GROUNDWATER EXPLORATION IN ADANSI NORTH DISTRICT OF GHANA

USING RESISTIVITY METHOD

by

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Declaration

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

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ABSTRACT

Resistivity Profiling and Vertical Electrical Sounding (VES) using McOhm Resistivity meter was carried out in seventeen communities in Adansi North District of Ashanti Region of Ghana. Dipole- Dipole array with 20 m chainage interval was employed for the profiling; stations which had low resistivities were noted and probed further to a depth of about 70 or sometimes 80 m using VES.

Points with low resistivities along profiles were interpreted to be due to groundwater, clays, weathered zones or fractures whereas high resistivities may be dike-like structures or boulders. The interpretations of the VES results revealed that most of the communities were underlain by an overburden of thickness between 12 and 16 m. Moderately weathered material ranging from less than one meter to several meters in thickness separate the overburden from the underlying weathered and fractured bedrock and subsequently hard bedrock. The bedrock may be associated with fractures in some of the communities. Recommendations for test drilling at each site was based on ascending order with low resistive points selected first. Borehole yields ranged between 17 and 150 lpm with an average of 38 lpm. Average borehole depth and static water level were 48 and 8 m respectively. Out of the 36 holes drilled 23 were successful whiles 13 were dry wells giving a success rate of 64 %.

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CHAPTER ONE

INTRODUCTION

1.1 GeneralIntroduction

Water is said to be life. It is a vital component of human body, without which metabolism and other activities in the body cannot be performed. Water is an indispensible ingredient in national economics and indeed the ecosystem (Derry, 1999). Groundwater is considered to have some advantages over surface water supply and is usually used as first choice option for community water supplies. It is more reliable throughout the year and generally requires no treatment (Ministry of Works and Housing, 2005).

Water is extremely important to man, animals and plants, thus without water life on earth would not exist. From the beginning of human civilization, people have settled close to water sources, along rivers, lakes or natural springs. Indeed where people live, some water is normally available for domestic use and for watering livestock. This does not imply, that the available source of water is convenient and of sufficient quantity, nor that the water is safe and wholesome. On the contrary, in many countries people live in areas where water is scarce. Often it has to be carried over long distances, especially during dry periods. Scarcity of water may also lead people to use sources that are contaminated by human or animal faeces, and are therefore dangerous to human health(International Centre for Community Water Supply and Sanitation, 1981).

A few litres of potable water each day is sufficient for a person's basic drinking and food preparation requirements, depending on climate and lifestyle. Much larger quantities are necessary when water is used for other purposes such as personal hygiene, cleaning of cooking utensils, laundry and house cleaning. Safe, adequate and accessible supplies of water,combined with proper sanitation, are surely basic needs and essential components of primary health care. Safe drinking water is important in the control of many diseases. This is particularly well established for water-related diseases such as diarrhoea, cholera, typhoid fever, infectious hepatitis, amoebic and bacillary dysentery.International Centre for Community Water Supply and Sanitation (1981) andAning (2000) have estimated that as many as 80% of all diseases in the world are associated with unsafe water.

Of the 0.62% of total water that is available as fresh water;about half is below a depth of 800m and so not practically accessible on the surface. The earth's fresh water that is obtainable for man's use is about $4x10^6 km^3$ and is mainly in the ground (Wilson, 1993)as shown in Table 1.

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Table 1: Estimates of the amount of water involved in the hydrological cycle and proportion (percentages) of the total water on earth (Wilson, 1993)

Location	**Volume (10 km^3)**	**Percentage (%) of total water**
Seas and oceans	1320000	97.25
Polar ice, glacier and snow	29200	2.1
Atmosphere	13	0.001
Saline lakes and inland seas	105	0.008
Fresh water lakes	125	0.009
Rivers	1.25	0.00009
Soil moisture	65	0.0048
Groundwater	8250	0.62

For rural community water supply systems, groundwater in many cases is the preferred source. Surface water sources are likely to be contaminated and much more subject to seasonal fluctuation. Groundwater withdrawals often can be continued long after drought conditions have depleted the rivers and streams. The utilization of groundwater for community water supplies is most likely still very much below its potential in many areas.

Frequently, the available data on groundwater resources are grossly inadequate. Successful development of groundwater supplies may then be promoted by prospecting. These would also bring to light the physical and chemical characteristics of the groundwater.The tapping of groundwater resources, both for drinking water supply and for irrigation purposes, date back to ancient times. The technology for tapping groundwater at great depth through tube wells is of more recent date (International Centre for Community Water Supply and Sanitation, 1981).

When groundwater is present at a shallow depth (less than 10m) it may be polluted from sources of faecal contamination such as pit latrines or septic tanks. Pathogenic bacteria and viruses from such sources can be carried by the groundwater, although they tend to attach themselves by absorption to the solid ground particles. When assessing the possible health hazards of groundwater sources, one should pay attention to the travel-time of the water through the ground strata than to the distance the water has to flow to the point of withdrawal. In limestone, karstic formations and fissured rock, humancontamination may be carried over a distance of several kilometers. In clayey formations, groundwater flow is much slower so that only contamination from nearby sources needs to be considered when selecting the point of groundwater withdrawal (International Centre for Community Water Supply and Sanitation, 1981).

1.2 Objectives

- To exploreresistivity anomaly points for borehole drilling.
- To provide potable drinking water for some communities in Adansi North District
- To provide information on groundwater potential for further hydrogeological studies and successful groundwater development.

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1.3 Scope of Work

The project was concerned with geophysical exploration using 1D resistivity method for 17 communities within the Adansi North District of Ashanti, Ghana. The objective is to establish a scientific basis for the siting of boreholes in this area. It is believed that investigation will contribute to the development of groundwater resources now and in the future.

Data acquisition on the site was recorded using McOhm-EL 2111 resistivity meter. Resistivity profiling was conducted on 41 profiles ranging from 120 to 320m. Survey on profiles wasdone at 20 m station intervals and 40 m constant depth using the dipole-dipole array. Employing the same array,vertical electrical sounding (VES) was used on sites of low resistivity to investigate to an estimated depth of 70 m. Profiling and VES results was processed using Grapher8 and 1X1Dv3 Interpex softwares respectively. In all 36 out of 71 sounding sites were drilled and 23 provided potable drinking water for the people.

CHAPTER TWO

LITERATURE REVIEW

2.1Groundwater occurrence, distribution and movement

Appreciable groundwater infiltration is promoted by the abundant pore spaces in loose soils and unconsolidated sands and gravels. Exposed bedrock that is fractured or inherently porous, such as coarse also allow substantial infiltration by surface water. On the other hand consolidated clay, which consist of closely packed particles with minute pore spaces, impede infiltration similar to unfractured crystalline bedrock such as plutonic igneous rocks (e.g. granite and diorite) and high grade metamorphic rocks (e.g. schist) (Ward and Robinson, 1990).

The terrain of the ground also affects the degree of infiltration in the soil. Surface water runs slowly on gentle slope terrain and this allows some ample time for the water to seep through the ground. On the other hand, water runs very fast on steep slopes into lakes and rivers such that infiltration is minimal (Ward and Robinson, 1990).

The amount of precipitation experienced over long-term or short-term period affects the amount of groundwater recharge in a terrain. Extended drought may curtail recharge significantly for several years or more. Short-term recharge such as rains generally replenishes the groundwater supply periodically. Hydrological interest is largely concerned with the speed and direction of movement of groundwater and hence very slow, compared with that of the surface, but that is very variable (Ward and Robinson, 1990).

