0.50	0.521	0.000222
Tp1/M	0.85 – 1.25	0.581	0.000415
Tp1/B	1.30 – 2.00	0.647	0.000636

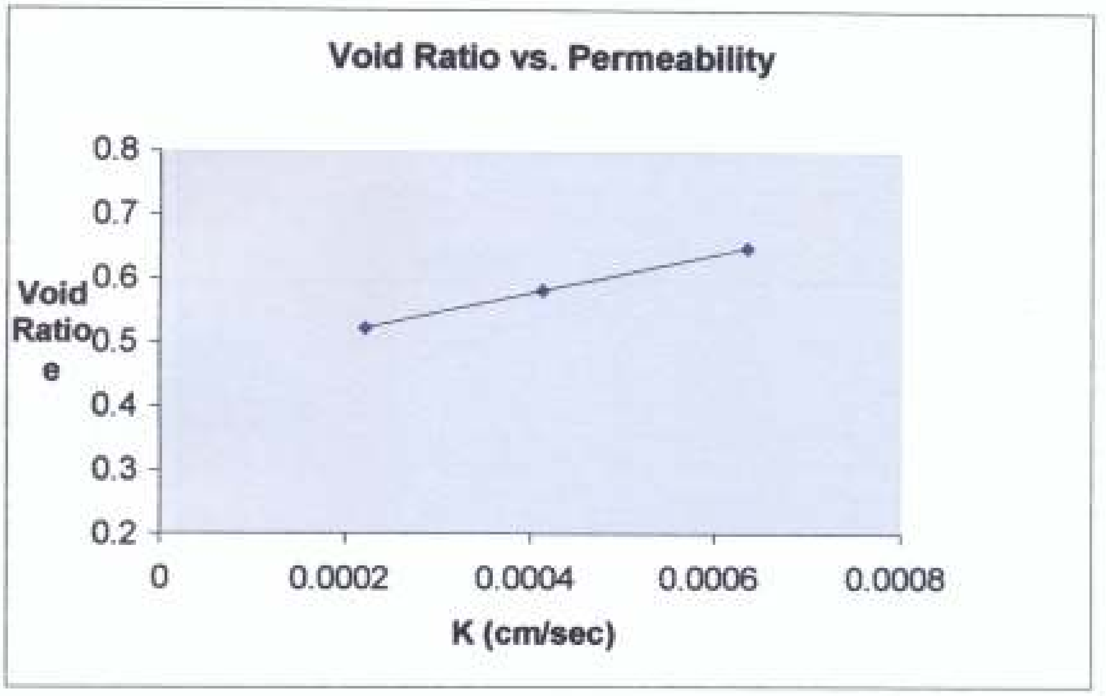

Figure.5.1b: Graph of Void Ratio against of Permeability for Elegbede Site

Location 3: Ladipo Ajulo Street

TABLE 5. 4c PERMEABILITY TEST RESULT FOR LADIPO AJULO SAMPLES

S/No	Depth (m)	Void Ratio (e)	K (cm/sec)
Tp1/T	0.25-0.50	0.733	0.000305
Tp1/M	0.85-1.25	0.705	0.000298
Tp1/B	1.30-2.00	0.643	0.000265

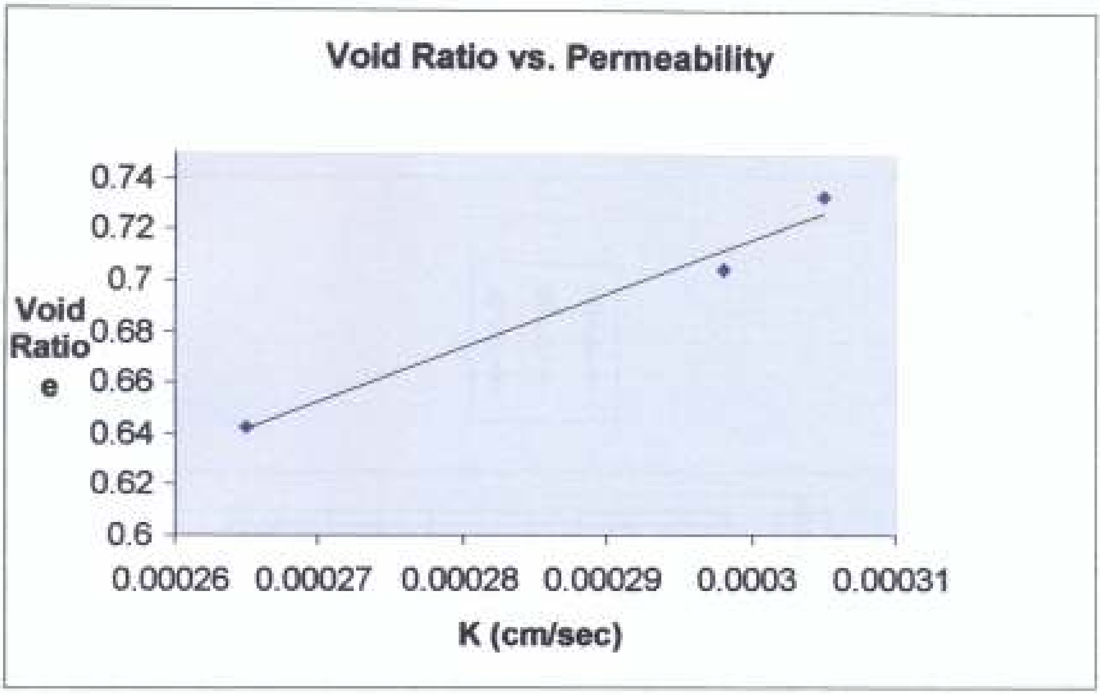

Figure.5.1c: Graph of Void Ratio against of Permeability for Ladipo Ajulo Street.

5.5 Particle Size Distribution

The particle size distribution of the soil samples are summarized in Appendix B, while the graphs of particle size and hydrometer analysis are shown in Figure 5.2. It can be deduced from the results that from location 1, the percentage of sand varies from 16 to 17% and for location 2, it varies from 19 to 39% while for location 3, it varies from 38 to 39%. Soils from location 2 and 3 have high percentage of fines. The value ranges from 39 to 59% and 58 to 59% for soil samples in locations 2 and 3, respectively. However, the percentage of fines for soil sample in location 1 ranges from 31 to 50%.

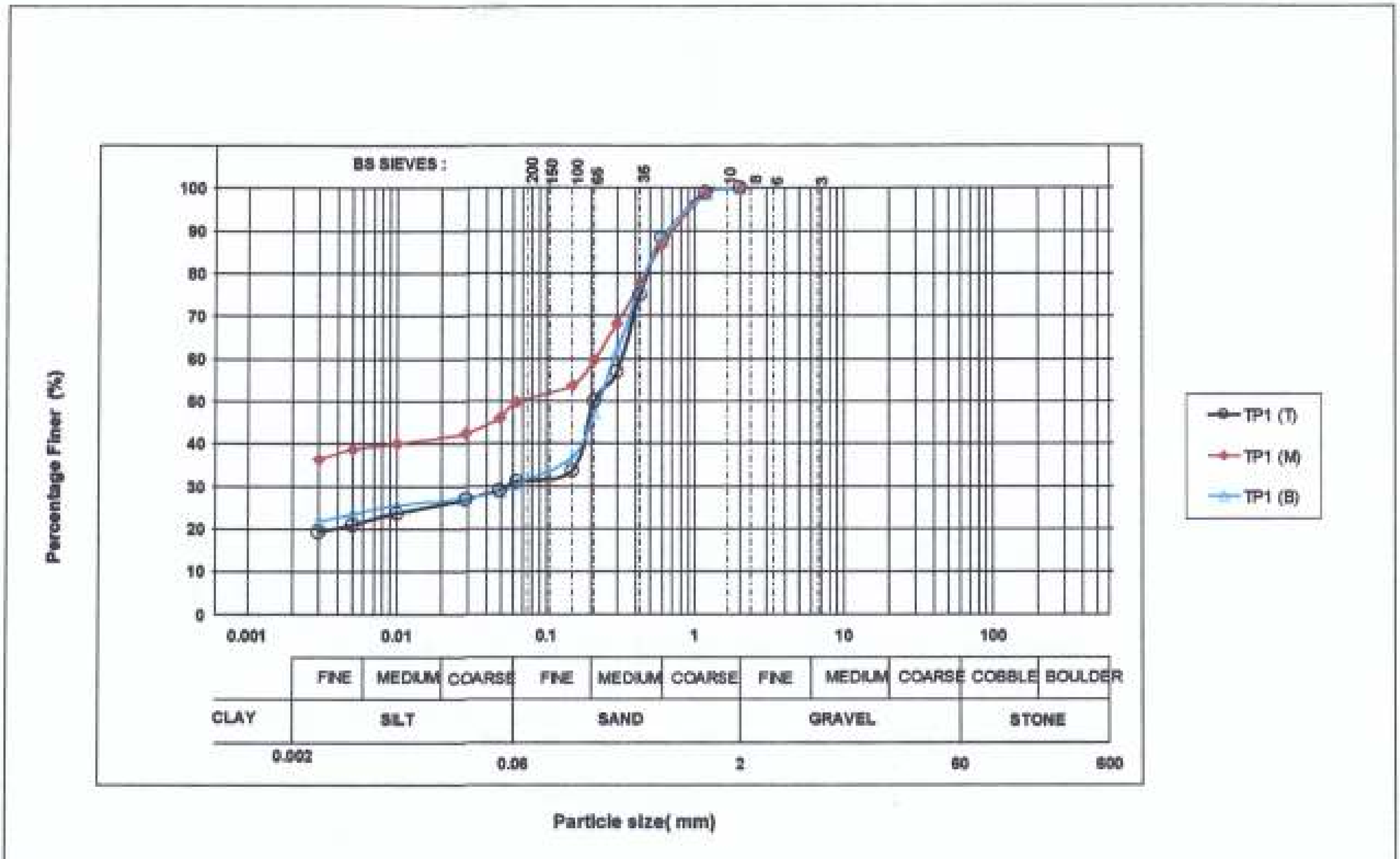

Fig. 5.2a. Particle Size Distribution Curve for all the samples in Oyewole close

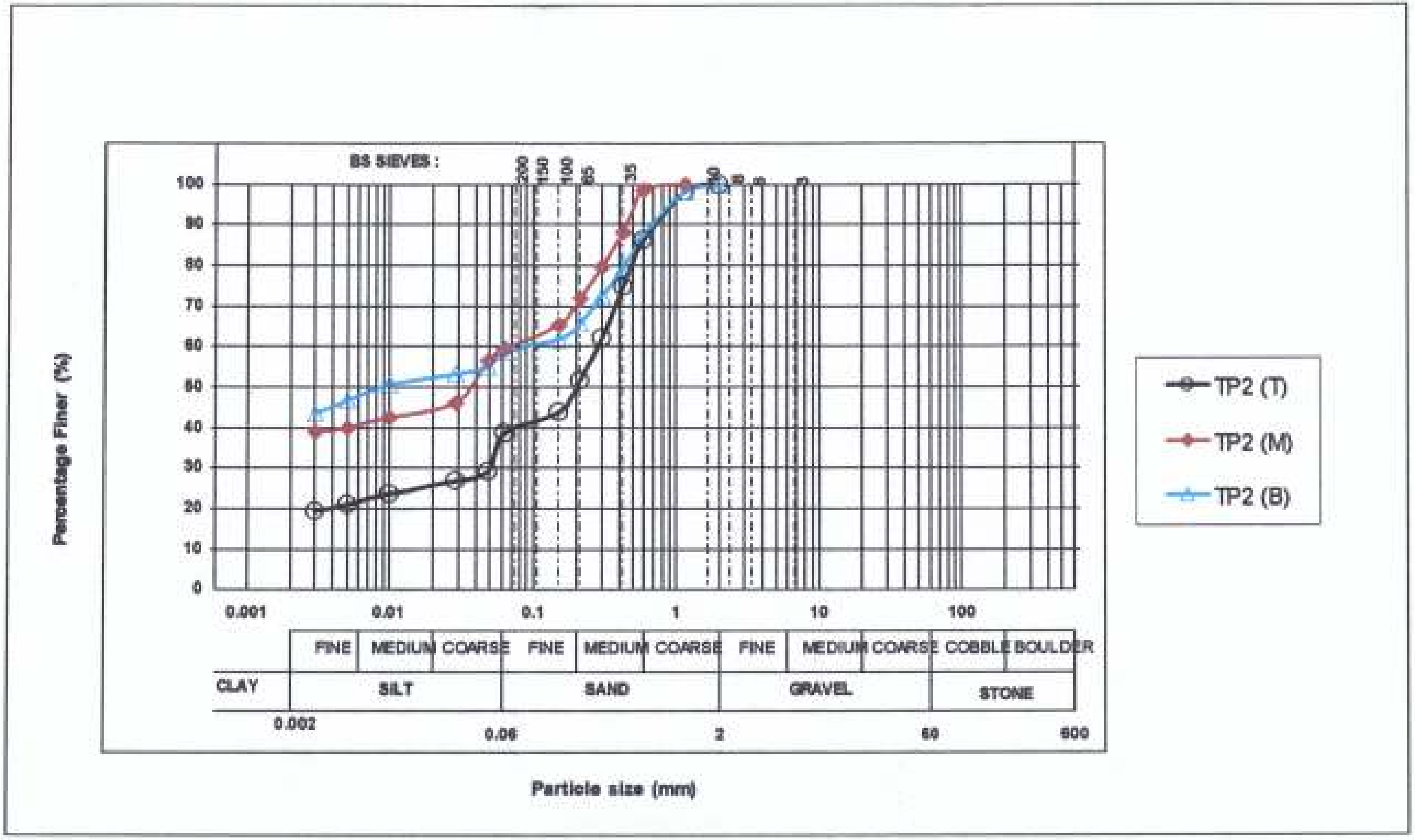

Fig 5.2b. Particle Size Distribution Curve for all the samples in Elegbede Street.

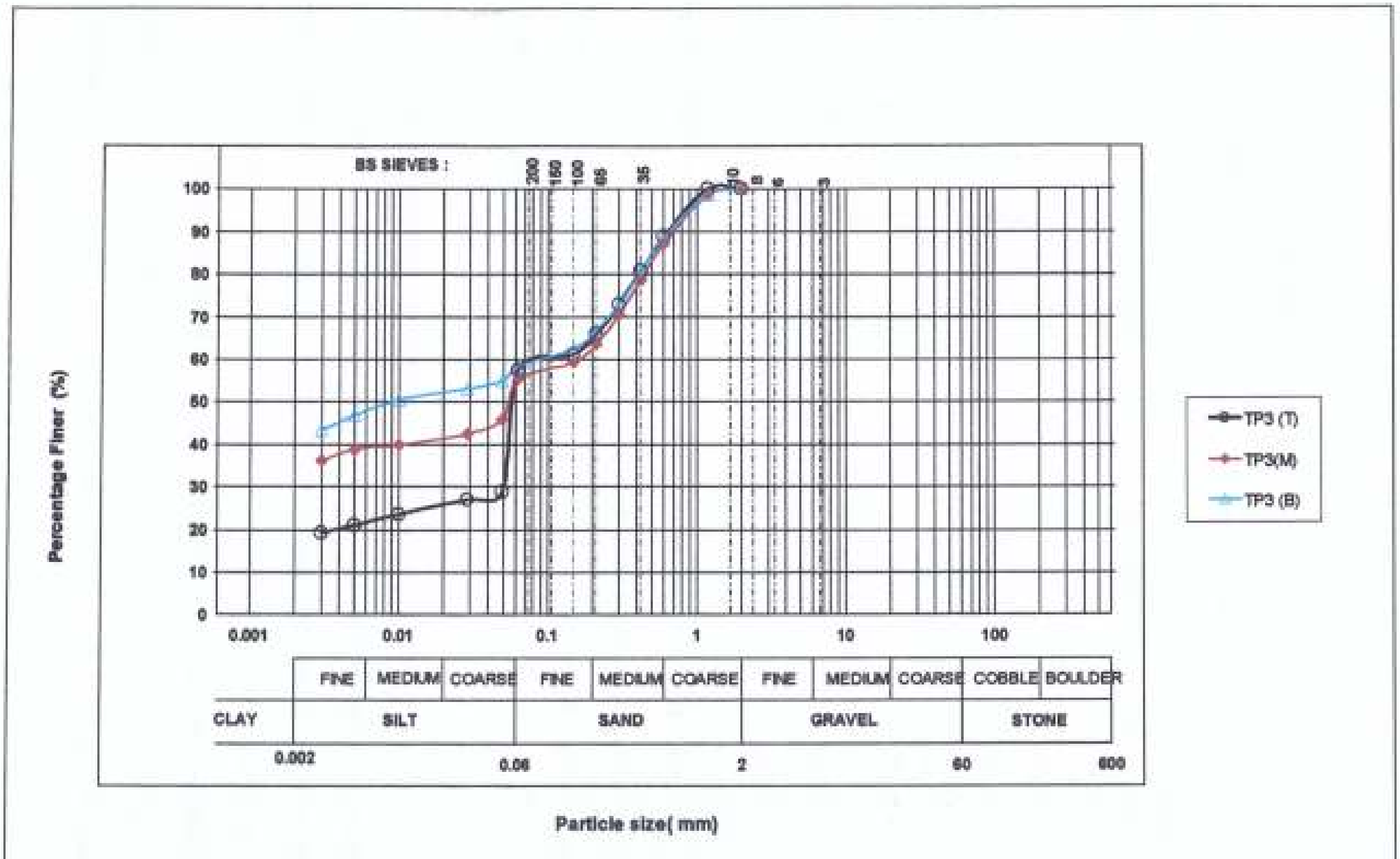

Fig 5.2c. Particle Size Distribution Curve for all the samples in Ladipo Ajulo Street.

5.6 Chemical Analysis

The results of the chemical analysis of the studied soils are presented in Table 5.5 and the following observations can be made of samples in the three locations:

TABLE 5.5: OXIDE COMPOSITION

COMPOUND	Concentration %		
	Oyewole Close Location 1	**Elegbede St. Location 2**	**Ladipo Ajulo St Location 3**
SiO_2	7.87	9.7	5.40
Al_2O_3	0.09	1.6	0.06
Fe_3O_4	4.10	5.56	3.20
CaO	10.51	11.42	10.32
MgO	1.55	1.63	1.90
Na_2O	12.86	14.89	12.80
K_2O	0.29	0.31	0.14

Lower values of soil chemical composition were generally observed for location 3 (Ladipo Ajulo) which is about 260m from the contaminant source. This is as a result of the presence of petroleum hydrocarbon within the soil matrix, which has impaired the purity of the soils.

5.7 X-Ray Diffraction Analysis

Identification of the minerals present in the soil samples was based on X-Ray powder data for minerals (Brown, 1961) as shown in Appendix B5. From the results of X-Ray Diffraction analysis, the following conclusions were arrived at regarding the mineralogy of the soil samples. It can be noted that in all the pits in Elegbede, quartz is prominent in pit 2T, kaolinite and halloysite in pit 2M, and also, in Oyewole close, the most prominent minerals are: kaolonite and felspar in pit 1T and 1M, quartz in pit 1M, halloyste in pit 1B. In Ladipo Ajulo, the mineral that are prominent are: chlorite and illite in pit 3B, kaolinite and quarts in pit 3T, halloyste in pit 3M and cristobalite in pit 3T. kaolonite was confirmed by the following characteristic peaks, 7.38 Å, 3.71 Å, 2.49Å, 2.25 Å peaks, while quartz was confirmed by 1.28 Å, 1.18 Å, 1.69 Å, 1.54 Å, 4.93 Å, 1.64 Å, 1.42 Å, 1.54 Å, 2.64 Å, 4.44 Å, feldspar by 8.85 Å, 4.04 Å, 6.63 Å, 3.56 Å, 5.54 Å, and cristobalite by the following peaks; 0.89 Å, to 0.98 Å.(see Figures 5.3 and Appendix D).