Movement and distribution of groundwater in groundwater system cannot be overruled. The flow of water through the ground is governed by differences in pressure. The difference in pressure is greatly influenced by the effect of gravity, as such groundwater in general moves from the higher land areas downwards towards the sea level. Just as the surface water moves from uphill towards downhill, groundwater also moves from points of higher elevations to lower elevations. The elevation differences depicts that a column of water exists whose weight creates pressure, which serves as the driving force for groundwater movement. In many real situations, groundwater flows systems are found in, say limestone and volcanic rocks(Meinzer, 1942).

The surface below which rocks are saturated with water is referred to as water table. At and below the water table all the voids in a formation are filled with water. This area is called the saturation zone. Some amount of water is retained above the water table by surface tension of the water. This area above the water table where water is retained by surface tension is aeration zone. The lower part of the aeration zone may range from few tens of centimeters to several meters above the water table (Meinzer, 1942).

2.2Groundwater Pollution

Beyond the natural addition of soluble minerals to water, various kinds of pollution arise through human activities. Any soluble material discharged into the air, left exposed on the ground surface, or buried unsealed underground has the potential to pollute groundwater supplies. Surface water pollution may lead to groundwater pollution in a situation where a polluted stream contributes to groundwater recharge (Montgomery, 1993).

Air pollutants can react with or be dissolved in rainwater. When rain falls and infiltrates into the soil, they can be carried along. Volatile metals, such as lead and mercury, are a particular problem in the air near smelters and other metal processing plants.Liquid and solid wastes from septic tanks, sewage plants and animal feedlots and slaughterhouses may contain bacteria, viruses and parasites that can contaminate groundwater. Liquid wastes from industries and military bases can be highly toxic, containing high concentration of heavy metals and compounds such as cyanide and polychlorinated biphenyls(PCBs) (Plummer and McGeary, 1991).

Pesticides and herbicides such as Dichloro Diphenyl Trichloroetane (DDT) and Dichlorophenoxy (Acetic acid) (2, 4-D) applied to agricultural crops can find their way into groundwater when rain or irrigation water leaches the poisons downward into the soil. Fertilisers are also a concern. Nitrate, one of the most widely used fertilizers, is harmful in even small quantities in drinking water (Plummer and McGeary, 1991).

Acid mine drainage from coal and metal mines as well as radioactive waste are very serious sources of groundwater pollution. The search for a permanent disposal site for solid, high level radioactive waste is a major national concern for United States. In the late 1988 theU.S. Congress chose the Yucca Mountains, Nevada, 180 km north-west of Las Vegas as the waste site but the final decision was not made until 1995 after much additional study (Plummer and McGeary, 1991; Montgomery, 1993).

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Groundwater is a valuable resource that has received much attention over the last couple of decades. Extremely large sums of money have been and will be spent on groundwater issues.Groundwater contamination problems and the public haveeven become the subject of a major Hollywood movie with the recent release of *A Civil Action* starring John Travolta (Travolta, 1999).

2.3 Groundwater Exploration

Groundwater exploration is an expensive venture, as such appropriate methods should be applied to its exploration to reduce cost and to increase the success rate of drilling wet wells. This is where exploration Geophysics can be used as an effective tool to increase the success rate of locating underground water (Charlesbois and Lee Jr, 1976).

Delineating sites as groundwater potential points depends largely on the availability of geological, hydrogeological and geophysical data on the area under study. The available information on the nature of rocks, nature of soil cover, topographical features, log and yields of existing previous boreholes and the amount of rainfall at the area are very important for desk studies (Kearey and Brooks, 1984).

Before any effective geophysical survey, the background information have to be obtained and they can be obtained from various departments, corporations and institutions such as Geological Survey Department, Water and Sewerage Corporation, Building and Road Research Institute. So many geophysical methods such as magnetic, gravity and seismic can be used for groundwater exploration but factors such as cost and time effectiveness of the method should be taken into consideration (Kearey and Brooks, 1984).

However, magnetic method is rarely used in groundwater exploration, but can be used in delineating faults and shear zones, which are good signatures of groundwater potential.Seismic on the other hand, is potentially useful in hydrogeological investigation but economically expensive for groundwater exploration. The refraction method can provide direct information on the depth of the water tables of the area of study.Electrical method on the contrary has proven very viable in groundwater exploration. The two main techniques used in electrical methods are the electromagnetic and resistivity techniques. The electromagnetic method is very fast in locating fracture zones and one advantage of this method is that it does not need ground contact. The resistivity method can be used to delineate lateral variation of apparent resistivity (profiling) as well as vertical variations with depth (vertical electrical sounding) (Kearey and Brooks, 1984).

2.4Tropical African Regolith (Overburden)

The tectonically inactive African Shield consists of Pre-Cambrian Basement Complex rocks, which are poor aquifers because of their crystalline nature. Deep chemical weathering has, however, produced from the rock relatively thick regolith in which extractable groundwater resources abound. However, regional differences in climate and/or marked spatial variations in weathering depth are reflected in the characteristics of regolith aquifers. The effects of these factors on the mode of the relationship between saturated zone thickness and weathering depth have been specifically reported (Enslin, 1943; Faniran and Omoribola, 1980a; Omoribola, 1982). For example, while isolated groundwater compartments occurring in discrete basins of decomposition, tend to characterize regolith aquifers in semi-arid areas (Enslin, 1943), the zone of saturation in the regolith (overburden) is generally widespread or spatially continuous in the more humid than low relief areas (Omoribola, 1982; 1983a). Even in the humid areas, local rainfall variations can be used to explain differences in the values of weathering depth threshold for the formation of a groundwater zone in tropical regolith (Omoribola, 1982).

Additionally, the hydrogeological significance and characteristics of tropical regolith have also been reported by Sikes (1934) for parts of Kenya, Ruddock (1967) for the Kumasi district in Ghana, and Asseez (1972) for the Basement Complex of southwestern Nigeria. Probably the greatest challenge posed by the hydrogeology of tropical Africa is to obtain reliable estimates of the groundwater resources (Challenges in African Hydrology, 1996).

2.5 Hydrogeological Provinces of Ghana

Hydrologic studies involve the estimation of the amount of rainwater that infiltrates through the soil into the ground system and the run-offs. The amount of rainfall infiltration through the surface soil depends largely on the drainage system and the permeability of the soil at the site. The hydrogeologic studies principally involve the study of rock types, their water-bearing properties, and the geologic structure likely to store groundwater (Davis and De Wiest, 1988).

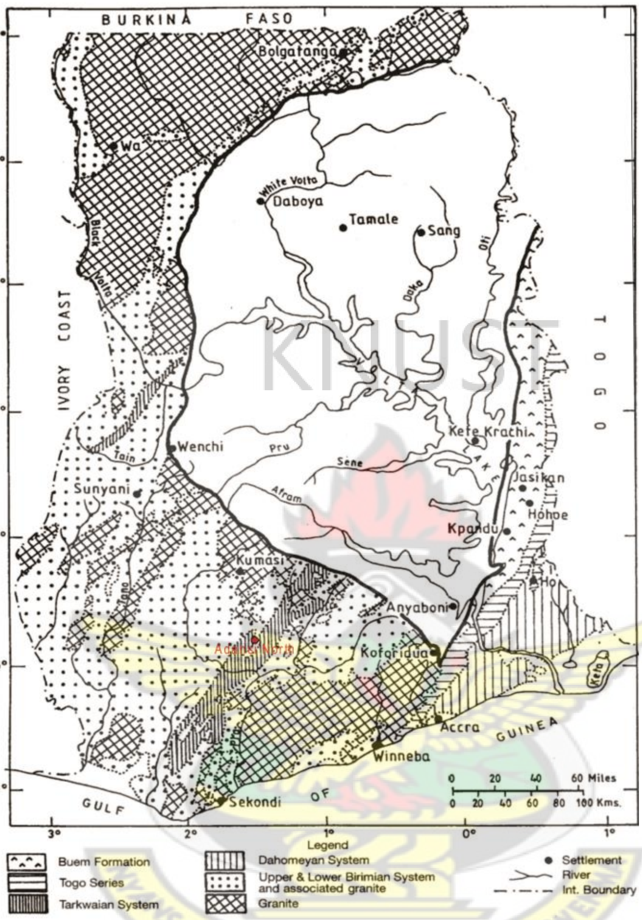

Fig.2.1 Hydrogeological Sub provinces of Basement Complex Rocks (Obuobie and Barry, 2010)

Ghana has two main hydrogeological provinces: (1) Basement Complex, having Precambrian Crystalline igneous and metamorphic rocks (2) Paleozoic Sedimentary Formations. The minor province consists of (1) Cenozoic, Mesozoic and Paleozoic Sedimentary rocks on the coast and (2) Quaternary Alluvium occurring along the major streams.

Basement Complex underlies about 54% of the country and has sub-provinces namely metamorphosed and folded rocks of the Birimian metavolcanics and metasediments, Dahomeyan, Tarkwaian Formation, Togo Series and Buem Formation (Fig.2.1). They consist of mainlygneiss, phyllite, schist, migmatite, granite-gneiss and quartzite with associated intrusions of large masses of granite in the Birimian rocks (Dapaah-Siakwan and Gyau-Boakye, 2000).

Paleozoic Sedimentary Formation (Voltaian) underlies 45% and consists mainly of sandstone, shale, arkose, mudstone, sandy and pebbly beds and limestone. It is divided into:

- Upper Voltaian (mainly sandstone)
- Obosum (mainly shale and mudstone beds) and Oti Beds (mainly sandy and pebbly beds).

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The remaining 1% comprises:

- Coastal Block- Fault Province which consists of narrow discontinuous belt of Devonian sedimentary rocks namely Accraian (sandstone, grit and shale) and Sekondian (sandstone, grit and shale, mudstone, nodules of limestone and siderite).
- Coastal- Plain Province underlain by consolidated to unconsolidated sediments (shale, sandstone, limestone, glauconitic sandstone, oil sand) from Cretaceous to Eocene in age in extreme southwestern and southern part of Ghana.
- Quaternary Alluvium occurs along the Voltariver, its major tributaries and the Volta delta (Ghana Geological Survey, 2005).

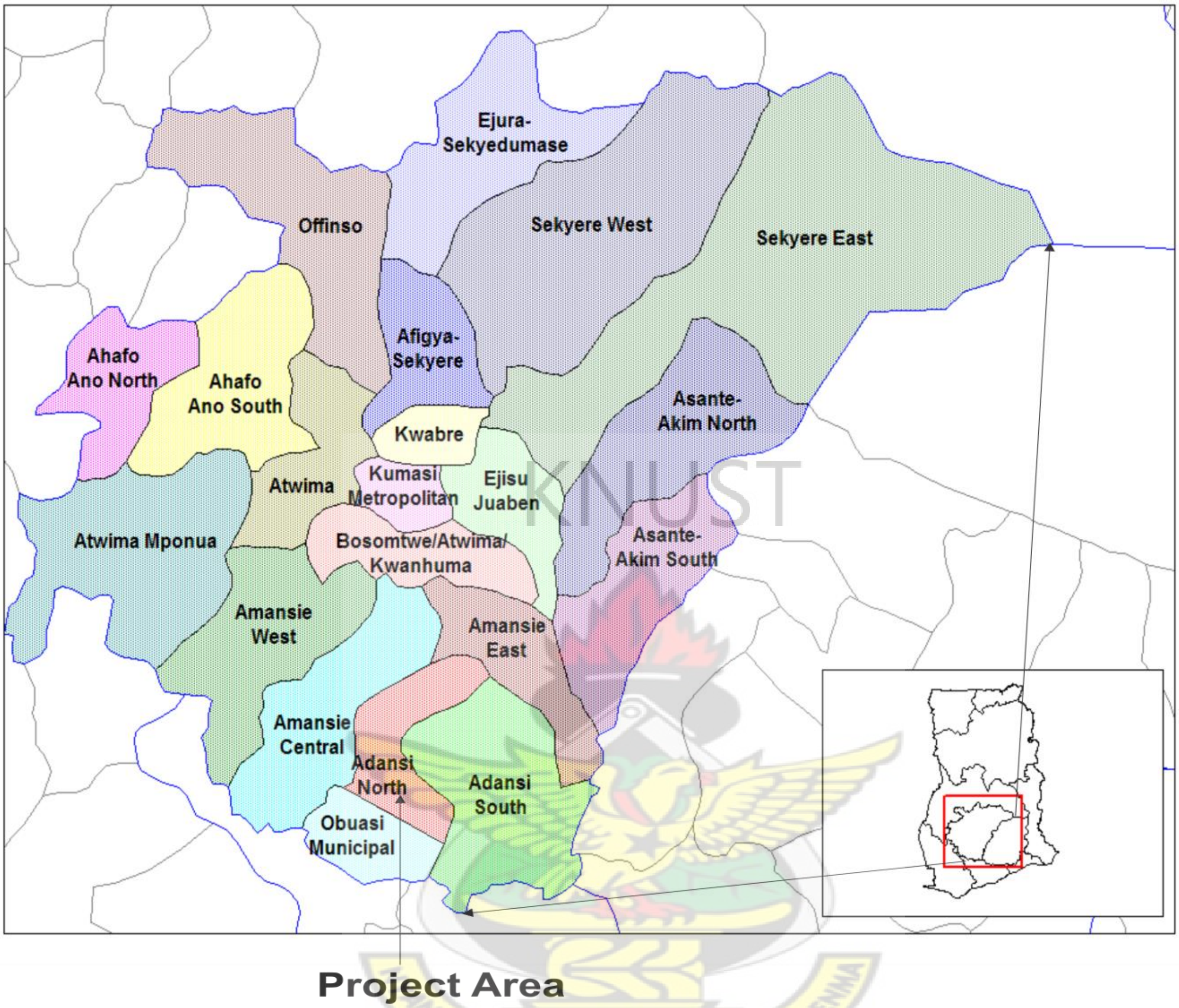

Fig.2.2 Location map of Ashanti Region, Ghana (Wikipedia, 2008).