5.7.1 X-ray diffraction analysis calculation

$d = n\lambda / 2\sin\theta$ λ= wavelength and θ= is the angle through which x-ray is scattered

where, $n = 1$

$\lambda = 1.5418$

$2\theta = 12$: Therefore $\theta = 12/2 = 6$.

$2\sin 6 = 0.209$

Therefore $d = 1 \times 1.5418/ 0.209$ and $d = 7.377$Å

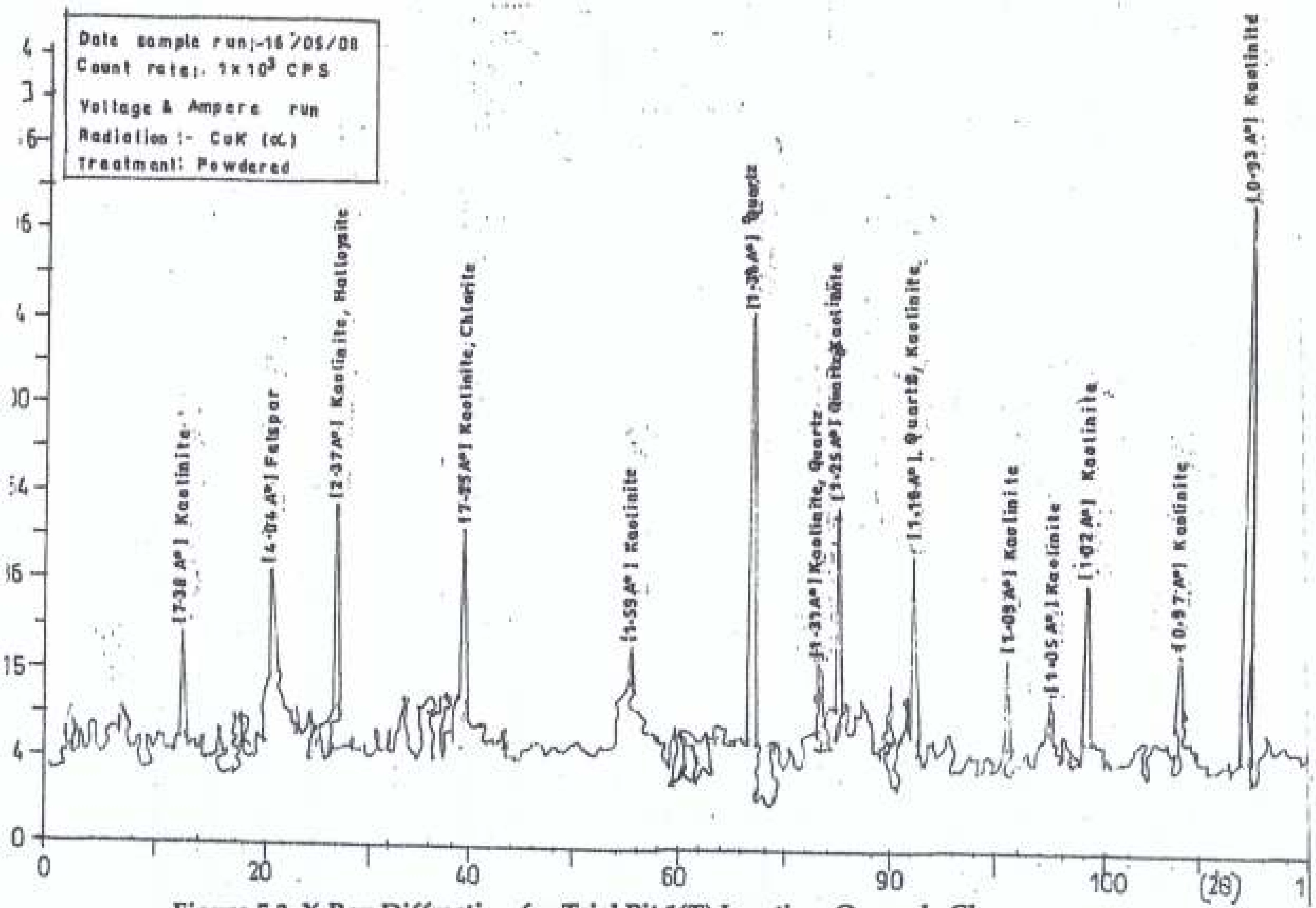

Figure 5.3 X-Ray Diffraction for Trial Pit 1(T) Location: Oyewole Close

5.8 Direct Current Resistivity Measurement

Vertical electrical sounding was used as a direct current resistivity method at the well locations and the lithologic description were taken at these well locations. For all the Six (6) monitored wells the Static water level, Depth, Liquid hydrocarbon, Depth to bottom of examined well are presented in Table 5.6a below.

Table 5.6a: S.W.L, Depth, Liquid Hydrocarbon, Depth to bottom of examined Well.

S/N	ID No	Static Water Level (m)	Depth to Bottom of well (m)	Elevation (h_e)	Thickness of liquid hydrocarbon above water surface in the wells (m)	Depth of water in the examined well (h_w)
1	10	23.13	75	59.2	0	51.87
2	15	23.36	70	54.4	0.65	46.64
3	20	24.40	81	47.7	0.72	56.60
4	30	23.81	92	51.3	0.2	68.19
5	41	24.60	101	44.7	0.35	76.40
6	69	22.60	70	47.1	0.12	47.40

The stratigraphic soil analyses of three (3) wells were also carried out at close range to determine the changes and the exact soil unit. This analysis is for wells 30, 41 and 69 and is presented below in Table 5.6b;

Released petroleum hydrocarbon in the subsurface soil at a depth of about 2.00m below ground level, migrates vertically downwards through the unsaturated/soil moisture zone. The several layers of high permeability (sandy) deposits in the upper Baruwa soil lithology (see Table 5.6b), hastened the pace of contaminant migration to the groundwater zone.

Table 5.6b: Soil Lithology before 2.5m at well 30, 41 and 69

Depth (m)	Well 30	Well 41	Well 69
0.50	CLAY, Sandy, reddish	SAND, Coarse grain, slightly reddish	CLAY, Sandy, reddish
0.75	SAND,Clayey, brownish, medium grain	CLAY, Sandy, brownish, coarse grain	SAND,Clayey, brownish, medium grain
1.00	CLAY, Sandy, slightly reddish, medium grain	SAND, Coarse grain, colourless	SAND, Coarse grain, slightly reddish
1.25	CLAY, Sandy, brownish, coarse grain	SAND, Medium grain, colourless	CLAY, Sandy, brownish, coarse grain
1.50	SAND,Clayey, brownish, coarse grain	SAND,Clayey, brownish, medium grain	SAND,Clayey, brownish, coarse grain
2.00	CLAY, Sandy, brownish, medium grain	SAND, Coarse grain, colourless	SAND, Coarse grain, colourless
2.50	SAND, Clayey, greyish coarse grain	SAND,Clayey, greyish, medium grain	CLAY, Sandy, greyish coarse grain

Analysis of Result Using Contour Maps, Liquid Flow Diagrams and Geosections

The area has over 30 wells with various degrees of pollution of petroleum product. Some have been blocked while some did not allow their well to be studied; hence six (6) were freely given for this study as shown in the basemap.

The buried petroleum pipeline product which is the suspected pollutant was referenced to the wells studied and the elevation of each well was used to produce an elevation contour map. The elevation map now shows the direction of liquid flow path which may also dictate the direction of flow of the pollutant. The elevation contour map and liquid flow path are shown as figure 5.4a and 5.4b respectively. The general stratigraphy of the study area shows that sand formation is more prominent while clay deposit is of thin thickness at depth above the static water level except for well 69 with more clay before the static water level.

5.9 Lithologic Description of the Monitored Wells

The borehole logs of the six wells monitored are presented in Appendix C. These wells consist of well 10, 15, 20, 30, 41 and 69, the stratigraphy of the wells are very similar and only well 10 will be discussed in full.

Well 10 consists of 5.0m of fine to coarse sand. Below this is a layer of reddish sandy clay about 6m thick. Fine to coarse sand occurs at a depth of 11.0 to 13.0m, and below this is a deposit of reddish clay from a depth of 13.0 to 17.0m. This is underlain by fine to coarse sand from a depth of 17.0 to 23.0m. Below this deposit are alternating deposits of clay and sand. The clay deposits are at the following depths: 23.0 to 24.0m (1.0m thick); 30.0 to 32.0m (2.0m thick); 38.0 to 44.0m (6.0m thick) and 48.0 to 62.0m (14.0m thick). The sand deposits are at the following depths: 24.0 to 30.0m (6.0m thick); 32.0 to 38.0m (6.0m thick); 44.0 to 48.0m (4.0m thick) and 62.0 to 75.0m (13.0m thick).

Well 15 consists of brown lateritic coarse, medium to fine SAND, some greyish, yellow, sandy CLAY trace silt. Well 20 consists of reddish brown lateritic coarse medium to fine SAND, and some greyish brown sandy CLAY. Well 30 consists of reddish lateritic coarse, medium to fine SAND and some greyish brown sandy CLAY. Well 41 consists of reddish lateritic coarse, medium to fine SAND and some greyish, brown sandy CLAY. Well 69 consists of reddish lateritic coarse, medium to fine SAND and some greyish brown sandy CLAY. The borehole logs for these wells are in Appendix C. Generally the layers above the water table consist of sandy layers, with a total sandy thickness varying from 6.65m to 17.0m while clay varies from 6.0m to 16.35m per well. The average depth to water table at Baruwa is 23.6 metres (Table 5.6). This stratigraphy reveals that about 58% of the aquitard thickness as sand, and this explains why the downward migration of the leaked petroleum hydrocarbon is unabated.

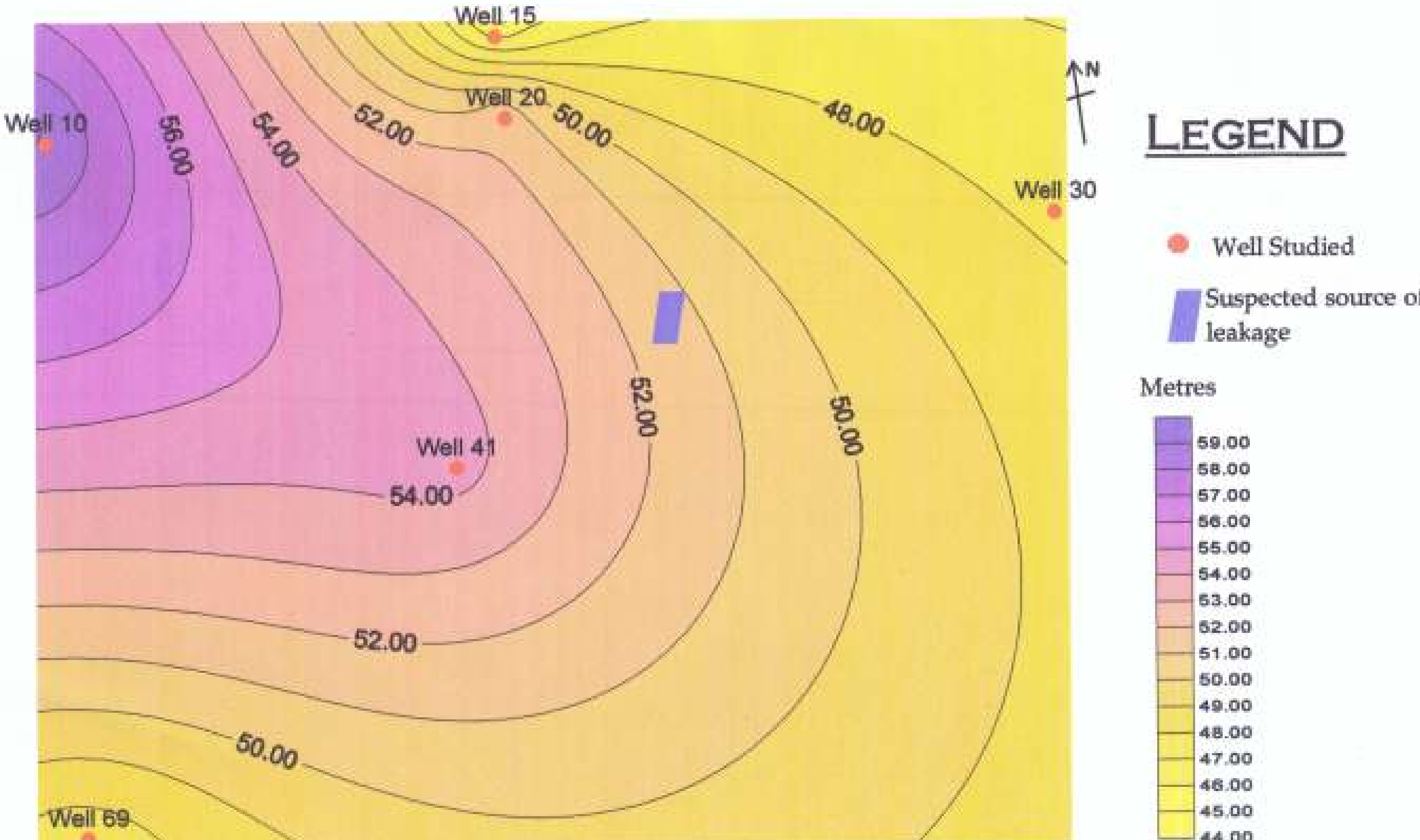

Figure 5.4a :Elevation contour of Study Area

From the field resistivity data of the formation carried out using vertical electrical sounding at depths of 3m, 6m and 12m beside each well as shown below, the average resistivity of the formation across the wells are 50.8Ωm, 75.7Ωm and 106.3Ωm respectively. The noticed analogy is that the resistivity of the formation increases with depth irrespective of the lithologic unit. The resistivity is lowest at each depth in well 69 which is farthest from the source of leakage.

TABLE5.7a Resistivity Results At 3, 6 & 12m Depth Across The Examined Wells

Depth	RESISTIVITY						
	Well 10	**Well 15**	**Well 20**	**Well 30**	**Well 41**	**Well 69**	**Average**
3m	Sand 57	Sand 55	Sand 50	Sandy Clay 56	Sand 45	Clayey Sand 42	50.8
6m	Sand 80	Clayey Sand 85	Clayey Sand 75	Sandy Clay 99	Clayey Sand 65	Sand 50	75.7
12m	Clayey Sand 110	Clay 128	Clay 110	Sand 138	Sand 92	Sand 60	106.3

The study, however is not within area of saline water intrusion, hence low resistivity will be indicative of clay material. The resistivity of rocks table (Omosuyi, 2009) is shown in Table 5.7b, while and the lateral extent of saline water in Lagos State is shown in Figure 5.5c.

TABLE 5.7b Showing Resistivity of Rocks

Lithology	Dry	Saturated
GRAVEL	400 – 700 Ωm	200 – 300 Ωm
SAND	200 – 400 Ωm	100 – 150 Ωm
SILT	100 – 200 Ωm	< 100 Ωm
CLAY	< 100 Ωm	15 – 20 Ωm (Very low when Plastic)

Source: Omosuyi (2009)

From the geosections Figures 5.5a-b, the point of suspected pollution is between well 20 and 30. When the resistivity of the lithologic unit was analysed and tabulated as shown in Table5.9c for Sand, Sandy clay, Clayey sand and Clay, the sand unit was continous across most of the wells at 3m depth, which implies a continous flow of contamination across the wells depending on the topography of the well locations. The clay deposit was also not continous hence; it was possible for continous fluid to infiltrate to the groundwater because the aquifer protective capacity is low.

On a regional basis the groundwater moves from north to south, while on local basis the groundwater moves from east to west. From the suspected source of leakage the hydrocarbon product migrates and causes a thickness of 0.72m on top of groundwater at well 20, 0.65m at well 15, 0.35m at well 41 and 0.12m at well 69. This also explains why well 30 east of the source is not severe but has 0.2m level of hydrocarbon.