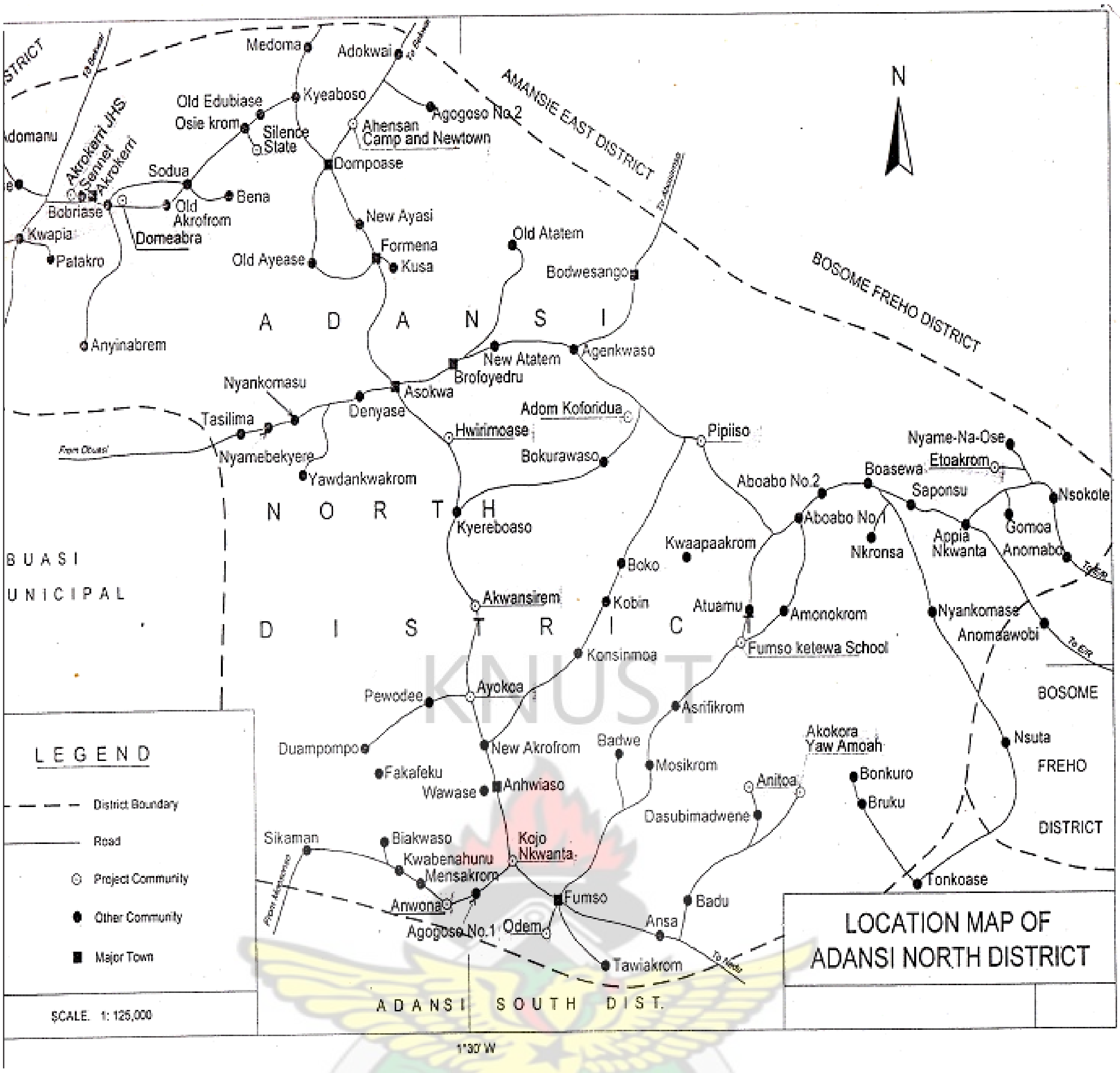

Fig.2.3 Map of Adansi North District, Ashanti Region (Community Water and Sanitation Project, 2009).

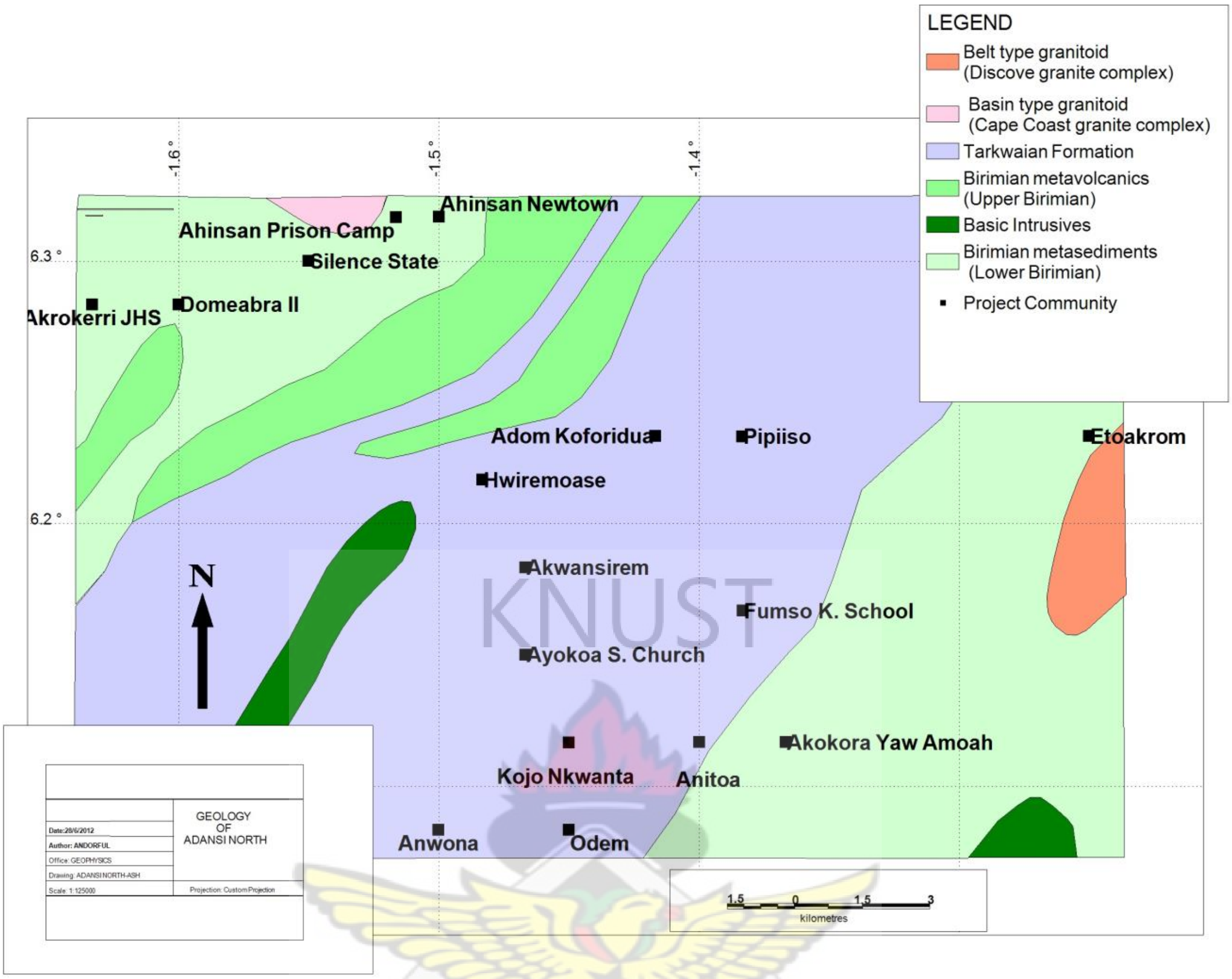

Fig.2.4 Geological Map of Adansi North District in AshantiRegion, Ghana (Ghana Geological Survey, 2009)

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2.6 Background of the Project area

Adansi North District is located between longitudes 1.25^{o}-1.65^{o}W and latitudes 6.10^{o}-6.35^{o} N (Fig.2.4). It covers an approximate area of 1140 km^2 representing about 4.7% of the total area of Ashanti Region. The district is bounded to the northwest by Amansie Central District, to the south by Obuasi Municipality, to the east by Adansi South District, to the northeast by Amansie

East District (Fig.2.2). It has its capital at Fomena, situated on the Kumasi- Cape Coast main road.

The north-western third of the district has an undulating terrain, averaging about 300 m above sea level. The rest of the district consists of ranges, generally trending southwest/northeast. These include the Anyabriem-Old Akrofuom-Kusa-Agogoso, Obuasi-Asokwa-Brofoyedru-Bodwesango, that from west of Sikaman through Hwiremoase to Agyenkwaso, and Kojo Nkwanta through Kwaapaakrom to Aboabo 1 and 2 and beyond. In-between these hilly areas are valleys, most of which contain streams (Fig.2.3).