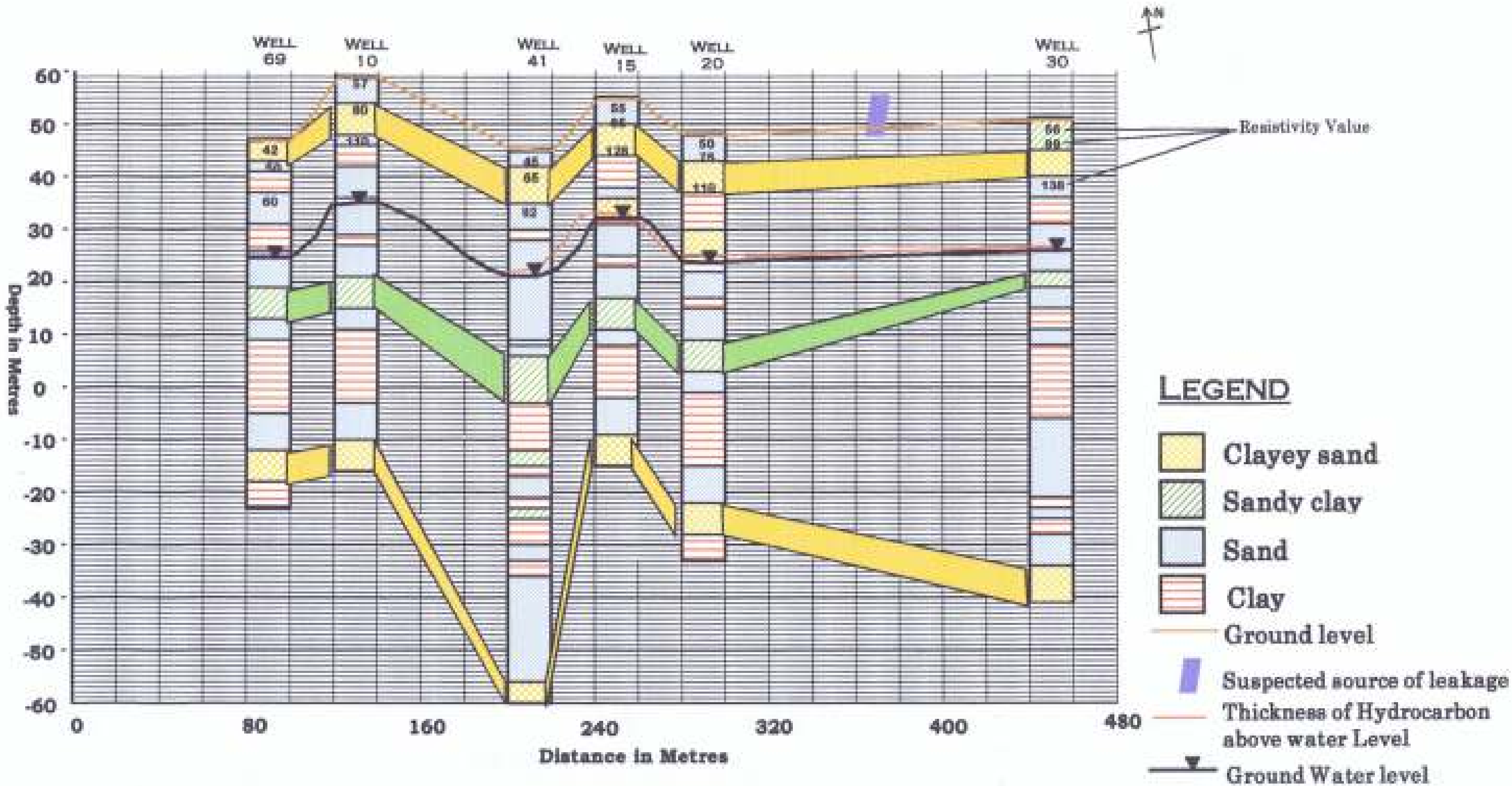

FIGURE 5.5a : LITHOLOGIC CORRELATION AND HYDROCARBON THICKNESS ABOVE WATER LEVEL IN EXAMINED WELLS ALONG Y - Y AXIS

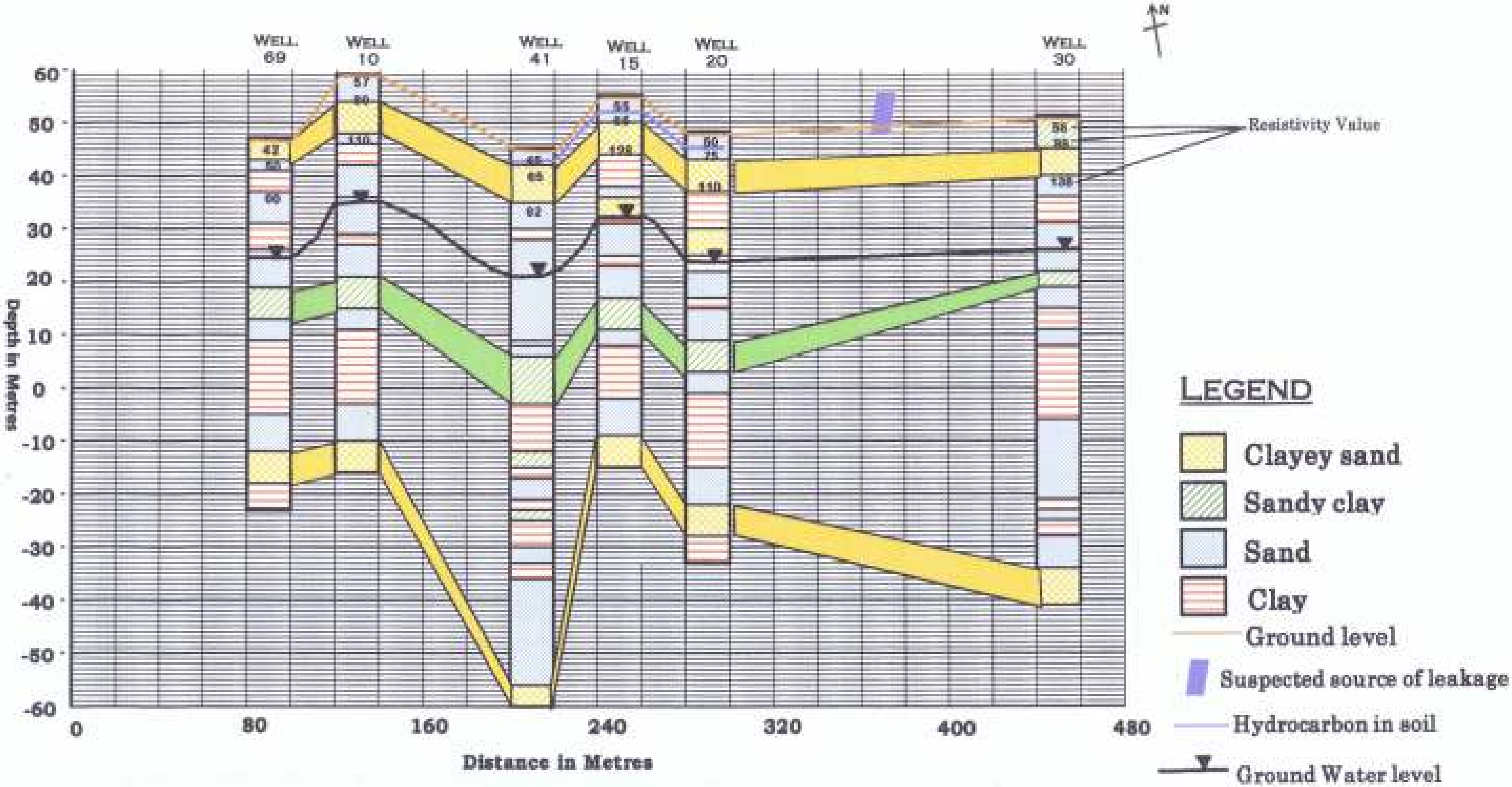

FIGURE 5.5b : LITHOLOGIC CORRELATION AND STATIC WATER LEVEL ACROSS THE EXAMINED WELLS ALONG Y- Y AXIS

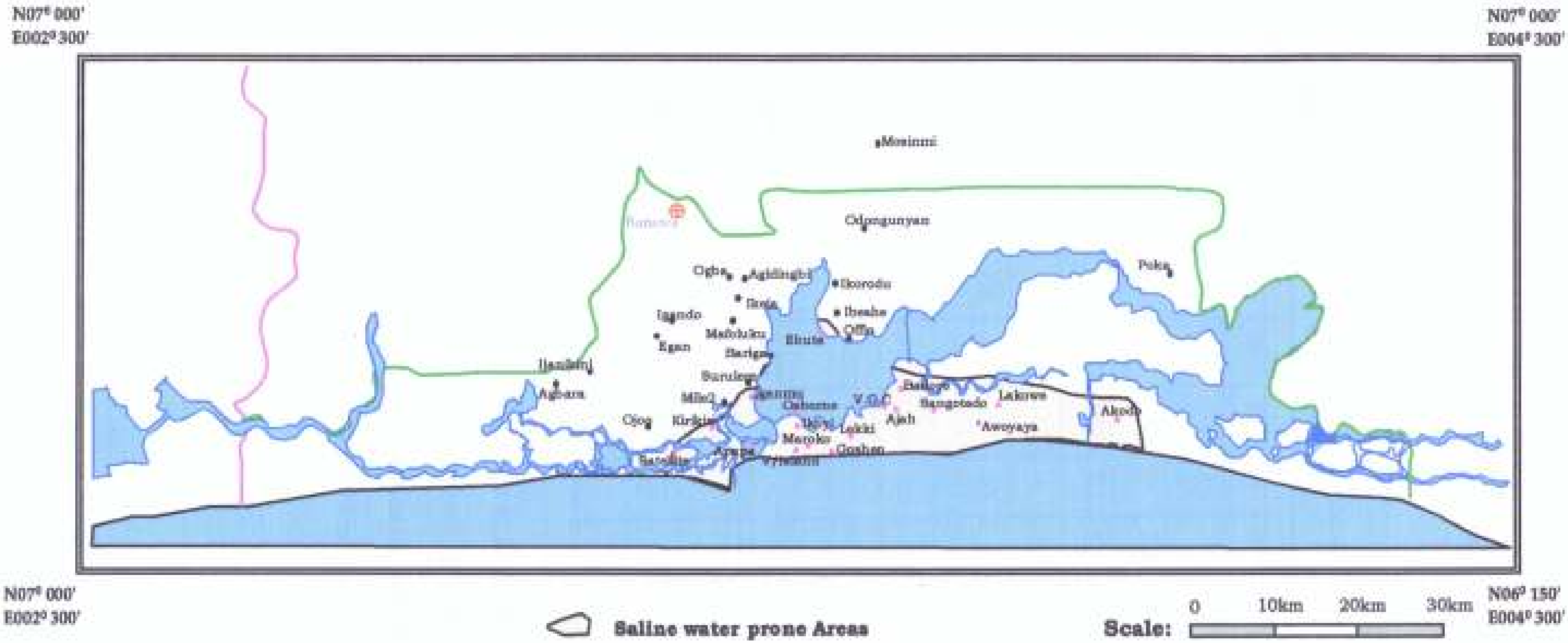

Figure 5.5c Map of Lagos State showing the Lateral Extent of Saline water across the State

TABLE5.7c : Resistivity of Lithologic formation at 3m, 6m and 12m depth from the studied wells

Lithology	Depth (m)	Resistivity (Ohm-m) WELL ID						Average Resistivity (Ohm-m)
		10	15	20	30	41	69	
Sand	3m	57	55	50	-	45	-	52
	6m	80	-	-	-	-	50	65
	12m	-	-	-	138	92	60	97
Clayey sand	3m	-	-	-	-	-	42	42
	6m	-	85	75	-	65	-	75
	12m	110	-	-	-	-	-	110
Clay	3m	-	-	-	-	-	-	-
	6m	-	-	-	-	-	-	-
	12m	-	128	110	-	-	-	119
Sandy clay	3m	-	-	-	56	-	-	56
	6m	-	-	-	99	-	-	99
	12m	-	-	-	-	-	-	-

For clayey sand, the average field resistivities are 42 Ωm, 75 Ωm and 110 Ωm at 3m, 6m and 12m respectively Table 5.7c). This lithologic unit directly underlies sand deposition in almost all the wells. Sandy clay was observed to be present only in well 30 from 0 to 6m. The resistivities recorded are 56 Ωm and 99 Ωm for 3m, and 6m respectively (see Table 5.7c).

5.10 Geosection and Contour Maps of the Soil at 3, 6 and 12m across the well

At 3m resistivity contour, the areas below the contour line of 40Ωm indicate clay and no well studied fall within the area (see figure 5.6a). From Table 5.9c (Resistivity of Lithologic formation) and Figure 5.6a to Figure 5.6c, lower average resistivity values of about 52Ωm observed at the upper 3m contour for the sandy formations, and higher average resistivity values for the lower 6m and 12m contours, where the formation is more clayey. The geophysical property of resistivity is usually high for petroleum hydrocarbon (Canadian Council of Ministers of the Environment, CCME, 1994)

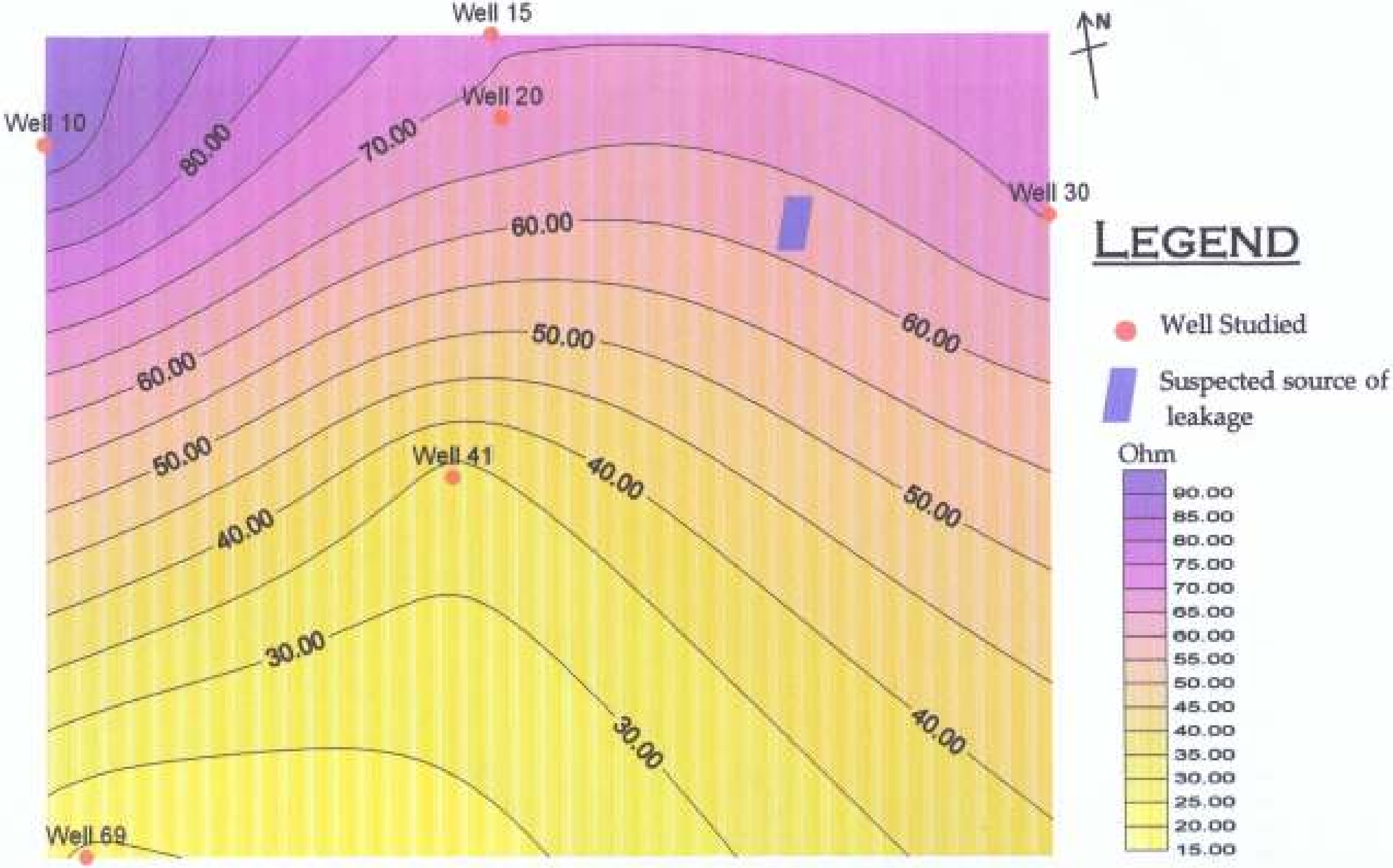

Figure 5.6a :Resistivity Contour at 3m across Baruwa Study Area

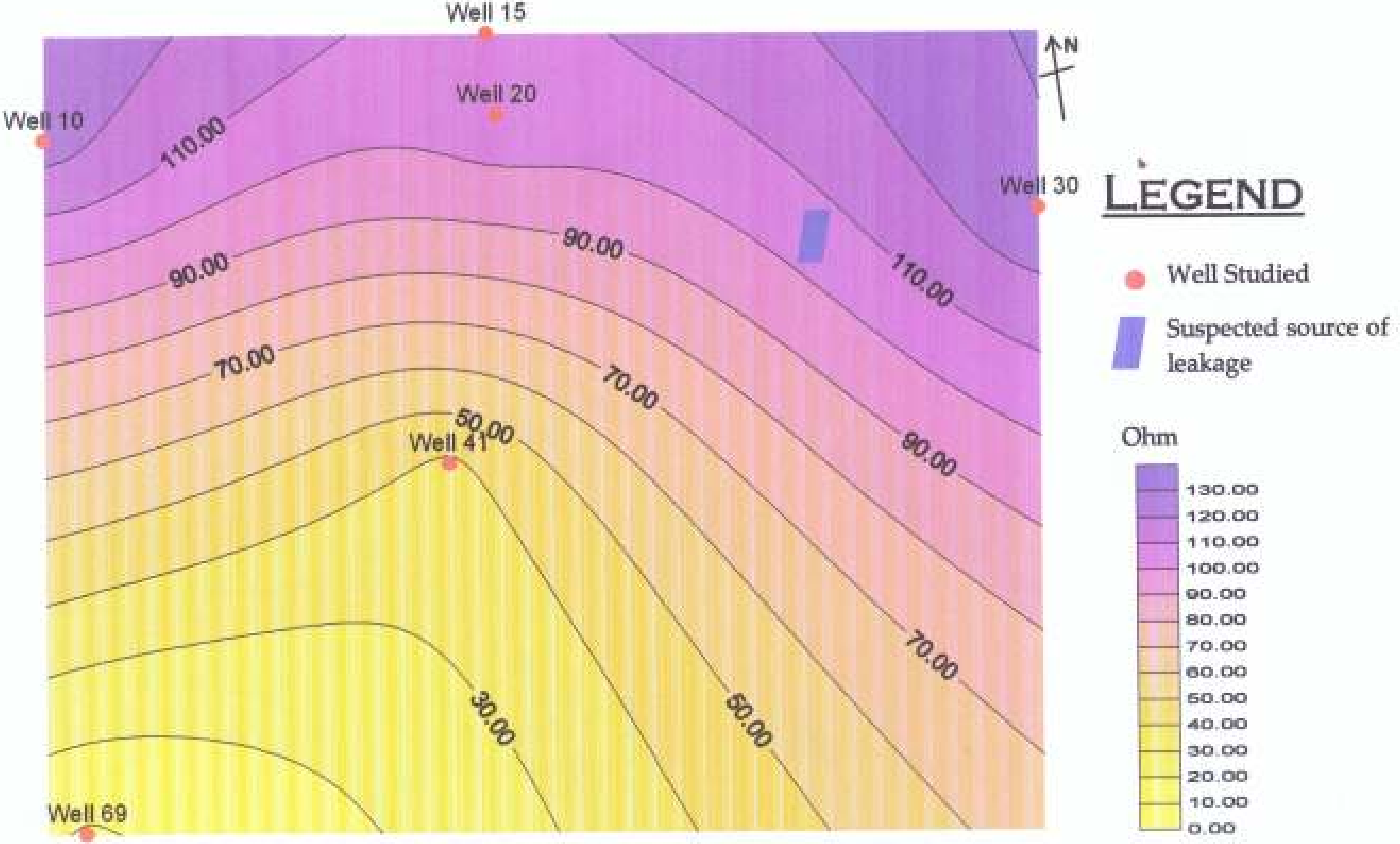

Figure 5.6b :Resistivity Contour at 6m across Baruwa Study Area

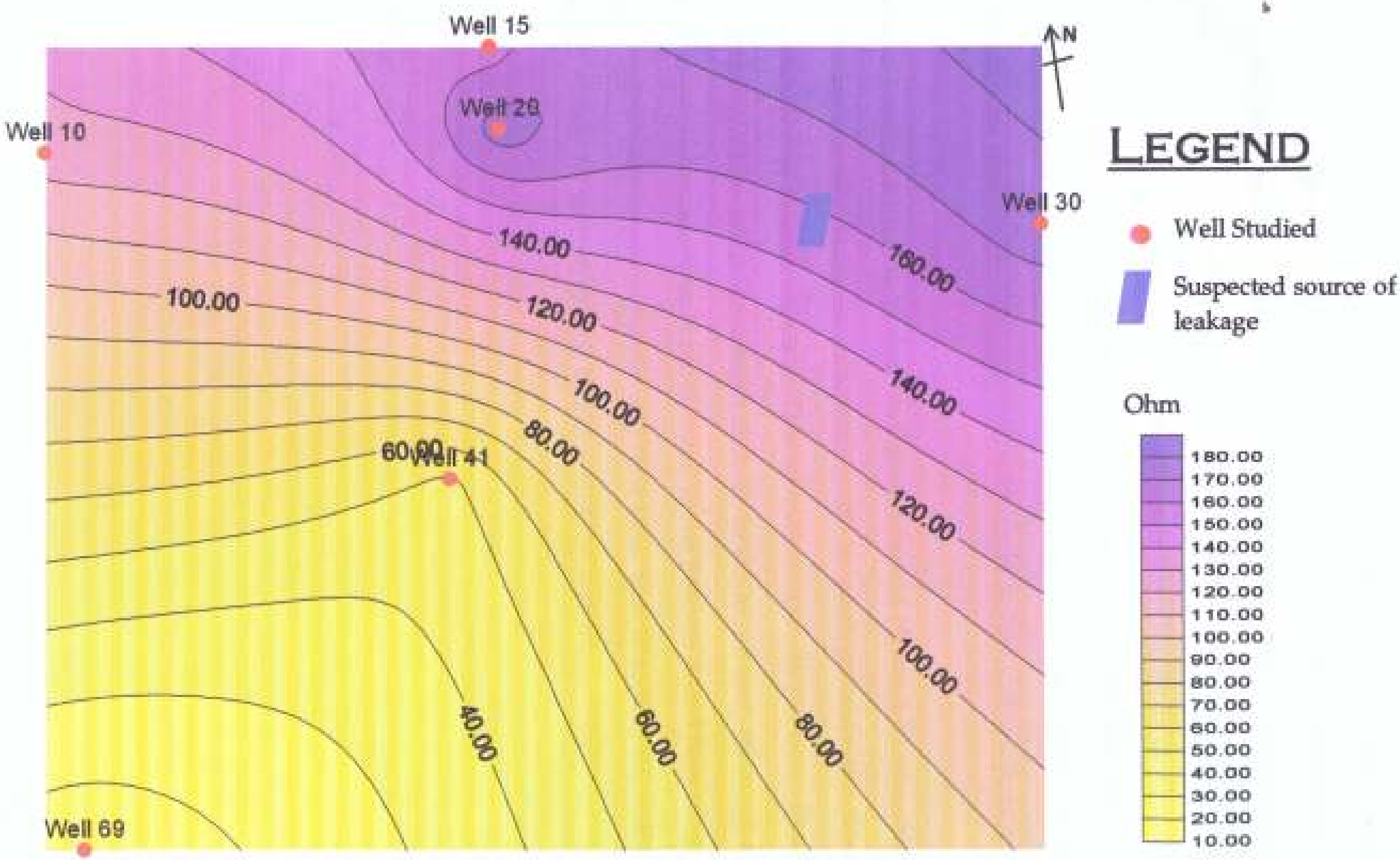

Figure 5.6c :Resistivity Contour at 12m across Baruwa Study Area

5.11 Groundwater Flow Modelling in Lagos State

The groudwater flow was studied by Coode Blizard and Akute Geo Resource (1997) with the aim of knowing the groudwater flow pattern of Lagos State. The nodal maps are presented as figure 5.7a and 5.7b. From the map and finding, the ground water flow is generally from north to south. There is cone of depression at Apapa and Ikeja. There is cone of depression and piezometric levels close to the sea level and had induced small scale and localised reversal of ground water flow (Figure 5.7c). The increase in the cone of depression has not resulted in dewatering the costal plain sand as the aquifer remains confined. However, the increasing size and deepening of the cone of depression are resulting in flow reversals which will induce saline infrusion.

The study area, Baruwa, is located on Figure 5.7a and Figure 5.7b on a nodal point -45 and -79 respectively. This also indicates a north to south groundwater flow movement and partially east to west direction. This is evident from -20 to -45 to -75 and -60 to -79 to -100 for north to south movement and -40 to -45 to -45 and -80 to -79 to -75 for the east to west movement. This is represented in the Baruwa liquid flow diagram between wells (figure 5.4b) as ground water will flow from well 10 to well 69, well 15 to well 20, well 20 to well 41, well 30 to well 41 and well 41 to well 69.

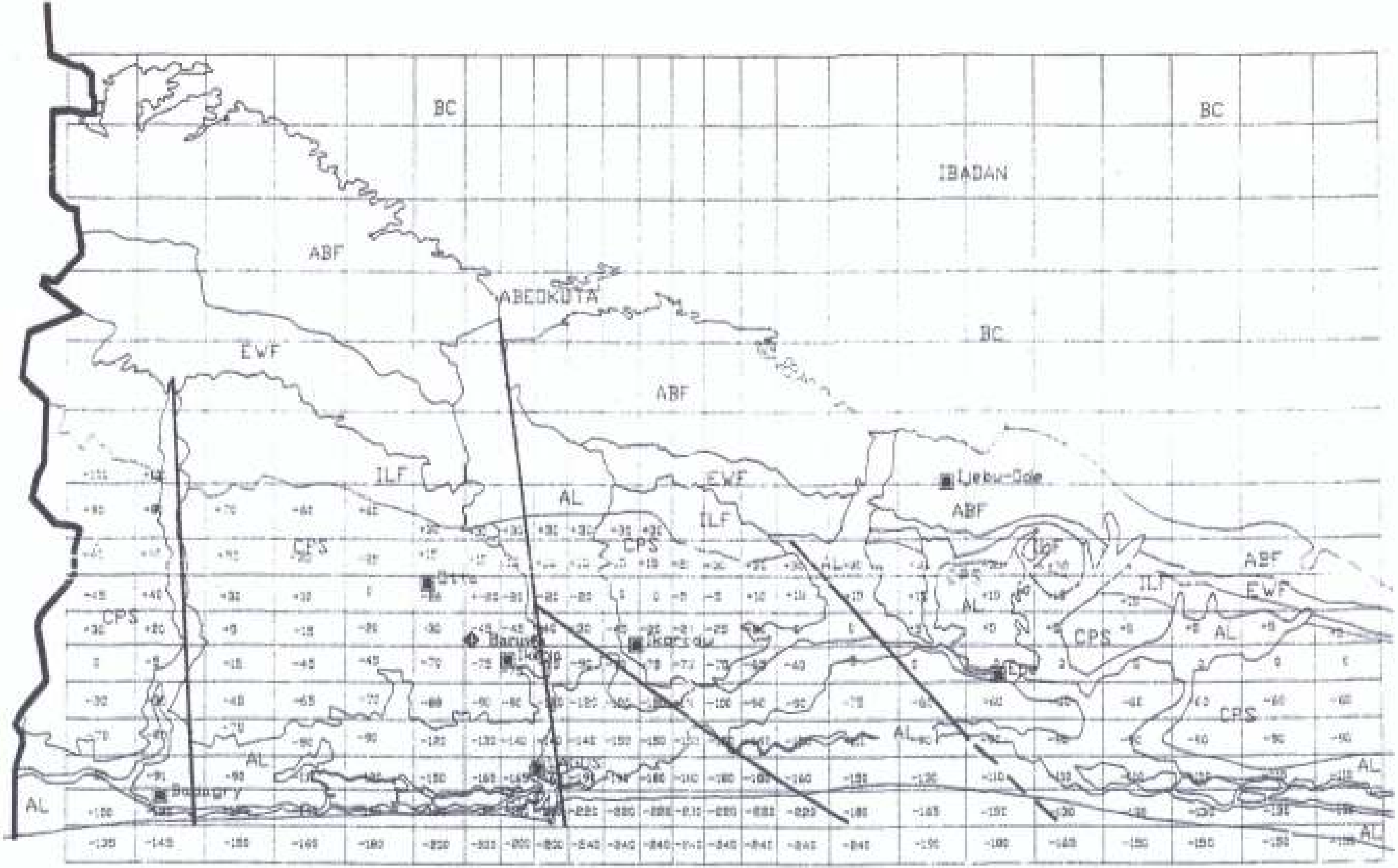

Figure 5.7a: Nodal Data as used in Groundwater model for elevation of Top of Lower Coastal Plain Sands in Lagos

After (Coode Blizard and Akute Geo Resource,1997)

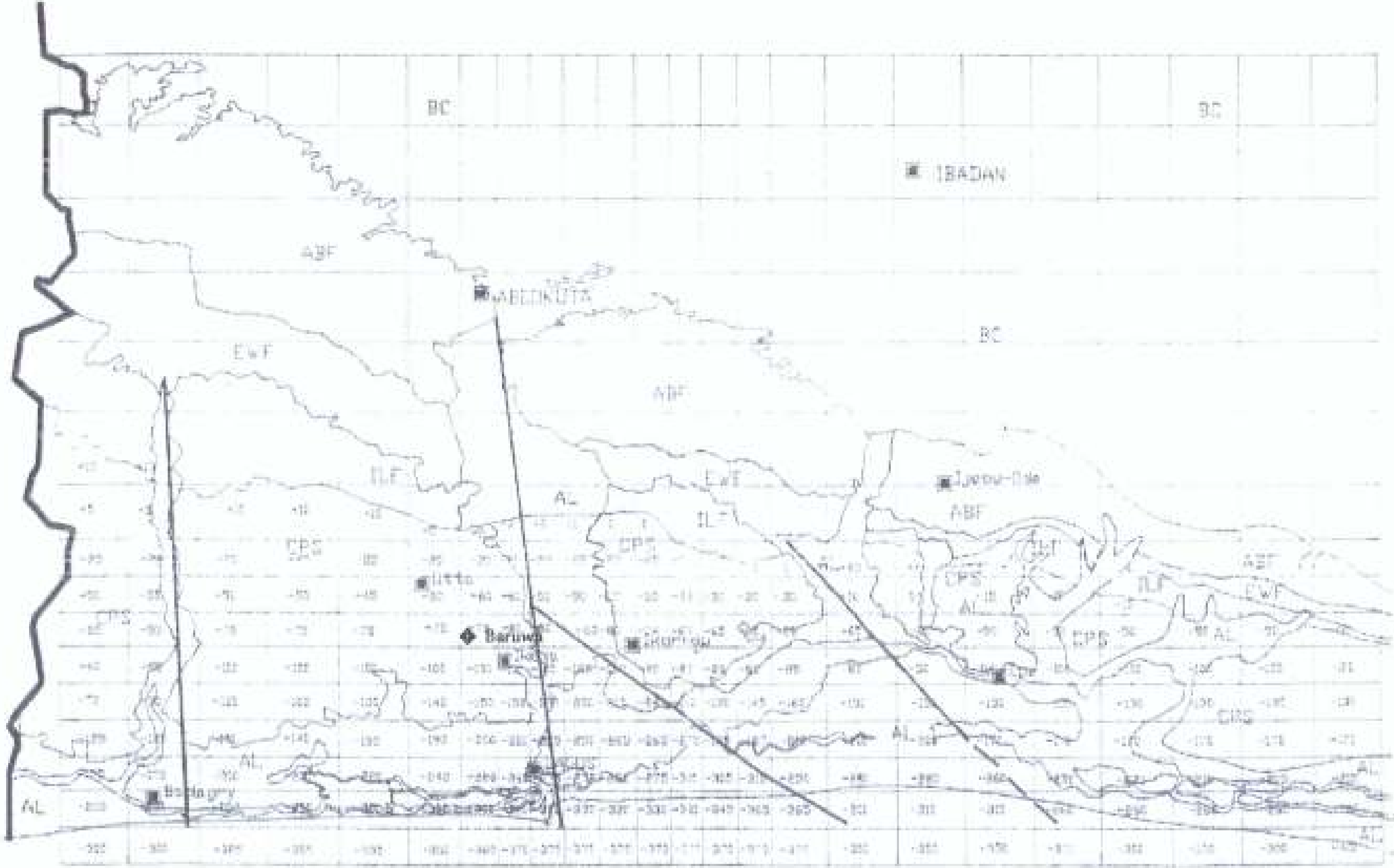

Figure 5.7b: Nodal Data as used in Groundwater model for elevation of Base of Lower Coastal Plain Sands in Lagos

After (Coode Blizard and Akute Geo Resource,1997)

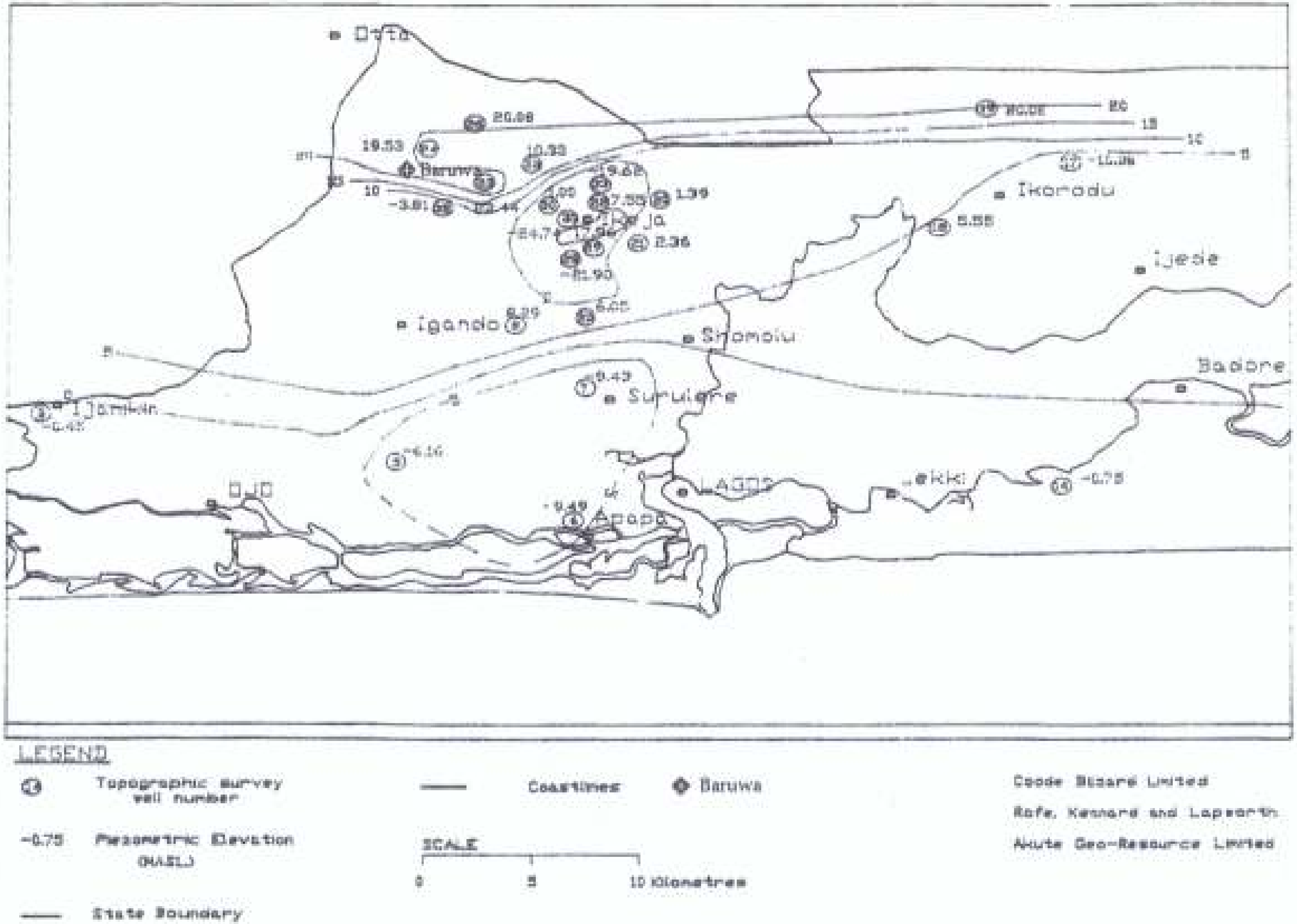

Figure 5.7c: Piezometric Map of Coastal Plains Sands Aquifer in Lagos State

After (Coode Blizard and Akute Geo Resource,1997)

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The determination of the stratigraphy / soil subsurface profile for Baruwa site using geophysical and geotechnical methods has revealed the role of unconsolidated lateritic soils, granular backfill and sand lenses in vertical contaminant migration for the subsurface, especially in the unsaturated soil moisture zone, and that this has hastened the pace of the leaked hydrocarbon through the thick surficial aquitard (Average aquitard thickness was 23.65m) in Baruwa.

The results of geochemical analysis show that values of SiO_2, MgO, and Na_2O are lower in location 3 (Ladipo Ajulo St) than other locations with the case study site, in line with the trend of mineralogical compositions of the analyzed soil samples. This shows the effects of contamination of the soils at this location. X-ray analysis shows that Kaolinite is the predominant clay mineral in all the locations studied. Furthermore, bulk densities of the soil samples increased with increasing depth as expected.

The topography, stratigraphy and hydraulic gradient of the area has aided the movement of the leakage from the source into the surrounding wells at various degrees. The severity of the pollution was also discovered to be based on the heterogeneous nature of the material immediately around the depth of burial of the source (2.0m), the direction of groundwater flow and the topography of the study area.

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Higher resistivity and lower soil mineralogical composition around well 20 shows both the presence of non aqueous phase hydrocarbon in the soil matrix and the existence of fractures and macropores in the Baruwa aquitard especially around the contaminant source area.

6.2 RECOMMENDATIONS

The entire pipeline should be inspected for leakage and carry out repair work if necessary. A proper enlightment programme should immediately be constituted within the Baruwa Community and its environs by Nigerian National Petroleum Corporation (NNPC) to avoid drilling within the contaminated zone. The Nigerian National Petroleum Corporation (NNPC) should drain the hydrocarbon by pumping it out with the water at the various wells to minimize the volume of hydrocarbon in the ground.

If possible the community should have its own Mini waterworks (Located at areas where there is no pollution) provided by the State government so that there will be no further boreholes within the contaminated area. In addition, the agency or parastals (PPMC) that are responsible for the pipeline products movement should maintain inventories of all pipelines and check periodically the release detection if there is any leakage within the network and provide spill prevention and leakage detection equipments that will capture any fuel release in the event of spills or leakage.

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APPENDIX A

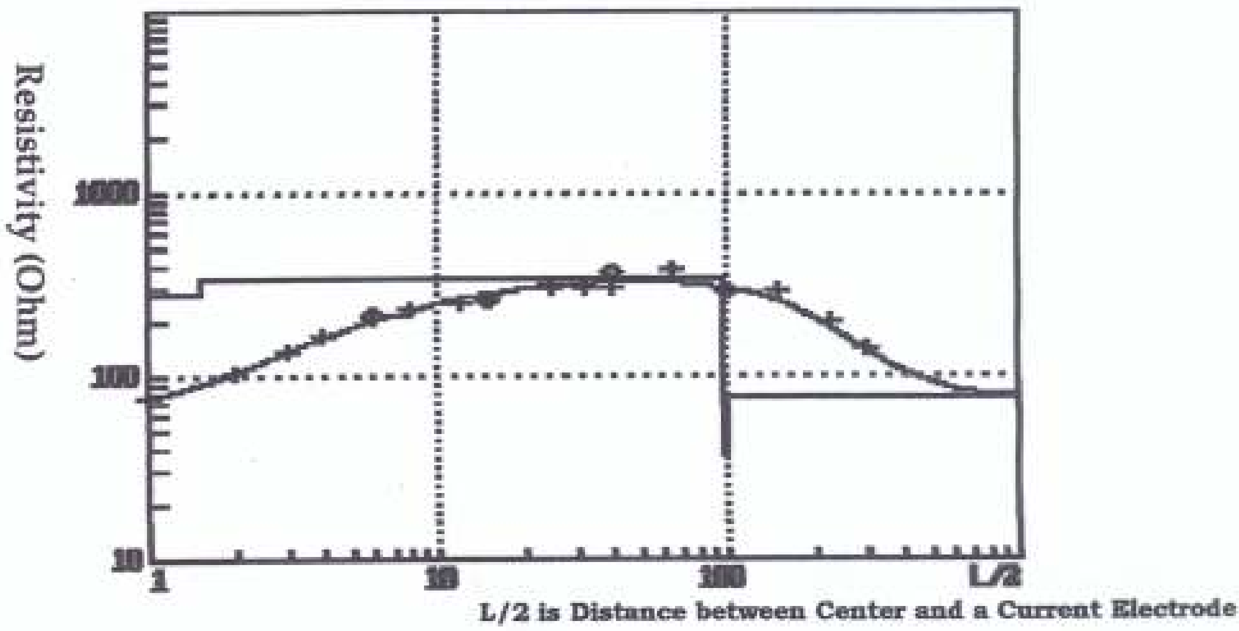
A1 SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	**Final year project**	**File Name**	**VES1**
Location	**Baruwa Ipaja**	**Student**	**Balogun 1**
VES Location	**Gemade Extension**	**Date of Collection**	**7/11/2006**
Co-ordinate	**N 06° 35.965' E 003° 16.353'**	**Type of Data**	**Schlumberger**
Instrument	**ABEM SAS 300C**	**Direction**	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	12.04	75.6
2	0.25	25.12	4.20	105.5
3	0.25	56.52	2.38	134.5
4	0.25	100.48	1.65	166.0
6	0.25	226.08	0.91	205.5
6	0.50	113.04	1.90	214.4
8	0.50	200.96	1.14	229.7
12	0.50	452.16	0.56	251.9
15	0.50	706.50	0.37	264.2
15	1.00	353.25	0.74	261.8
25	1.00	981.25	0.31	299.3
32	1.00	1,607.68	0.19	301.4
40	1.00	2,512.00	0.12	308.2
40	2.50	1,004.80	0.36	365.7
65	2.50	2,653.30	0.15	387.1
100	2.50	6,280.00	0.05	296.4
100	5.00	3,140.00	0.09	297.4
150	5.00	7,065.00	0.04	288.2
225	5.00	15,896.25	0.01	197.4
300	5.00	28,260.00	0.00	139.6
300	10.00	14,130.00	0.01	159.7