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The district is well-drained: major streams in the district include the Bemin, Fum, Gyimi, Kyeabo, Ankafo, Adiembra, Asabri, Subbing, Konwia, Kyekye and Atraime. Most of the streams are perennial.The district experiences semi-equatorial climatic conditions. Temperatures are generally high throughout the year with mean monthly temperatures between 26 and 30^{o}C. The mean annual temperature is 27^{o}C with February and March being the hottest periods in the year.Double maxima rainfall regime is experienced in the district with annual total rainfall between 1,250 and 1,750 mm. The major rains occur between April and July whilst the minor one is between September and December. Relative humidity is about 80 % in rainy season and falls as low as 20 % in the dry season.

As a result of the varying climatic conditions experienced in the district, the vegetation is a semi-deciduous forest made up of three layers, namely: the under growth, the middle layer and the upper layer. The natural environment of the district originally was hilly and this was accompanied with rain forest vegetation. However, about 80 % of the rainforest vegetation in the district have been destroyed due to some adverse human activities such as slash and burn, bush fallowing, etc. The vegetation has, as a result of these, changed from its original forest vegetation to secondary forest vegetation (Community Waterand Sanitation Project, 2009).

2.7 Geology of the Project Area

Adansi North District is underlain mainly by metamorphic rocks of the Tarkwaian and Birimian System. The Birimian metavolcanics are made up of lavas, pyroclastic rocks and phyllite. The Birimian metasediments consist of phyllite, tuff, schist and greywacke which occupy the north-western and eastern parts of the district. The Birimian rocks are intensely folded, often sheared and fractured. Quartz veining is common in the Birimian schist and phyllite. Project communities in the north-western are Ahinsan Newton, Ahinsan Prison Camp, Akrokerri JHS, Domeabra II and Silence State whereas those in the eastern include Akokora Yaw Amoah and Etoakrom(Community Water and Sanitation Project, 2009).

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Tarkwaian rocks dominate the mid-part along the NE-SW direction and consist mainly of quartzite, phyllite, grits, conglomerates and schist. Project communities within this region are Adom Koforidua, Hwiremoase, Akwansirem, Ayokoa Saviour Church, Fumso Ketewa School, Kojo Nkwanta, Odem, Anitoa, Anwona and Pipiiso. Granite outcrops also occur in areas like Akrokerri, Dompoase, Patakro and Kwapia. Most parts of the district lie within the gold and sand belts; unfortunately no meaningful mining or exploration has been done(Community Water and Sanitation Project, 2009).

Two types of granitoids exist in this district;

- Belt type granitoids (Dixcove granite complex): The Dixcove Granitoids Complex consists of hornblende granite, granite and granidiorite grading locally into quartz-diorite and hornblende- diorite. This zone is situated close to Etoakrom.
- Basin type granitoids (Cape Coast granite complex): These are often well foliated, magmatic and potassium- rich. This area is located close to Ahinsan Prison Camp and Ahinsan Newton (Community Water and Sanitation Project, 2009).

Basic Intrusives: There is a strip of basic intrusives within the Tarkwaian Formation and a small portion south east within the Birimian. They are igneous rocks of basically comprising, made of gabbro, dolerite, epidiorite, niorite, serpentine(Ghana Geological Survey (2005).

The potential for contamination from point sources including refuse dumps, latrines and unprotected water points is therefore very high. The rocks in the basement complex have little or no primary porosity. Groundwater occurrence is associated with the development of secondary porosity as a result of jointing, shearing, fracturing and weathering. This has given rise to two main types of aquifers; the weathered zone aquifer and the fractured zone aquifers. The weathered zone aquifers usually occur at the base of the thick weathered layer. The fractured zone aquifers normally occur at some depth beneath the weathered zone. Both types of aquifer are normally discontinuous and limited. Due to the sandy clay nature of the weathered overburden, the groundwater occurs mostly under semi-confined or leaky conditions (Kortatsi, 1994).

Data on existing boreholes in the district indicate that the boreholes tap their water from weathered and fractured quartzite, phyllite, schist and granites. Weathering in the phyllite is deeper than in the granites. Borehole yields range between 17 and 150 lpm. Average borehole depth is about 48 m and average static water level is about 8 m (Community Water and Sanitation Project, 2009).

2.8 Socio-Economic Activities

The district's population stands at 120,000 people as of the year 2010 with growth rate of 2.6 % per annum. The population density is 105 persons per square km and male-female ratio is 48.6 to 51.4 %. About 48 % of the population is in the active labour force (15 – 60 years).It has 29 Basic Schools, 4 Senior High Schools and 2 Tertiary Institutions. The area is predominately agrarian with about 77 % being farmers who are mostly subsistence crop farmers and livestock keepers (Adansi North District Assembly, 2010).

Services such as buying and selling, tourism, banking, communication, dressmaking, hairdressing and operation of private schools also employ about 15 %.The remaining 8 % are engaged in manufacturing activities which include extraction of palm oil and palm kernel, processing of cassava into gari, production of T&G, mining and quarrying (Adansi North District Assembly, 2010).

ELECTRICAL RESISTIVITY

2.9 Geophysics

Geophysics is the science, which deals with investigation of the Earth using the principles of Physics. The physical properties of the Earth (rocks, air and water masses) such as density, elasticity, magnetic susceptibility and electrical conductivity all allow inference about those materials to be made from measurements of the corresponding physical fields such as gravity, seismic waves, magnetic fields and electrical fields etc.

Geophysics is an interdisciplinary physical science that incorporates Physics, Mathematics, Geology and to some extent Chemistry.

Geophysics can be divided into two main branches:

- Global Geophysics: This studies large-scale problems relating to the earth's structure and dynamic behaviour (Coruh, 1988).
- Exploration Geophysics: Application of geophysical techniques to explore minerals (Sharma, 1986).

2.10 Geoelectric Survey

The ability of the Earth to produce and respond to electric field supports a variety of geophysical exploration techniques. This concept was initially successfully used in the exploration of ores as the method to detect ore concentrations that possessed natural electrical polarization (Coruh, 1988).

The electrical methods include the following:

- Induced potential (IP) method, which uses electrodes with time-varying currents and voltages to map the variation of electrical permittivity (dielectric constant) in the Earth at low frequencies.
- Self potential (SP) method, which measures naturally occurring electrical potentials which are usually caused by charge separation in clay or other minerals, due to presence of semi-permeable interface impeding the diffusion of ions through the pore space of rocks, or by natural flow of a conducting fluid through the rocks.
- Electrical resistivity surveying where electrical signal is injected into the ground and the resulting potential (how the earth responds to the signal) is measured (Loke, 2011).
- Electromagnetic methods, which are based on the measurement of EM fields associated with alternating currents induced in the subsurface by a primary field. In most of the EM methods, the primary or inducing field is produced by passing an alternating current through a coil or along a long wire placed over the ground. The primary field spreads out in space above and below the ground and induces currents in subsurface conductors, in accordance with the laws of EM induction. These give rise to secondary EM fields which distort the primary field (Sharma, 1986).

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2.11 Resistivity and Conductivity

Metals and most metallic sulphides conduct electricity efficiently by flow of electrons, as a resultelectrical methods are important in environmental investigations, where metallic objects are often the targets, and in the search for sulphides ores. Graphite is also a good ‘electronic’ conductor and since it is not itself a useful mineral, it is a source of noise in mineral exploration. Most rock-forming minerals are very poor conductors and ground currents are therefore carried mainly by ions in the pore waters. Pure water is ionized to only a very small extent and the electrical conductivity of pore waters depends on the presence of dissolved salts, mainly sodium chloride. Clay minerals are ionically active and clays conduct well if even slightly moist (Milsom, 2003).