RE_1	24.11	DB_1	0.11
RE_2	92.65	DB_2	0.54
RE_3	66.8	DB_3	1.13
RE_4	281.02	DB_4	1.72
RE_5	344.97	DB_5	97.35
RE_6	37.07	DB_6	100.71
RE_7	76.11		

Layer1 CLAY
" 2 SAND, Clayey
" 3 CLAY, Sandy
" 4 SAND
" 5 SAND
" 6 CLAY
" 7 CLAY, Sandy



A2

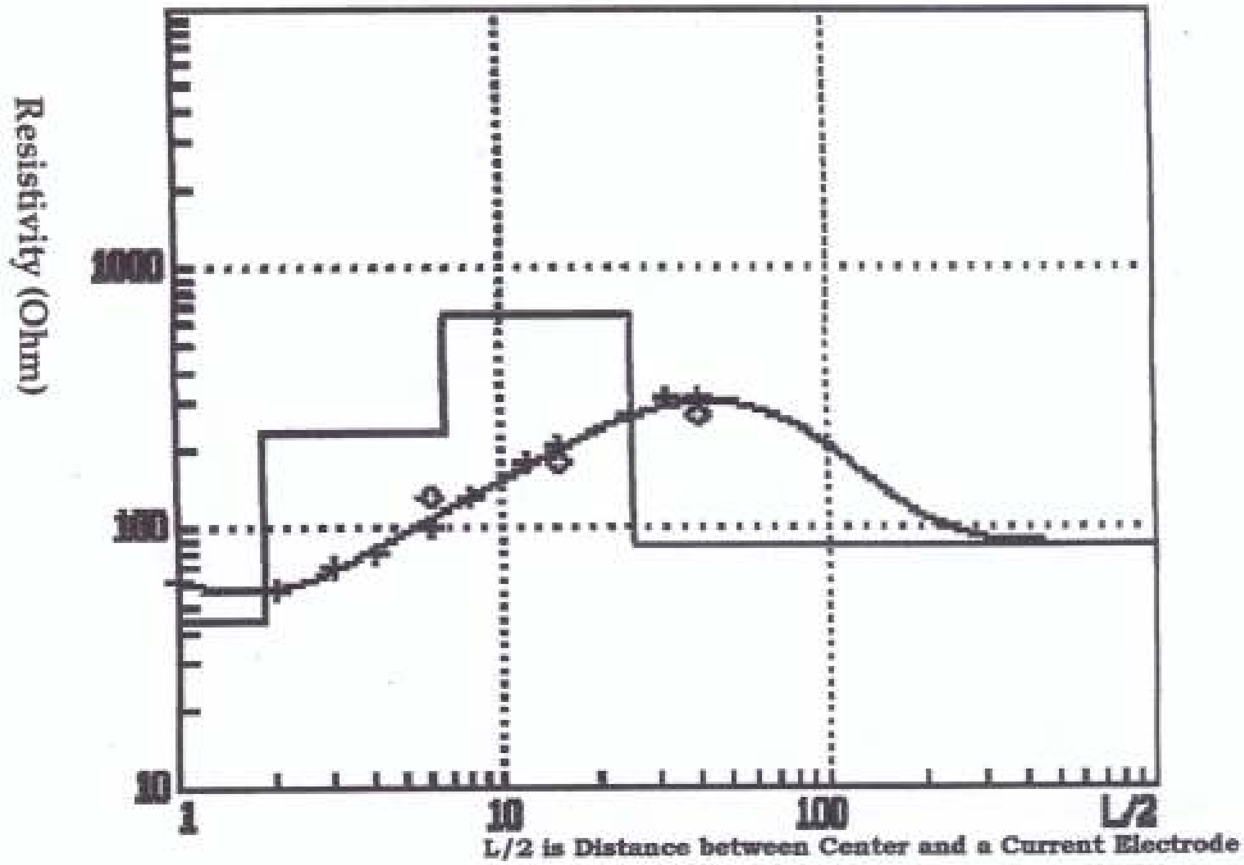
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	Final year project	File Name	VES2
Location	Baruwa Ipaja	Student	Balogun 2
VES Location	Dele Oinpona Street	Date of Collection	7/11/2006
Co-ordinate	N 06° 36.109' E 003° 16.462'	Type of Data	Schlumberger
Instrument	ABEM SAS 300C	Direction	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	10.05	63.1
2	0.25	25.12	3.54	88.8
3	0.25	56.52	1.25	70.4
4	0.25	100.48	0.78	78.6
6	0.25	226.08	0.45	101.7
6	0.50	113.04	1.14	128.8
8	0.50	200.96	0.66	132.8
12	0.50	452.16	0.39	176.8
15	0.50	706.50	0.29	207.7
15	1.00	353.25	0.51	180.2
25	1.00	981.25	0.28	270.8
32	1.00	1,607.68	0.20	321.5
40	1.00	2,512.00	0.13	316.8
40	2.50	1,004.80	0.27	271.3

RE_1	89.68	DB_1	0.36
RE_2	45.36	DB_2	1.84
RE_3	236.86	DB_3	6.73
RE_4	649.55	DB_4	25.08
RE_5	84.88		

Layer1 SAND
" 2 CLAY, Sandy
" 3 SAND
" 4 SAND
" 5 SAND, Clayey



LIBRARY

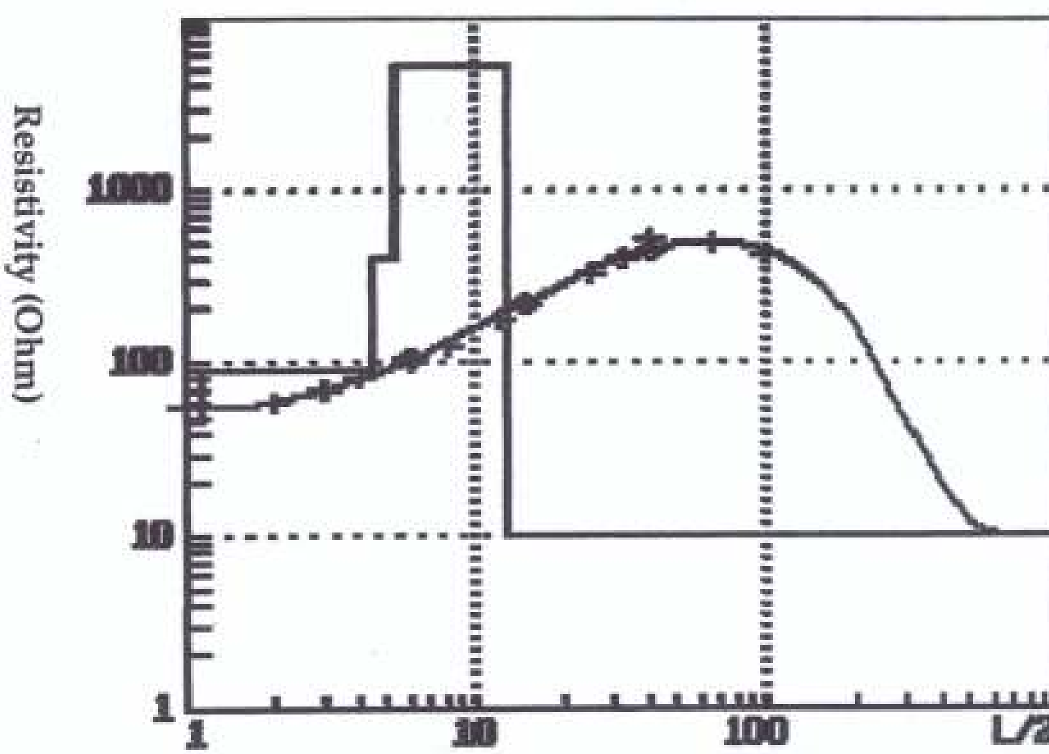
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	Final year project	File Name	VES3
Location	Baruwa Ipaja	Student	Balogun 3
VES Location	Baale Street	Date of Collection	7/11/2006
Co-ordinate	N 06° 36.173' E 003° 16.357'	Type of Data	Schlumberger
Instrument	ABEM SAS 300C	Direction	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	9.17	57.6
2	0.25	25.12	2.43	61.0
3	0.25	56.52	1.22	68.8
4	0.25	100.48	0.81	81.6
6	0.25	226.08	0.44	100.6
6	0.50	113.04	0.95	107.5
8	0.50	200.96	0.61	122.8
12	0.50	452.16	0.39	175.4
15	0.50	706.50	0.30	210.5
15	1.00	353.25	0.60	210.9
25	1.00	981.25	0.34	332.6
32	1.00	1,607.68	0.25	408.4
40	1.00	2,512.00	0.21	515.0
40	2.50	1,004.80	0.45	448.1
65	2.50	2,653.30	0.19	494.0
100	2.50	6,280.00	0.07	422.6

RE_1	63.92	DB_1	0.43
RE_2	45.54	DB_2	1.13
RE_3	88.66	DB_3	4.45
RE_4	402.13	DB_4	5.31
RE_5	5035.64	DB_5	12.9
RE_6	9.81		

Layer1 SAND,Clayey
" 2 CLAY, Sandy
" 3 SAND, Clayey
" 4 SAND
" 5 SAND,dry
" 6 CLAY



L/2 is Distance between Center and a Current Electrode

A4

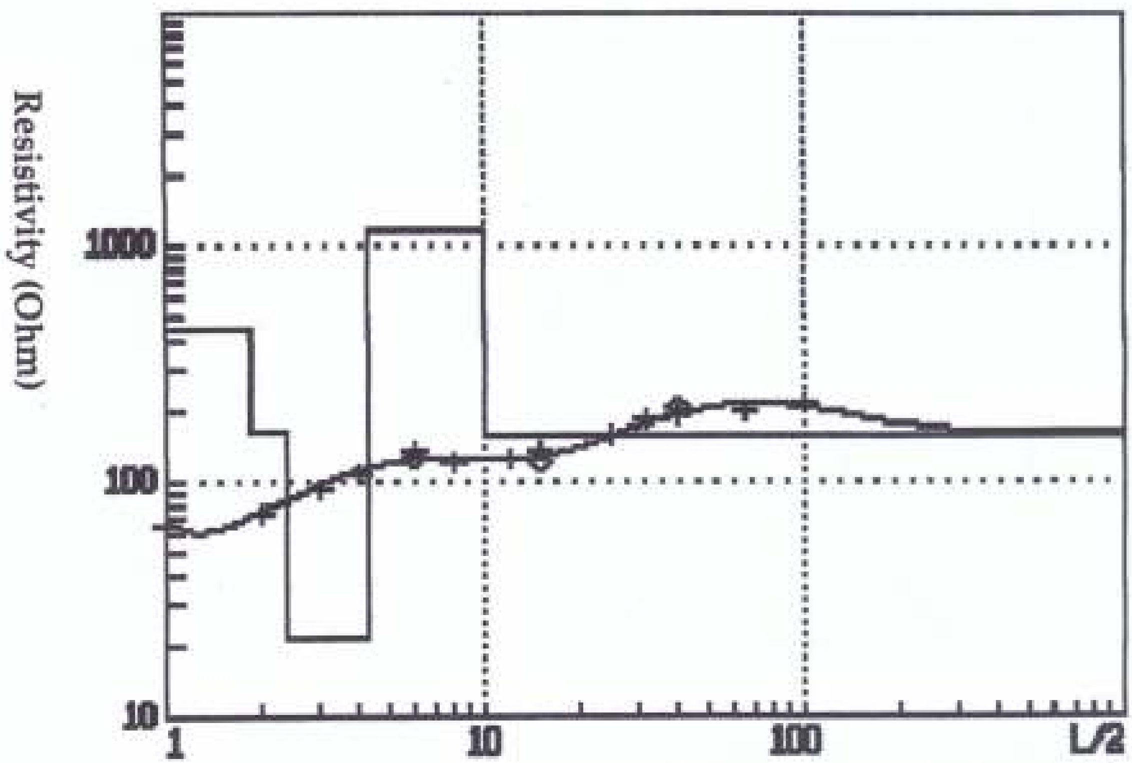
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	Final year project	File Name	VES4
Location	Baruwa Ipaja	Student	Balogun 4
VES Location	Along Ipaja Rd	Date of Collection	14/11/2006
Co-ordinate	N 06° 36.230' E 003° 16.214'	Type of Data	Schlumberger
Instrument	ABEM SAS 300C	Direction	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	10.53	66.1
2	0.25	25.12	2.91	73.1
3	0.25	56.52	1.66	93.8
4	0.25	100.48	1.09	110.0
6	0.25	226.08	0.59	133.8
6	0.50	113.04	1.11	125.0
8	0.50	200.96	0.60	121.0
12	0.50	452.16	0.28	124.8
15	0.50	706.50	0.19	133.8
15	1.00	353.25	0.34	119.1
25	1.00	981.25	0.16	158.6
32	1.00	1,607.68	0.12	185.4
40	1.00	2,512.00	0.08	190.2
40	2.50	1,004.80	0.21	206.0
65	2.50	2,653.30	0.08	200.6
100	2.50	6,280.00	0.03	211.6

RE_1	313.25	DB_1	0.28
RE_2	16.25	DB_2	0.61
RE_3	448.69	DB_3	1.83
RE_4	165.43	DB_4	2.39
RE_5	21.15	DB_5	4.3
RE_6	1181.95	DB_6	9.98
RE_7	161.03		

Layer1 SAND
" 2 CLAY
" 3 SAND
" 4 SAND
" 5 CLAY
" 6 SAND
" 7 SAND



L/2 is Distance between Center and a Current Electrode

A5

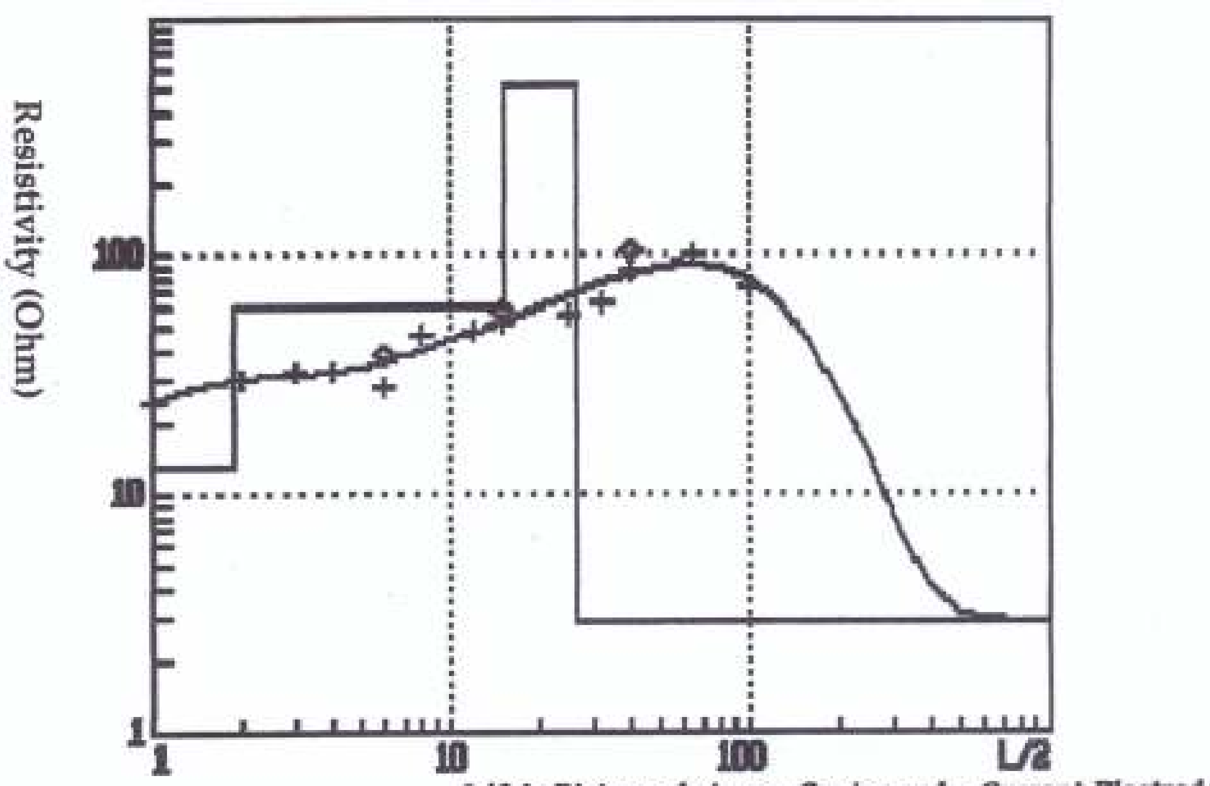
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	**Final year project**	**File Name**	**VES5**
Location	**Baruwa Ipaja**	**Student**	**Balogun S**
VES Location	**Elegbede Street**	**Date of Collection**	**14/11/2006**
Co-ordinate	**N 06° 36.176' E 003° 16.214'**	**Type of Data**	**Schlumberger**
Instrument	**ABEM SAS 300C**	**Direction**	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	3.81	23.9
2	0.25	25.12	1.21	30.3
3	0.25	56.52	0.58	33.0
4	0.25	100.48	0.33	32.9
6	0.25	226.08	0.13	28.7
6	0.50	113.04	0.34	37.9
8	0.50	200.96	0.23	46.6
12	0.50	452.16	0.11	48.8
15	0.50	706.50	0.07	51.2
15	1.00	353.25	0.17	58.5
25	1.00	981.25	0.06	56.3
32	1.00	1,607.68	0.04	63.3
40	1.00	2,512.00	0.03	86.4
40	2.50	1,004.80	0.10	104.1
65	2.50	2,653.30	0.04	101.9
100	2.50	6,280.00	0.01	73.5

RE_1	11.24	DB_1	0.27
RE_2	40.39	DB_2	0.44
RE_3	64.25	DB_3	0.99
RE_4	13.14	DB_4	1.87
RE_5	60.14	DB_5	15.05
RE_6	521.27	DB	26.57
RE_7	2.88		

Layer1 CLAY
" 2 CLAY, Sandy
" 3 SAND, Clayey
" 4 CLAY
" 5 SAND, Clayey
" 6 SAND
" 7 CLAY



A6

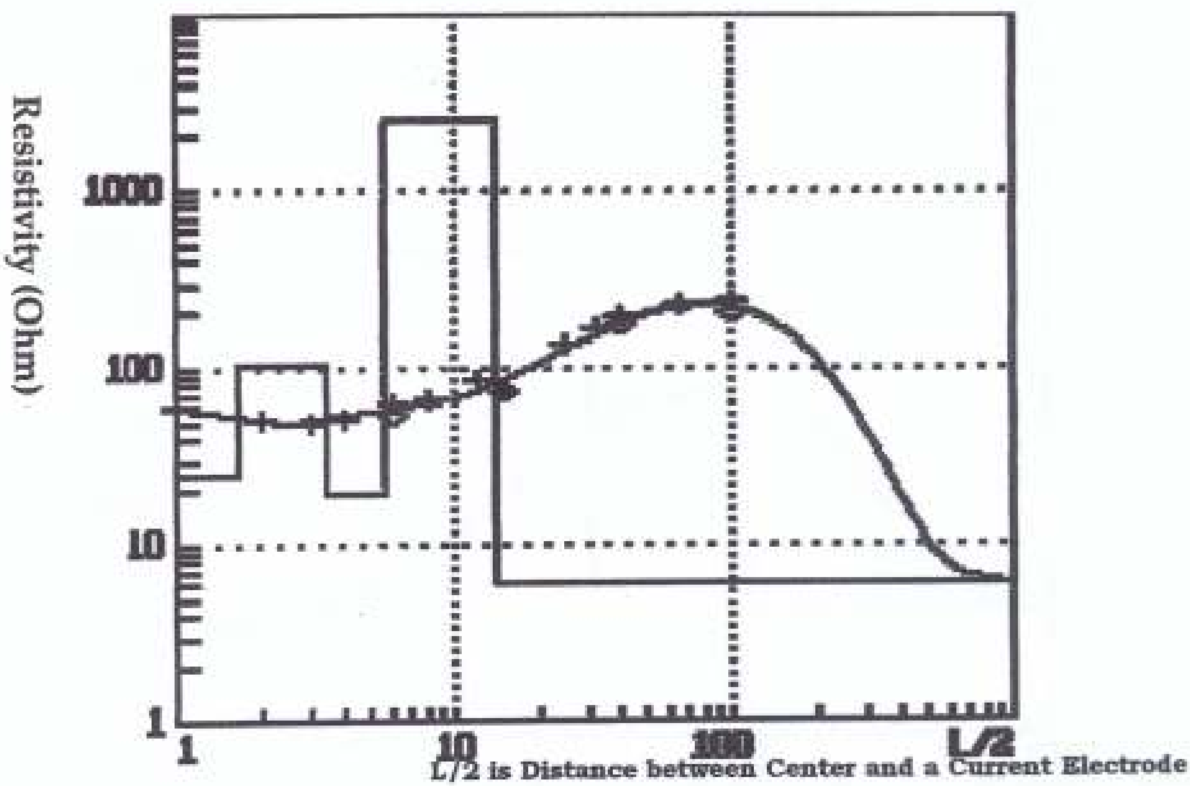
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	**Final year project**	**File Name**	**VES6**
Location	**Baruwa Ipaja**	**Student**	**Balogun 6**
VES Location	**Mosalasi Street**	**Date of Collection**	**14/11/2006**
Co-ordinate	**N 06° 36.187' E 003° 16.127'**	**Type of Data**	**Schlumberger**
Instrument	**ABEM SAS 300C**	**Direction**	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	9.44	59.3
2	0.25	25.12	2.07	52.0
3	0.25	56.52	0.88	49.8
4	0.25	100.48	0.52	52.3
6	0.25	226.08	0.28	62.9
6	0.50	113.04	0.47	52.9
8	0.50	200.96	0.32	65.1
12	0.50	452.16	0.19	85.7
15	0.50	706.50	0.10	73.5
15	1.00	353.25	0.21	73.1
25	1.00	981.25	0.14	136.5
32	1.00	1,607.68	0.10	166.0
40	1.00	2,512.00	0.08	189.7
40	2.50	1,004.80	0.17	174.7
65	2.50	2,653.30	0.09	225.8
100	2.50	6,280.00	0.04	234.2

RE_1	63.82	DB_1	0.91
RE_2	25.7	DB_2	1.66
RE_3	107.42	DB_3	3.45
RE_4	19.57	DB_4	5.58
RE_5	2492.79	DB_5	14.21
RE_6	6		

Layer1 CLAY, Sandy
" 2 CLAY
" 3 SAND
" 4 CLAY
" 5 SAND,dry
" 6 CLAY



A7

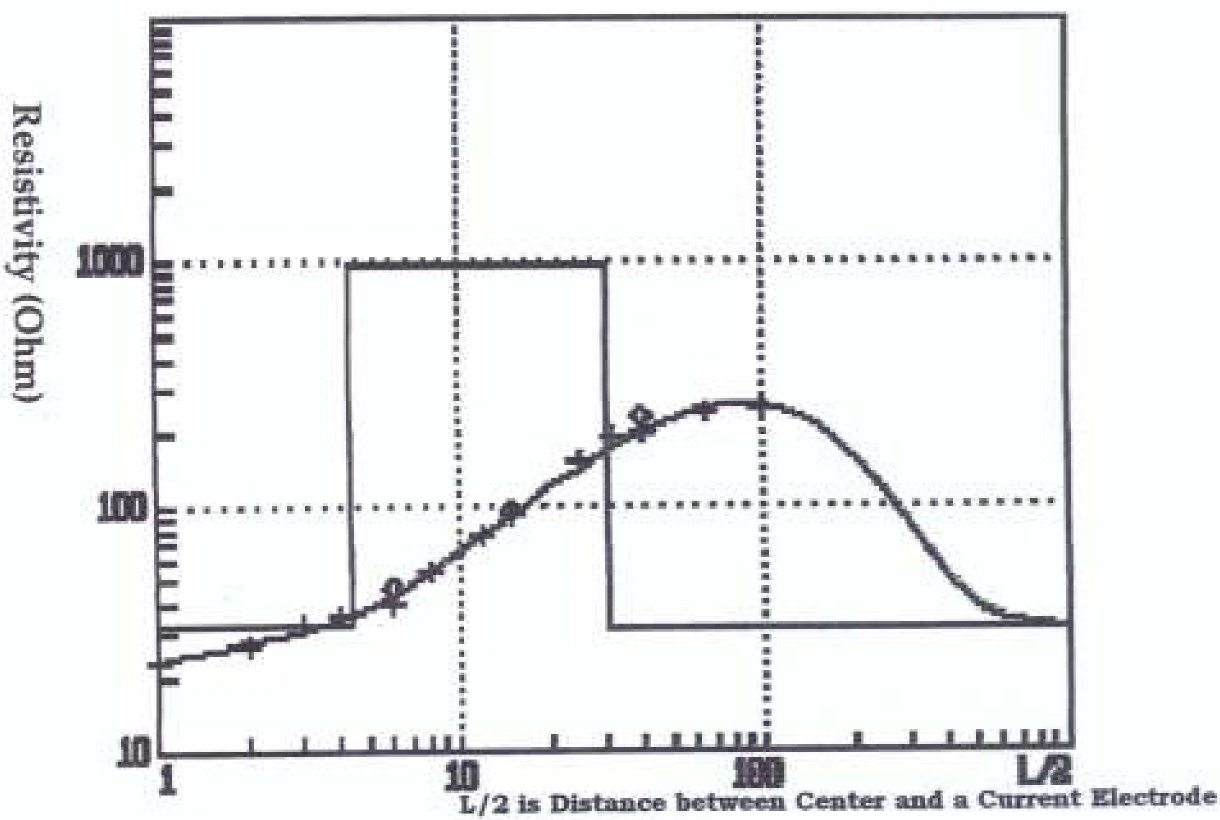
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	**Final year project**	**File Name**	**VES7**
Location	**Baruwa Ipaja**	**Student**	**Balogun 7**
VES Location	**Oluode Street**	**Date of Collection**	**14/11/2006**
Co-ordinate	**N 06° 36.108' E 003° 16.164'**	**Type of Data**	**Schlumberger**
Instrument	**ABEM SAS 300C**	**Direction**	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	3.77	23.7
2	0.25	25.12	1.08	27.1
3	0.25	56.52	0.58	32.5
4	0.25	100.48	0.35	35.1
6	0.25	226.08	0.18	40.5
6	0.50	113.04	0.41	46.9
8	0.50	200.96	0.27	53.9
12	0.50	452.16	0.17	76.4
15	0.50	706.50	0.13	94.0
15	1.00	353.25	0.27	96.8
25	1.00	981.25	0.16	154.1
32	1.00	1,607.68	0.12	189.7
40	1.00	2,512.00	0.08	196.0
40	2.50	1,004.80	0.23	235.1
65	2.50	2,653.30	0.09	244.9
100	2.50	6,280.00	0.04	249.3

RE_1	21.55	DB_1	0.66
RE_2	32.49	DB_2	4.35
RE_3	950	DB_3	30.5
RE_4	31.4		

Layer1 CLAY
" 2 CLAY,Sandy
" 3 SAND
" 4 CLAY



A8

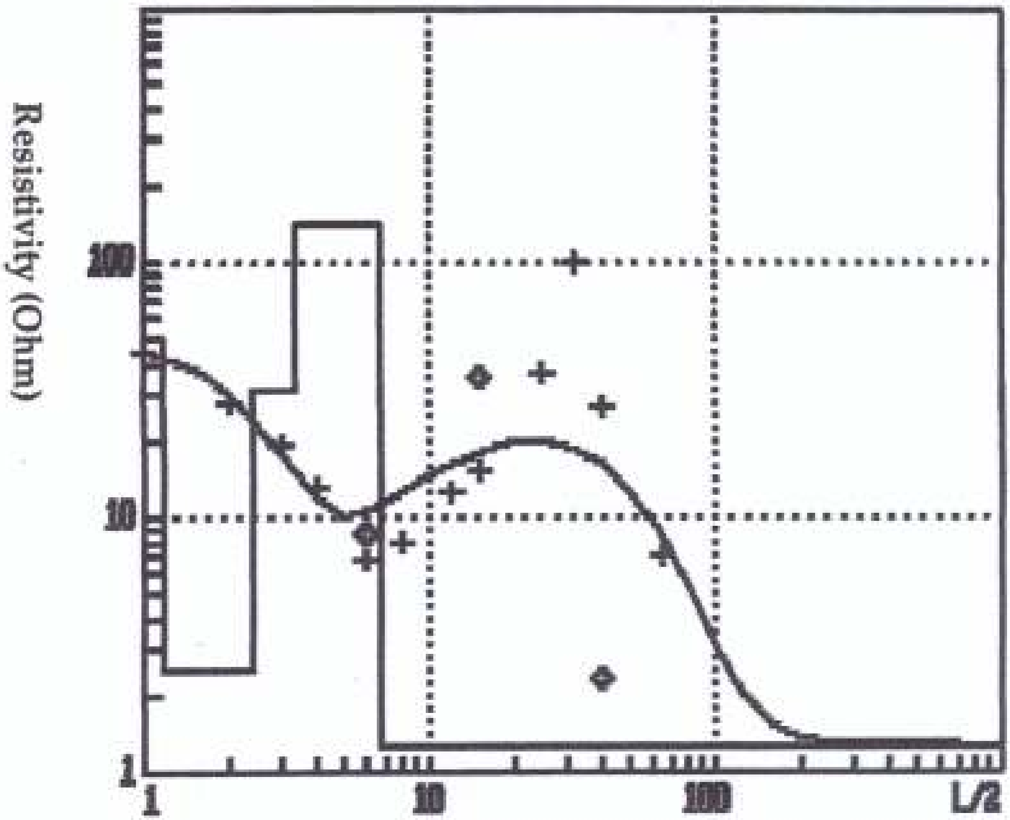
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	Final year project	File Name	VES8
Location	Baruwa Ipaja	Student	Balogun S
VES Location	Fatade Road	Date of Collection	14/11/2006
Co-ordinate	N 06° 35.998' E 003° 16.213'	Type of Data	Schlumberger
Instrument	ABEM SAS 300C	Direction	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	7.09	44.5
2	0.25	25.12	1.14	28.6
3	0.25	56.52	0.33	18.9
4	0.25	100.48	0.13	13.0
6	0.25	226.08	0.03	6.9
6	0.50	113.04	0.08	8.7
8	0.50	200.96	0.04	7.8
12	0.50	452.16	0.03	12.6
15	0.50	706.50	0.02	15.1
15	1.00	353.25	0.10	35.1
25	1.00	981.25	0.04	36.4
32	1.00	1,607.68	0.06	101.0
40	1.00	2,512.00	0.01	27.0
40	2.50	1,004.80	0.00	2.3
65	2.50	2,653.30	0.00	7.0

RE_1	49.93	DB_1	1.18
RE_2	2.53	DB_2	2.42
RE_3	32	DB_3	3.35
RE_4	143.64	DB_4	6.76
RE_5	1.27		

Layer1 CLAY,Sandy
" 2 CLAY
" 3 CLAY,Sandy
" 4 SAND
" 5 CLAY



A9

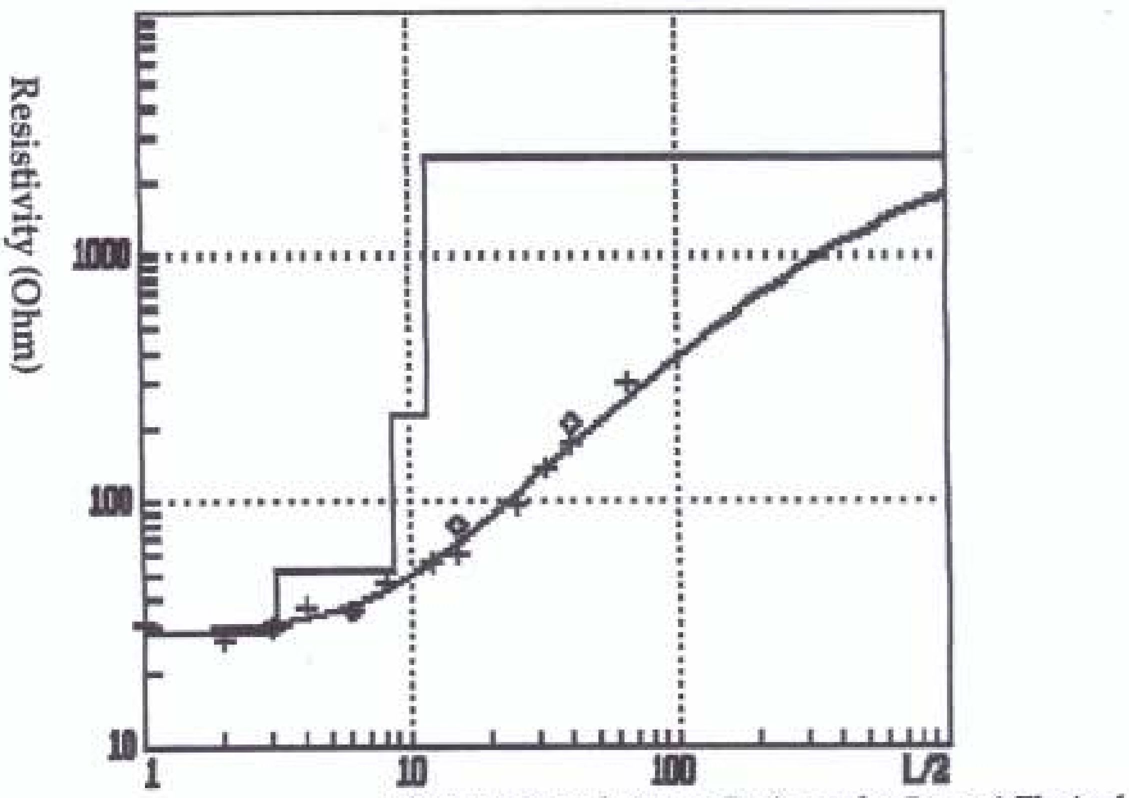
SCHLUMBERGER AND WENNER ANALYSIS PROGRAM

Project Name	Final year project	File Name	VES9
Location	Baruwa Ipaja	Student	Balogun 9
VES Location	Akinduro lane Church St.	Date of Collection	14/11/2006
Co-ordinate	N 06° 36.187' E 003° 16.127'	Type of Data	Schlumberger
Instrument	ABEM SAS 300C	Direction	

AB/2	MN/2	K	R	App.R
1	0.25	6.28	4.97	31.2
2	0.25	25.12	1.09	27.5
3	0.25	56.52	0.55	30.9
4	0.25	100.48	0.36	36.4
6	0.25	226.08	0.16	35.3
6	0.50	113.04	0.32	36.1
8	0.50	200.96	0.23	47.2
12	0.50	452.16	0.12	56.1
15	0.50	706.50	0.09	61.4
15	1.00	353.25	0.22	78.4
25	1.00	981.25	0.10	97.7
32	1.00	1,607.68	0.08	136.2
40	1.00	2,512.00	0.07	169.1
40	2.50	1,004.80	0.21	208.0
65	2.50	2,653.30	0.12	306.7

RE_1	29.47	DB_1	3.11
RE_2	52.24	DB_2	8.65
RE_3	224.44	DB_3	11.48
RE_4	2550		

Layer1 CLAY
" 2 CLAY,Sandy
" 3 SAND
" 4 SAND,dry



APPENDIX B

PARTICLE DISTRIBUTION/HYDROMETER TEST RESULTS

B1 Location 1: OYEWOLE CLOSE. TP 1(T)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.0	1.0	99.0
600 micron	10.8	10.8	88.2
425 micron	13.2	13.2	75.0
300 micron	18.0	18.0	57.0
212 micron	16.1	16.1	49.9
150 micron	7.2	7.2	33.7
63 micron	2.7	2.7	31.0

TP 1(M)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.2	1.2	98.8
600 micron	12.0	12.0	86.8
425 micron	9.2	9.2	77.6
300 micron	9.4	9.4	68.2
212 micron	8.5	8.5	59.7
150 micron	5.9	5.9	53.8
63 micron	4.0	4.0	49.8

TP 1(B)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.2	1.2	98.8
600 micron	10.3	10.3	88.5
425 micron	11.9	11.9	76.6
300 micron	14.8	14.8	61.8
212 micron	14.6	14.6	47.2
150 micron	10.6	10.6	36.6
63 micron	6.0	6.0	30.6

B2 Location 2: ELEGBEDE STREET . TP 2(T)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.6	1.6	98.4
600 micron	12.3	12.3	86.1
425 micron	11.3	11.3	74.8
300 micron	12.6	12.6	62.2
212 micron	10.5	10.5	51.7
150 micron	8.0	8.0	43.7
63 micron	5.0	5.0	38.7

TP 2(M)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.4	1.4	98.6
600 micron	10.5	10.5	88.1
425 micron	8.3	8.3	79.8
300 micron	7.8	7.8	72.0
212 micron	6.7	6.7	65.3
150 micron	5.7	5.7	59.5
63 micron	3.0	3.0	56.5

TP 2 (B)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.8	1.8	98.2
600 micron	10.7	10.7	87.5
425 micron	8.3	8.3	79.2
300 micron	6.7	6.7	72.5
212 micron	6.7	6.7	65.8
150 micron	4.2	4.2	61.6
63 micron	2.9	2.9	58.7

B3 Location 3: LADIPO AJULO STREET. TP 3(T)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm			100
600 micron	11.1	11.1	88.9
425 micron	8.1	8.1	80.8
300 micron	8.0	8.0	72.8
212 micron	6.9	6.9	65.9
150 micron	4.8	4.8	61.1
63 micron	3.6	3.6	57.5

TP 3(M)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.3	1.3	98.7
600 micron	11.5	11.5	87.2
425 micron	8.5	8.5	78.7
300 micron	8.2	8.2	70.5
212 micron	6.7	6.7	63.8
150 micron	4.6	4.6	59.2
63 micron	3.7	3.7	55.5

TP 3 (B)

Test Sieves (Normal Size)	Wt Retained (gms)	Percentage Retained	Total % Passing
2.0mm			100
1.18mm	1.2	1.2	98.8
600 micron	10.0	10.0	88.8
425 micron	8.1	8.1	80.7
300 micron	7.8	7.8	72.9
212 micron	6.2	6.2	66.7
150 micron	4.2	4.2	62.5
63 micron	4.0	4.0	58.5

B4 PARTICLE SIZE DISTRIBUTION/HYDROMETER TEST RESULTS.