The electrical resistivity method is the geophysical technique in which artificially generated currents are injected into the ground and the resulting apparent resistivity due to the subsurface formations are measured. One advantage of this method is that it can be used to probe deeper structures. The various electrical methods of exploration all test the flow of electric current in the ground. An electric charge particle, which flows through the ground, can take three forms namely electronic, electrolytic and dielectric conductions (Telford et al., 1994).

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2.12 Conductivity of Rocks and Minerals

Electrical conduction in most rocks is electrolytic. This is because most of the mineral grains, with the exception of clay minerals are insulators and electrical conduction is through the interstitial pore fluids as well as fissures (Telford et al., 1994).

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2.13 Factors affecting terrain resistivity/conductivity

Most rocks and minerals are electrical insulators of very high resistivity. Occasionally, conductive minerals such as magnetite, disseminated hematite, granite, pyrite, pyrhotite, when they occur in rocks in significant amount increase the conductivity and decrease the resistivity of the rocks (McNeil, 1980).

In general conductivity or resistivity of rocks depends on the following:

- Porosity, shape and size of pores, number and shape of interconnecting passages,

- The extent to which pores are filled with water (saturation) that is moisture content,
- Concentration of the dissolved electrolytes in the pores moisture,
- Temperature and phase state of the pore water,
- Amount and composition of colloids.

In sedimentary formations the resistivity of pore fluids, ρ_w and the resistivity of the formations ρ and the ratio ρ/ρ_w , is called the formation factor, F.This tends to be constant for a particular formation (Telford et al., 1994).The figure below represents the resistivities and conductivities of some common rocks, minerals and chemicals as a guide for interpretation.

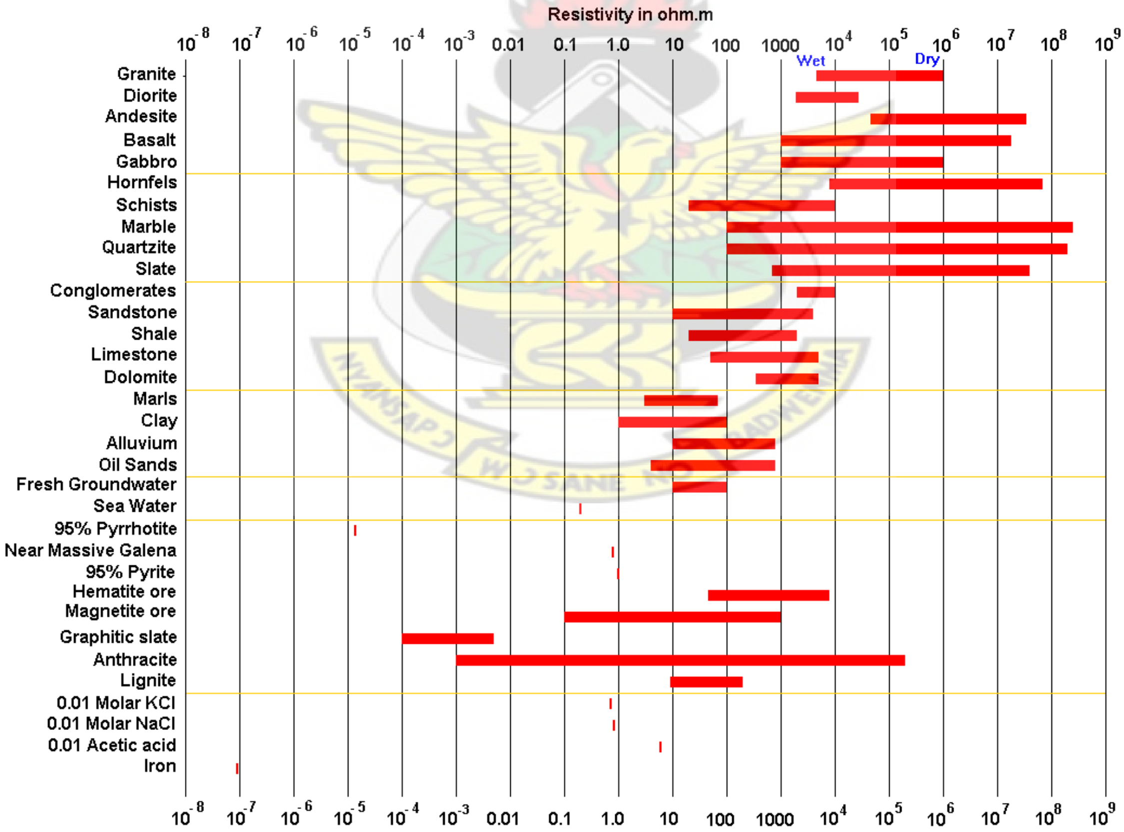

Fig.2.5: Resistivity of rocks, soils and minerals (Loke, 2011).

2.14 Archie's law

Archie in 1942 gave an empirical relation for the relationship between primary porosity and bulk resistivity of water saturated rocks as: $\rho = \rho_w \phi^{-m} s^{-n}$

Where ϕ is the porosity, ρ_w is the resistivity of the water contained in the pores. The parameter m is sometimes called cementation factor, which depends on degree of cementation of the formation in question. It varies from about 1.30 for loose sediments to about 1.95 for well sedimented formations. S is the fraction of the pore space filled by water and n is a parameter. The value of n is about 2.0. If n ≥ 30 % pore space is water filled but can be greater or lesser water content (Telford et al., 1994).

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2.15Ohm's law

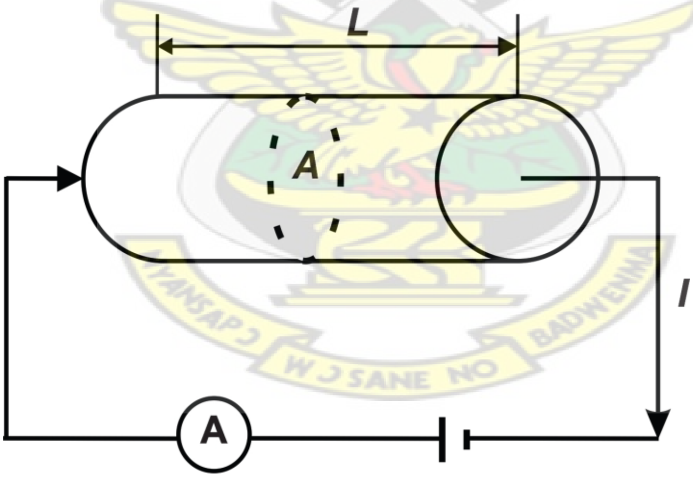

Fig.2.6: A simple circuit diagram demonstrating Ohm's law

Electrical resistivity surveying is fundamentally based on Ohm's law: $V = IR$.

The constant of proportionality, R, is the resistance of the conductor. For a given conductor the resistance is proportional to the length, L and inversely proportional to the cross-sectional area, A of the conductor (Fig.3.1): $R = \frac{\rho L}{A}$, the constant of proportionality is the resistivity, which is a physical property that expresses the ability of the material to oppose the flow of currents.