Sample No:	SOIL FRACTION CLAY SIZE	SILTS SIZE	SAND SIZE	SOIL FRACTION CLAY AND SILTS SIZE
TP 1/ T	16	15	69	31
TP 1/ M	33	24	50	54
TP 1/ B	20	14	69	34
TP 2/ T	19	20	61	39
TP 2/ M	36	21	43	57
TP 2/ B	39	20	41	59
TP 3/ T	18	20	42	38
TP 3/ M	33	18	44	51
TP 3/B	39	20	41	59

Quartz		Kaolinite		Kaolinite		Illite		Feslpar		Chlorite		Halloysite		Cristobalite	
d(A°)	I	d(A°)	I	d(A°)	I	D(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I	d(A°)	I
4.26	35	7.16	10+	1.619	6	10.0	10	6.44	2	14.2	10	10.1	10	4.15	100
3.343	100	4.46	4	1.584	4	4.94	2	6.35	<1	7.08	4	4.46	8	2.92	5
2.458	12	4.36	5	1.542	5B	4.47	9	5.84	<1	4.71	6	3.40	5	2.53	80
2.282	12	4.48	5	1.489	8	3.68	2B	5.65	<1	3.534	6	2.56	5	2.17	10
2.237	6	4.14	3	1.467	2	3.32	9	4.04	9	2.829	9	2.37	3	2.07	30
2.128	9	3.845	4	1.452	4B	3.16	½	3.89	2	2.684	2	1.67	3	1.99	5
1.980	6	3.741	2	1.429	4	2.86	1	3.75	7	2.567	2	1.48	3	179	3
1.817	17	3.573	10+	1.403	2	2.60	6	3.64	4	2.458	3	1.28	5	1.69	3
1.801	1	3.372	4	1.390	2	2.50	1	3.48	1	2.273	3	1.23	1	1.47	50
1.672	7	3.444	3	1.371	2	2.41	4	3.37	1	2.013	2		1	1.37	20
1.659	3	3.097	3	1.338	4	2.458	2	3.210	>15	1.886	2			1.21	30
1.608	1	2.753	3	1.305	6B	1.982	1	3.178	10	1.717	3			1.13	20
1.541	15	2.558	6	1.292	2	1.689&1.639	3	3.128 & 3.021	3&1	1.567	3			1.09	3
1.453	3	2.526	4	1.282	5	1.53	6	2.953 & 2.920	2&1	1.549	3			1.03	3
1.418	1	2.91	8	1.264	3			2.833 & 2.826	2	1.392	2			1.00	10
1.382	7	2.370	6	1.246	3									0.96	10
1.375	11	2.338	9	1.235	3									0.93	10
1.372	9	2.288	8	1.217	1										
1.288	3	2.247	2	1.200	3										
1.256	4	2.186	3	1.190	3										
1.228	2	2.131	3	1.168	2										
1.1997	5	2.061	2	1.124	1										
1.973	2	1.989	6	1.094	3										
1.838	4	1.939	4	1.082	2										
1.1802	4	1.896	3	1.057	1										
1.1530	2	1.869	2	1.049	2										
1.1408	1	1.839	4	1.039	2										
1.1144	1	1.809	2	1.021	2										
1.0816	1	1.781	4	1.013	2										
1.0636	1	1.707	2												
1.0477	2	1.683	2												
1.0437	2	1.662	7												
1.0316	2														

B5: X-RAY POWDER DATA FOR MINERALS (BROWN GEORGE, 1961)

APPENDIX C

C1. Borehole Log for Well 10

Layers	Depths From (m)	To (m)	Description of Strata
1	0.00	5.00	Fine to Coarse SAND
2	5.00	11.00	Reddish Sandy CLAY
3	11.00	13.00	Fine to Coarse SAND
4	13.00	17.00	Reddish CLAY
5	17.00	23.00	Fine to Coarse SAND
6	23.00	24.00	Hard grey CLAY
7	24.00	30.00	White Coarse SAND
8	30.00	32.00	Greyish CLAY
9	32.00	38.00	Medium to Coarse SAND
10	38.00	44.00	Greyish Sandy CLAY
11	44.00	48.00	Fine to Coarse SAND
12	48.00	62.00	Greyish CLAY
13	62.00	69.00	White Medium SAND
14	69.00	75.00	White Clayey SAND

Source: Lagos State Water Corporation

C2. Borehole Log for Well 15

Layers	Depths From (m)	To (m)	Description of Strata
1	0	5.00	Surface Brownish SAND
2	5.00	11.00	Yellowish Clayey SAND
3	11.00	17.00	Yellowish white Clay
4	17.00	19.50	Medium to Fine SAND
5	19.50	23.00	White Clayey SAND
6	23.00	24.00	Greyish CLAY
7	24.00	30.00	Fine to Medium SAND
8	30.00	32.45	Greyish CLAY
9	32.45	38.00	Fine to Coarse SAND
10	38.00	44.00	Greyish Sandy CLAY
11	44.00	47.00	Coarse SAND
12	47.00	57.25	Greyish CLAY
13	57.25	64.00	Fine Silty SAND
14	64.00	70.00	Greyish Clayey SAND

Source: Lagos State Water Corporation

C3. Borehole Log for Well 20

Layers	Depths From (m)	To (m)	Description of Strata
1	0	5.00	Surface Reddish SAND
2	5.00	11.00	Brownish Clayey SAND
3	11.00	18.00	Brownish Clay
4	18.00	23.00	Reddish Clayey SAND
5	23.00	26.50	Brownish Clay
6	26.50	31.00	Mediun to Coarse SAND
7	31.00	33.00	Greyish CLAY
8	33.00	39.00	Coarse SAND
9	39.00	45.45	Greyish Sandy CLAY
10	45.45	49.00	White Medium to Fine SAND
11	49.00	53.00	Greyish CLAY
12	53.00	70.00	Medium to Coarse SAND
13	70.00	76.00	Greyish Clayey SAND
14	76.00	81.00	Greyish CLAY

Source: Lagos State Water Corporation

C4. Borehole Log for Well 30

Layers	Depths From (m)	To (m)	Description of Strata
1	0.00	6.00	Surface Sandy CLAY
2	6.00	11.00	Reddish ClayeySAND
3	11.00	15.00	Fine to Coarse SAND
4	15.00	20.00	Brownish CLAY
5	20.00	29.00	Medium to Coarse SAND
6	29.00	32.00	Greyish Sandy CLAY
7	32.00	36.00	Fine to Medium SAND
8	36.00	40.00	Brownish CLAY
9	40.00	43.00	Fine to Coarse SAND
10	43.00	57.00	Greyish sandy CLAY
11	57.00	72.00	Fine to Coarse SAND
12	72.00	74.00	Greyish CLAY
13	74.00	76.00	Fine to Coarse SAND
14	76.00	79.00	Greyish CLAY
15	79.00	85.00	Fine to Medium SAND
16	85.00	92.00	Greyish Sandy CLAY

Source: Lagos State Water Corporation

C5. Borehole Log for Well 41

Layers	Depths From (m)	To (m)	Description of Strata
1	0.00	3.00	Surface Red SAND
2	3.00	10.45	Yellowish Clayey SAND
3	10.45	15.00	Medium SAND
4	15.00	17.00	Reddish CLAY
5	17.00	18.00	Fine to Coarse SAND
6	18.00	34.45	Brownish Sandy CLAY
7	34.45	36.00	Fine to Coarse SAND
8	36.00	37.00	Greyish CLAY
9	37.00	39.00	Medium to Fine SAND
10	39.00	48.00	Greyish Sandy CLAY
11	48.00	57.00	Greyish CLAY
12	57.00	60.00	Greyish Sandy CLAY
13	60.00	62.00	Greyish brown CLAY
14	62.00	66.00	Coarse SAND
15	66.00	68.00	Brownish CLAY
16	68.00	70.00	Greyish Sandy CLAY
17	70.00	73.00	Greyish CLAY
18	73.00	75.00	Fine to Medium SAND
19	75.00	79.00	Greyish CLAY
20	79.00	97.00	Fine to Medium SAND
21	97.00	101.00	Greyish Sandy CLAY

Source: Lagos State Water Corporation

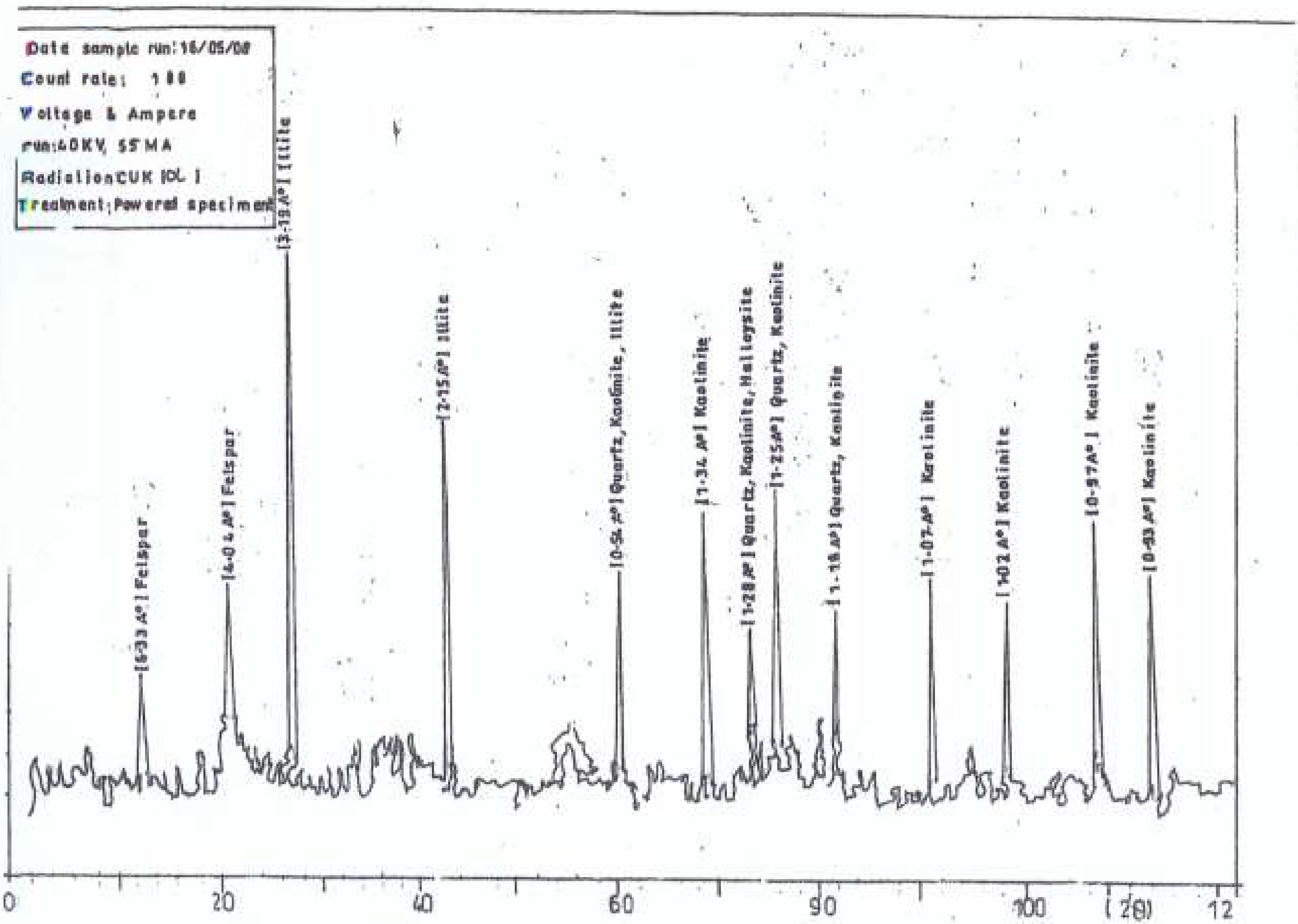
C6. Borehole Log for Well 69

Layers	Depths From (m)	To (m)	Description of Strata
1	0.00	4.50	Surface Reddish Sandy CLAY
2	4.50	6.00	Yellow Coarse SAND
3	6.00	10.00	Reddish CLAY
4	10.00	12.45	Reddish Sandy CLAY
5	12.45	16.00	Fine to Coarse SAND
6	16.00	21.40	Greyish CLAY
7	21.40	28.00	Fine to Coarse SAND
8	28.00	31.25	Greyish Sandy CLAY
9	31.25	34.00	Brownish Clayey SAND
10	34.00	38.00	Fine to Coarse SAND
11	38.00	45.50	White Coarse SAND
12	45.50	52.00	Brownish CLAY
13	52.00	59.00	Fine to Coarse SAND
14	59.00	65.00	Greyish Sandy CLAY
15	65.00	70.00	Greyish CLAY

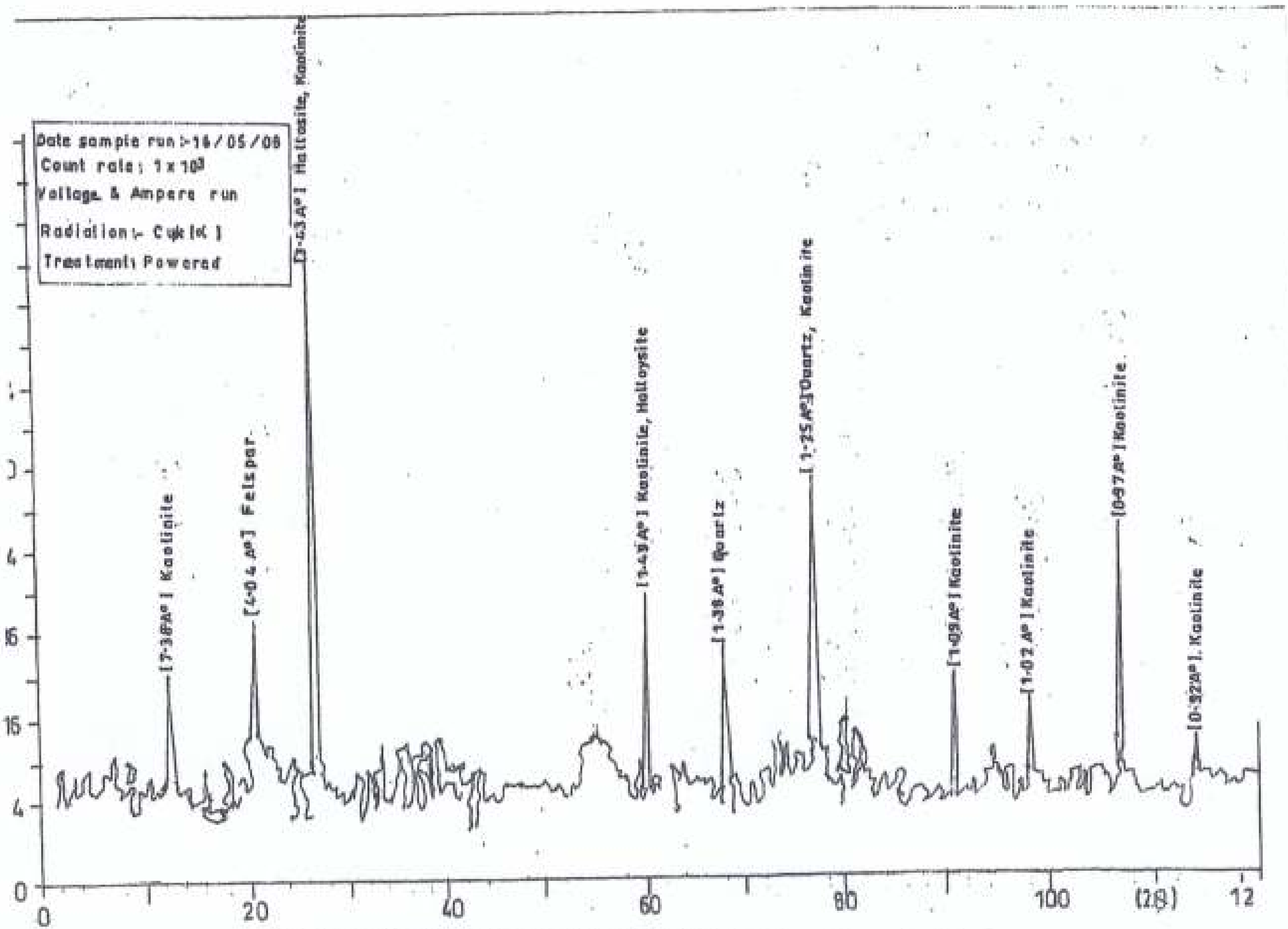
Source: Lagos State Water Corporation

APPENDIX D

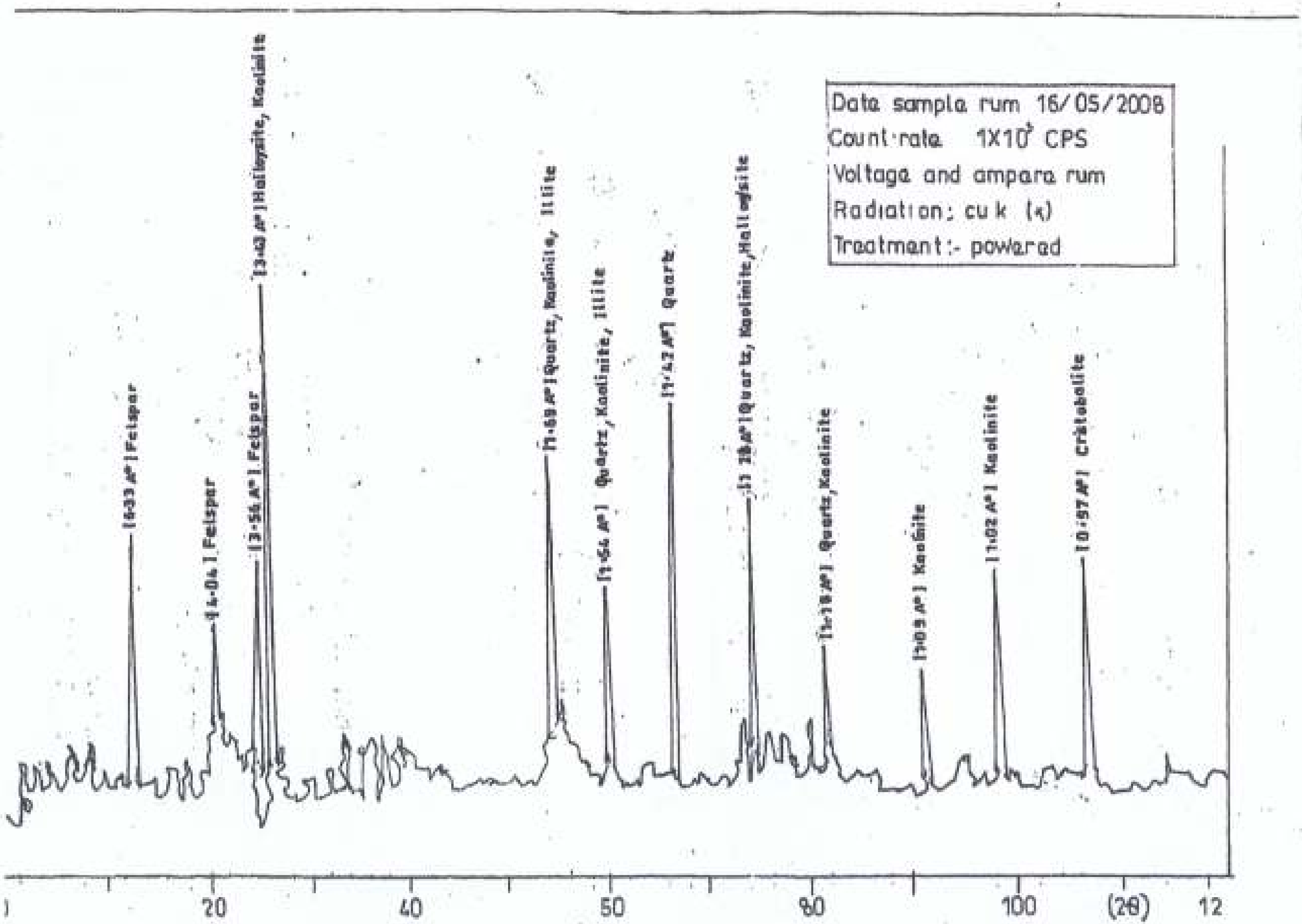
LIBRARY



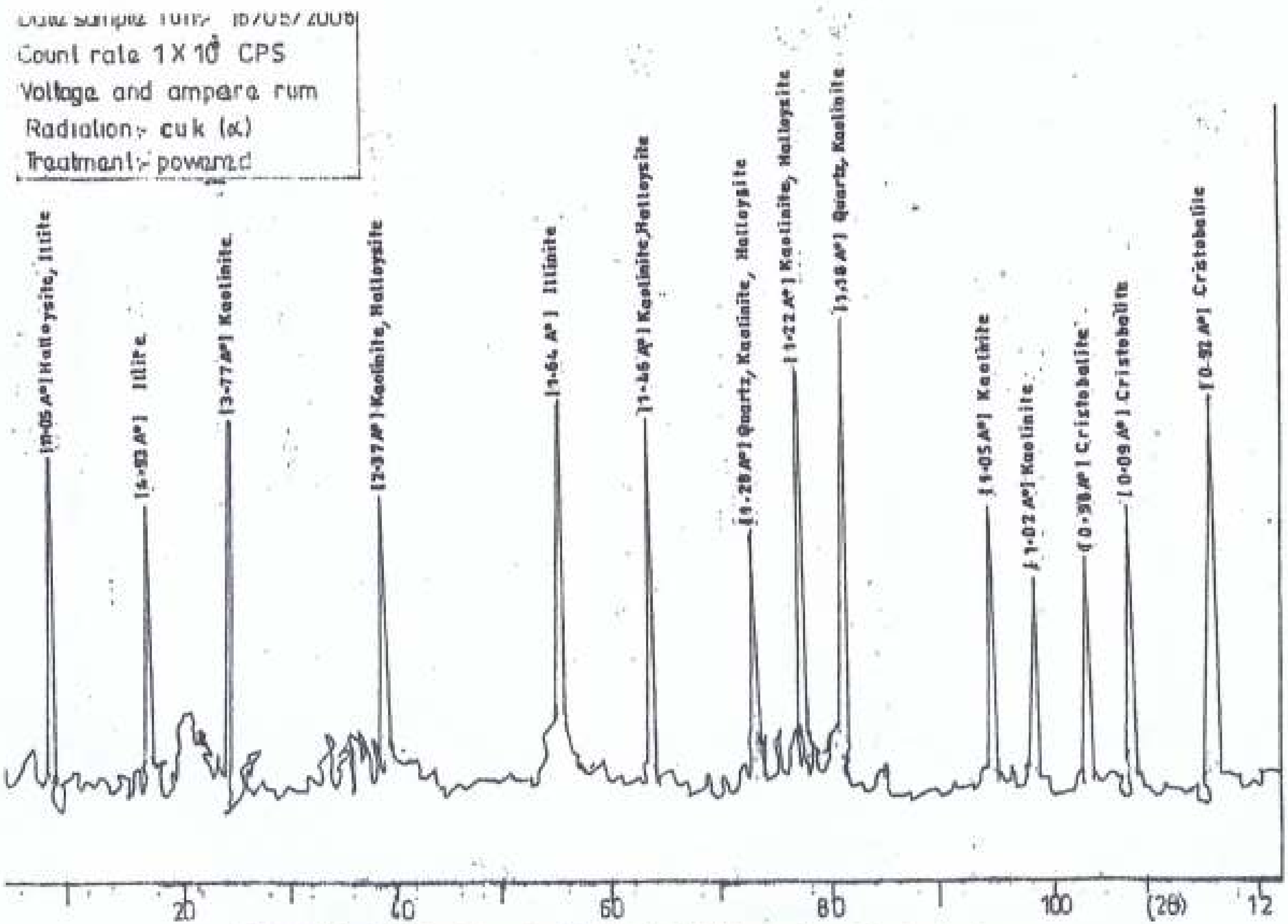
D1: X-Ray Diffraction for Trial Pit 1(M) Location: Oyewole Close



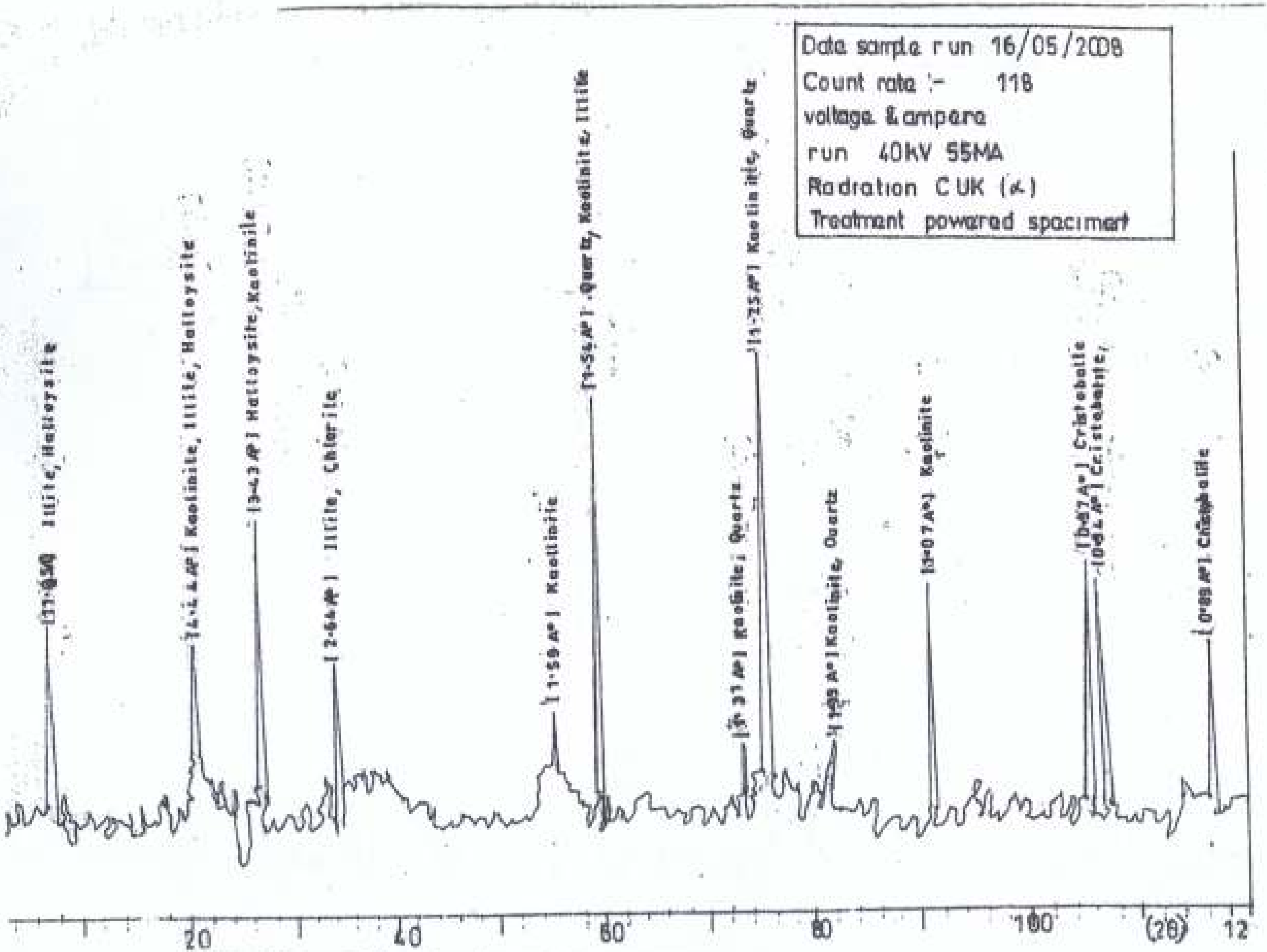
D2: X-Ray Diffraction for Trial Pit 1(B) Location: Oyewole Close



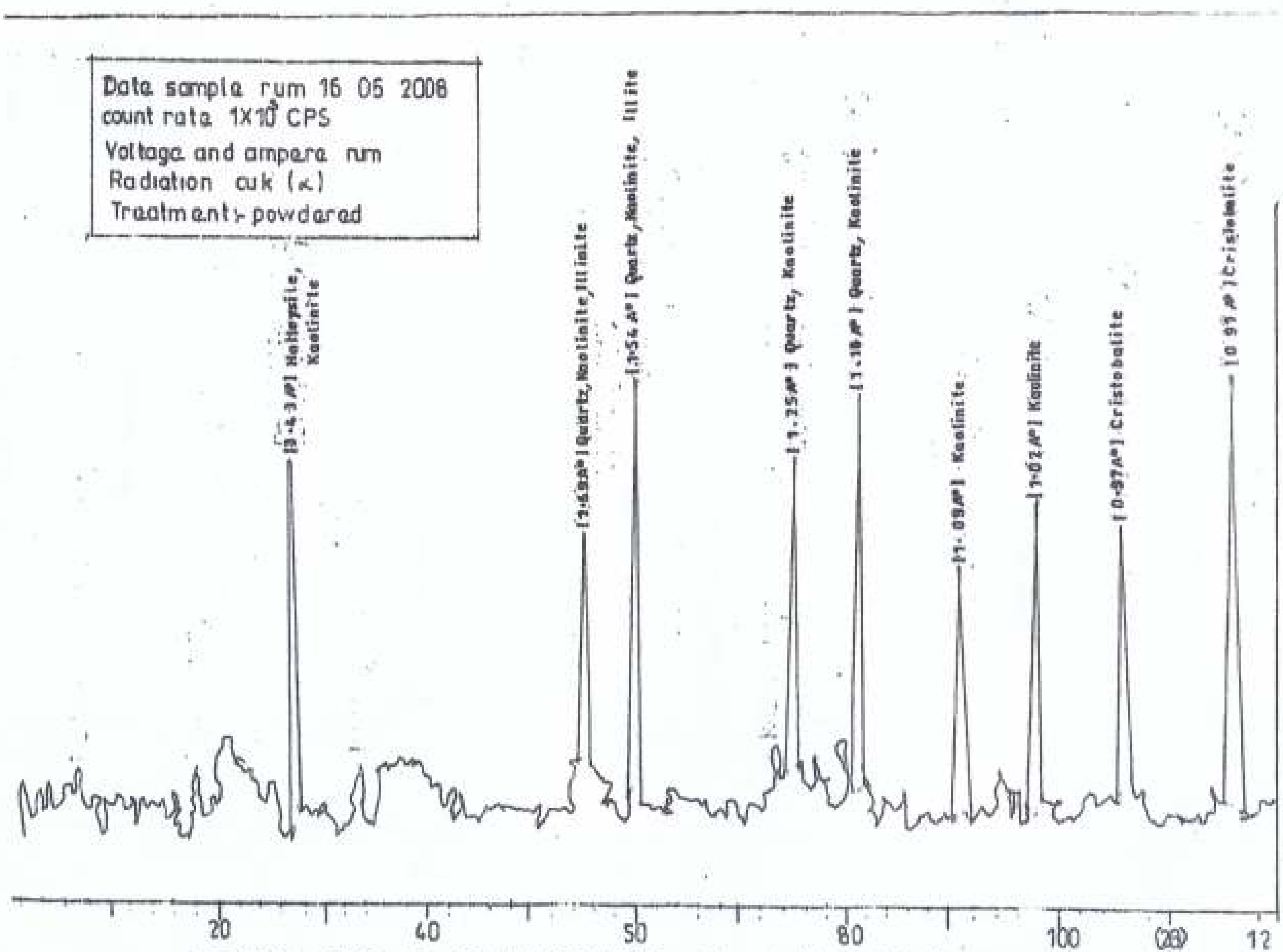
D3: X-Ray Diffraction for Trial Pit 2(T) Location: Elegbede Street



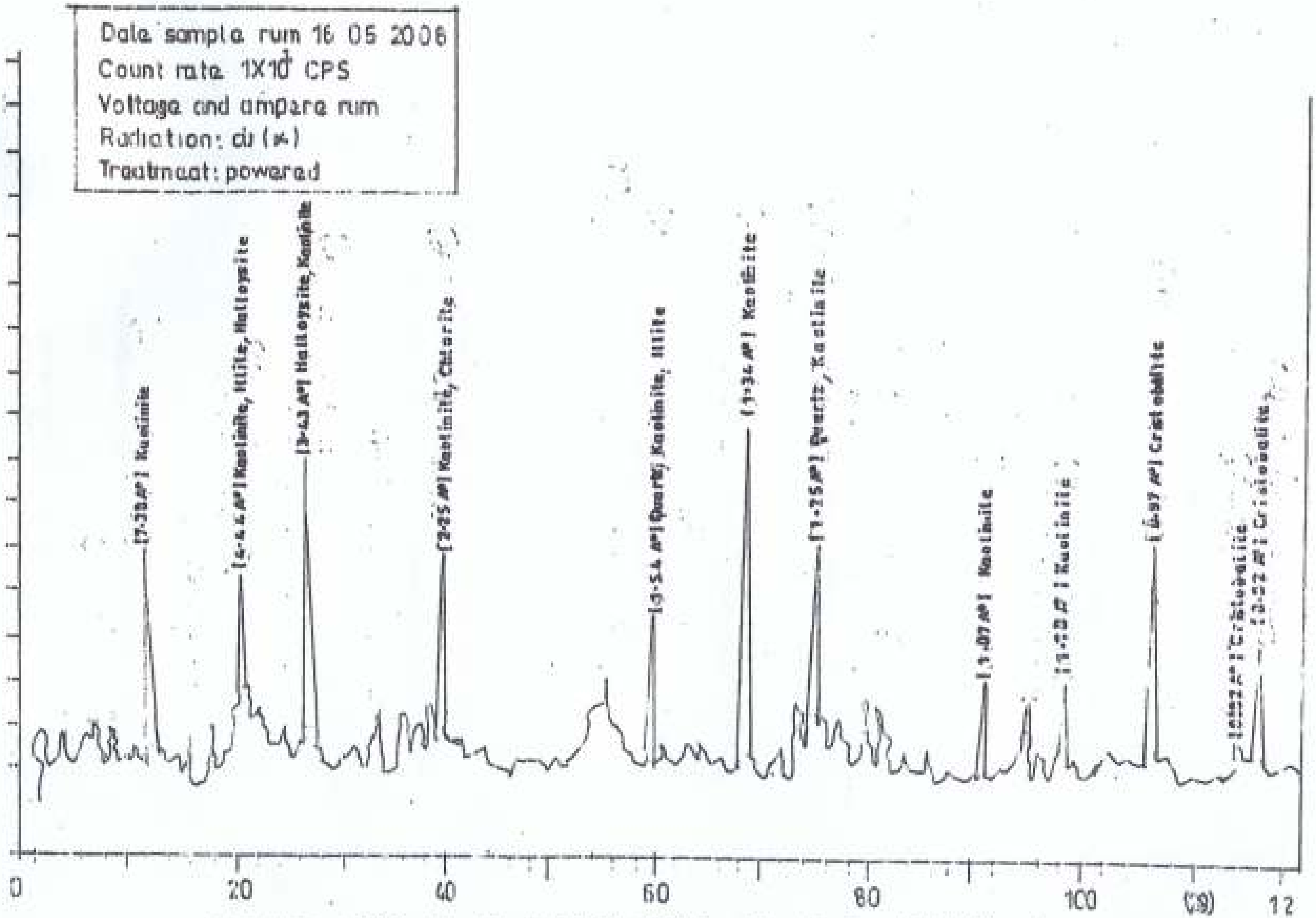
D4: X-Ray Diffraction for Trial Pit 2(M) Location: Elegbede Street



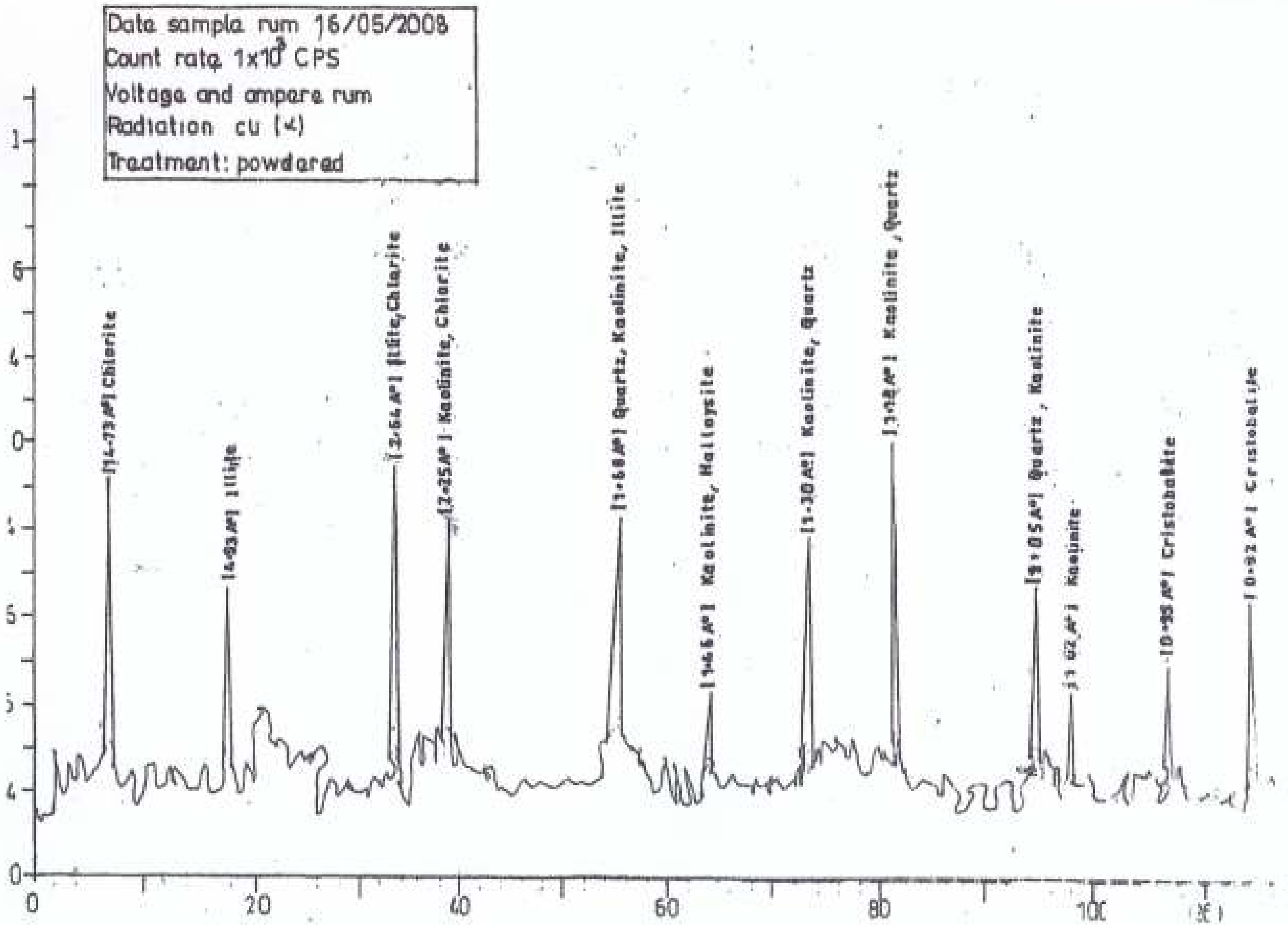
D5: X-Ray Diffraction for Trial Pit 2(B) Location: Elegbede Street



D6: X-Ray Diffraction for Trial Pit 3(T) Location: Ladipo Ajulo Street



D7: X-Ray Diffraction for Trial Pit 3(M) Location: Ladipo Ajulo Street



D8: X-Ray Diffraction for Trial Pit 3(B) Location: Ladipo Ajulo Street