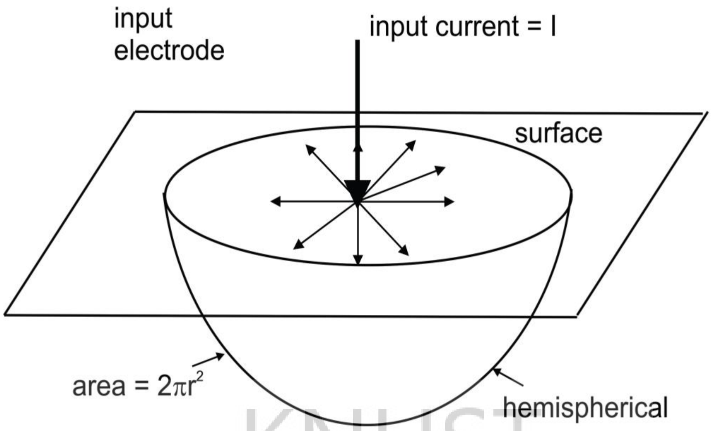

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Fig.2.7: Sketch of potential distribution caused by a point current source

As shown in Fig.3.2 potential, V at a distance, r from a single point current source, I of a homogeneous subsurface is related to the resistivity, ρ by the equation: $V = \frac{\rho I}{2\pi r}$ (Loke, 2000).

For a complete circuit, 2 current electrodes are needed one as a source and another as a sink(Fig.3.3). Potential difference at a point would be $V = \frac{\rho I}{2\pi}(\frac{1}{r_1} - \frac{1}{r_2})$.

On the field it is the potential difference between two points that is measured. Due to contact resistance, it is not advisable to use the same pair of electrodes as current and potential simultaneously. High-impedance voltmeters are used to measure the voltage across the potential pair of electrodes in order to avoid contact resistances.

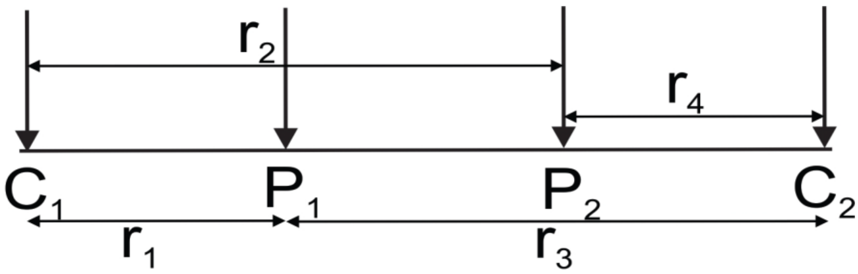

Fig.2.8: Sketch of a typical four electrode arrangement for measurement

The potential difference between two points for a four electrode arrangement could be expressed as: $\Delta V = \frac{\rho I}{2\pi}(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4})$. Apparent resistivity could be written as: $\rho_a = \frac{k\Delta V}{I}$ and $k = 2\pi(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4})$ where k is the geometric factor and it depends on how the potential and current electrodes are arranged.

2.16 Types of arrays

There are different electrode arrangement used for measurement namely Wenner, Schlumberger, Gradient, Pole-Dipole, Pole-Pole, Dipole-Dipole.

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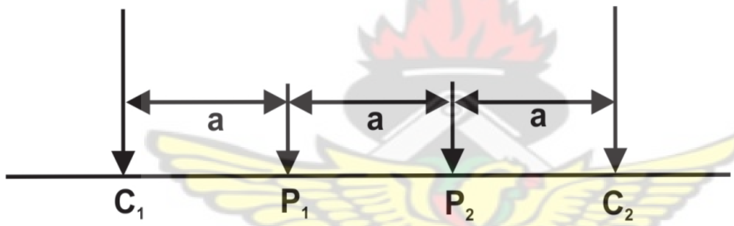
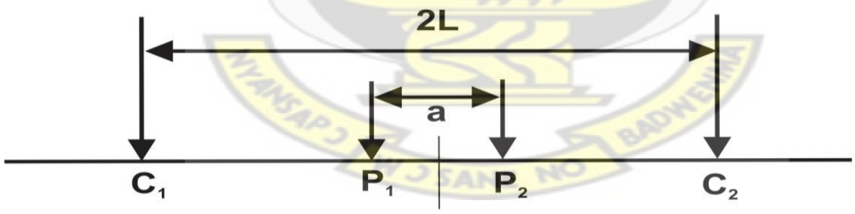
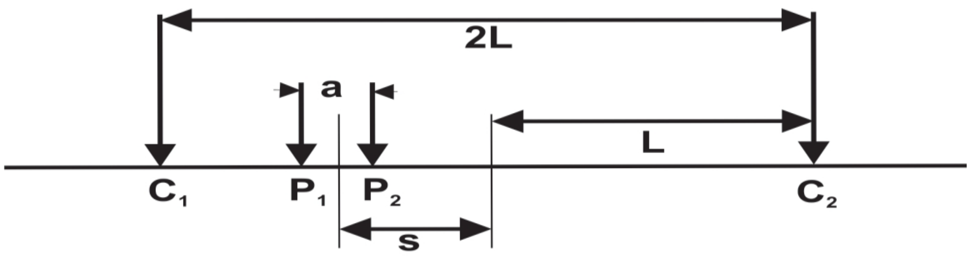


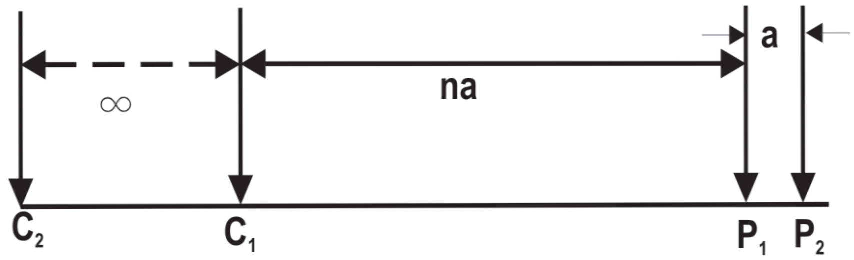
(a)Wenner array



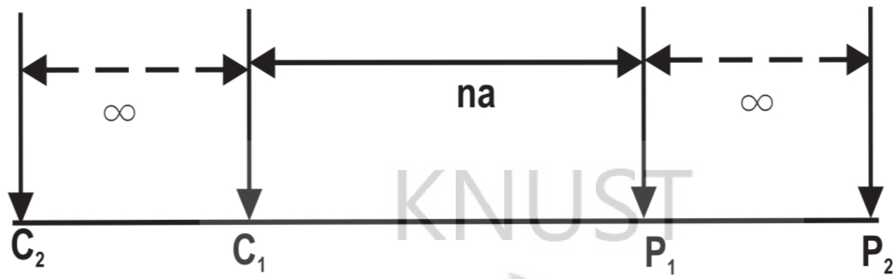
(b)Schlumberger (symmetrical) array



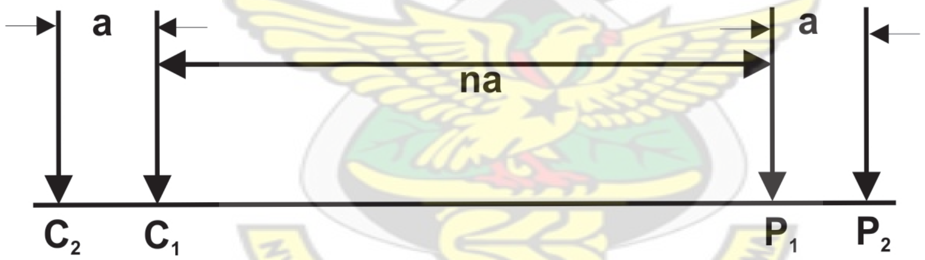
(c) Gradient (asymmetrical Schlumberger) array



(d) Pole-Dipole array



(e) Pole-Pole array



(f)Dipole-Dipole array

Fig.2.9: Types of electrode arrays used for resistivity surveys (Loke, 2011).

2.17 Dipole-Dipole array

This array has been, and is still, widely used in resistivity and I.P. surveys because of the low electromagnetic coupling between the current and potential circuits. The arrangement of the electrodes is shown in figure 2.9f. The chainage (spacing) between the current electrode pair,

C_2-C_1, is given as "a" which is the same as the distance between the potential electrodes pair P_1-P_2. This array has "n" and "na" as the dipole separation factor and dipole separation respectively as shown in figure 3.4f. The dipole separation factor is the ratio of the distance between the C_1 and P_1 electrodes to the C_2-C_1 (or P_1-P_2) called the dipole separation "a". For surveys with this array, the "a" chainage is initially kept fixed and the "n" factor is increased from 1 to 2 to 3 until up to about 6 in order to increase the depth of investigation. The dipole-dipole array is very sensitive to horizontal changes in resistivity, but relatively insensitive to vertical changes in the resistivity. That means that it is good in mapping vertical structures, such as dikes and cavities, but relatively poor in mapping horizontal structures such as sills or sedimentary layers (Loke, 2000).

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2.18Profiling and Sounding

Resistivity profiling is used to detect lateral changes in subsurface resistivity (Milsom, 2003). Surveys of lateral variations in resistivity can be useful for the investigation of any geological features that can be expected to offer resistivity contrasts with their surroundings. Deposits of gravel particularly if unsaturated have high resistivity and have been successfully prospected for by resistivity methods. Steeply dipping faults may be located by resistivity traverses crossing the suspected fault line, if there is sufficient resistivity contrast between the rocks on the two sides of the fault. Solution cavities or joint openings may be detected as a high resistivity anomaly, if they are open or low resistivity anomaly if they are filled with soilor water (US Army Corps of Engineers, 1995).

Vertical electrical soundings are applied to a horizontally or approximately horizontally layered earth. Geological targets may be, e.g., sedimentary rocks of different lithology, layered aquifers of different properties, sedimentary rocks overlying igneous rocks, or the weathering zone of igneous rocks. In the most favourable case, the number of layers, their thicknesses and correspondingresistivities are the outcome of a sounding survey. The basic idea of resolving the vertical resistivity layering is to stepwise increase the current-injecting electrodes *a* spacing, which leads to an increasing penetration of the current lines and in this way to an increasing influence of the deep-seated layers on the apparent resistivity, ρ_a (Kirsch, 2006).

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CHAPTER THREE

METHODOLOGY AND FIELD PROCEDURE

The general scope of work carried out in all the beneficiary communities can be summarized as follows:

- Reconnaissance survey/terrain evaluation
- Geophysical survey
- Processing of the results

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3.1Reconnaissance survey/terrain evaluation

To enhance the project a careful survey of the study area was undertaken. The topography,geology,water resources available such as rivers, existing boreholes and hand dug wells were well ascertained.

The community participated in this exercise to identify potential groundwater pollutions sources such as cemeteries, public toilets, existing and abandoned refuse dump sites etc.

Structural features such as rock outcrops, vegetation, stream patterns and anthills were examined as they gave clues and help in the planning of the survey. Fractured outcrops might serve as recharge for aquifers and underneath anthills are good groundwater deposition points because the soil tends to be more porous. Also areas of thick weathered regolith are well noted as they serve as groundwater conduit.

Other valued information was tapped from local residents such as areas earmarked for future developments, sacred places etc. because interference with these sites could cause inconvenience. Areas which fell within the chosen traverse lines were cleared to make it accessible.

3.2 Geophysical Survey

The following were done to make this scientific process accurate:

- The batteries in McOHM-EL2 were tested to see if they had the desired voltage.
- The Global Positioning System (GPS) coordinates of each traverse line was taken at the beginning and the end using a GPS meter. GPS coordinates of project communities were recorded (see appendix 2).
- Wooden pegs were used to mark points for Sounding.

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Geophysical survey was done in two phases, namely:

1) Profiling

2) Sounding

Profiling

Profilingwhich is the lateral variation in resistivity was conducted in the communities along traverses, pre-determined during reconnaissance survey.The dipole-dipole array was used for the profiling. Measuring tape was usedto measure the total length of each profile and the measuring points. The spacing *a*between the current electrode pair, C_2-C_1 and the potential electrode pair P_1-$P_2$was 10 m. The "n" factor which was the ratio of the distance between the C_1 and P_1 electrodes to the C_2-C_1 (or P_1-P_2) was 7, which connote a spacing of 70 m. The depth of penetration was 40 m. The separation between measuring points was 20 m.Low resistive points were selected for sounding.

Sounding

Sounding is the vertical changes in resistivity, and it was carried out at stations with anomalies selected from the profiling. The dipole-dipole array was used for the vertical electrical sounding. The separation *a* between the current electrode pair C_2-$C_1$and the potential electrode pair P_1-P_2 was 4 m for the first sounding point; $C_1P_1$was 12 m (n = 3)and this probed to a depth of ≈ 8 m. To probe further to a depth of 12 and 16 m,*a* was unchanged and the value of *n* was increased to 5 and 7 respectively.

For penetration to greater depths, spacing*a*wasincreased to 10 m whiles C_1P_1spanneda distance of 30 m (n = 3), this made it possible to investigate to a depth of about 20 m. Distance *a* was fixed and the value of *n* was increased from 3 to 8 in order to probe to a depth of 45 m.

Exploration to depths 50, 60 and 70 mwas feasible because chainage*a*wasaugmented to 20 m and*n* increased from 4, 5and 6 correspondingly. Substrata conditions such as the depth of the weathered or fractured zone were vital to the depth of investigation.

3.3Processing of the results

Profiling results

Data recorded on the resistivity meter was recorded on forms designed for this purpose.Data from the profiling were keyed onto the Grapher spreadsheet. On the program the graph option was clicked. The graph wizard appeared on the screen and the plot type which is line is selected to open the graph for on-screen viewing. The tick marks and labels were modified to make it more presentable. The line width was increased to make it more eligible and the axes title added to complete the process.Golden Software Grapher8 was used to process the data and low resistive points were labeled.

Sounding results

Measured formation resistivity values were laterinverted using 1X1Dv3 Interpex program. This program models the data into layers usually the overburden on top, followed by weathered/ highly-fractured rock, then slightly-fractured rock and subsequently the hard bedrock.

The 1X1D icon was clicked and the cursor was placed on File, New, Sounding and DC Resistivity Soundings in sequential order. The DC Resistivity was clicked and New Sounding Parameters window appeared on screen, Dipole-Dipole Array and Apparent Resistivity Only under Array Type and Type of Data were selected respectively.Data was entered into Apparent Resistivity Entry/Edit window which had two columns namely “n” for depth (m) and Apparent Resistivity (ohm.m). Apparent Resistivity (ordinate) against n-spacing (abscissa) represents data plot and logged depth against Resistivityfor the model were shown separately on screen. View properties were used to modify the line width of plot and axes range to make it more eligible.

Single and Multiple Iteration buttons reduced the root mean square (RMS) error value of the model so that it would fit on the data plot when displayed. The model on data plots were stored on the computer and used for analysis in this work.

Low resistive layers represented anomalies, which could be weathered/fractured zone with mineralization or groundwater. Clay also has relatively lower resistivities than other formations hence these clayey zones may result in unsuccessful test holes or may yield marginal groundwater.

The drilling points in each community were ranked based on the depth of the low resistive layer and this analysis was affirmed by the drilling results.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Criteria for selecting drilling points

Geoelectric methods for groundwater prospecting depend on the correlation of subsurface electrical properties. Resistivity profiling was conducted and selected points within low resistive zones were selected for vertical electrical sounding. It is important to note that low resistive zones may not all be potential groundwater areas. Depths with high resistivities may have hard consolidated material like granites, boulders or a dike–like structure, whereas low resistivities could be an indication of zones of fractured/ weathered rocks orclays.The lowest apparent resistivity points on the sounding models were selected and drilled.

4.2 ADOM KOFORIDUA

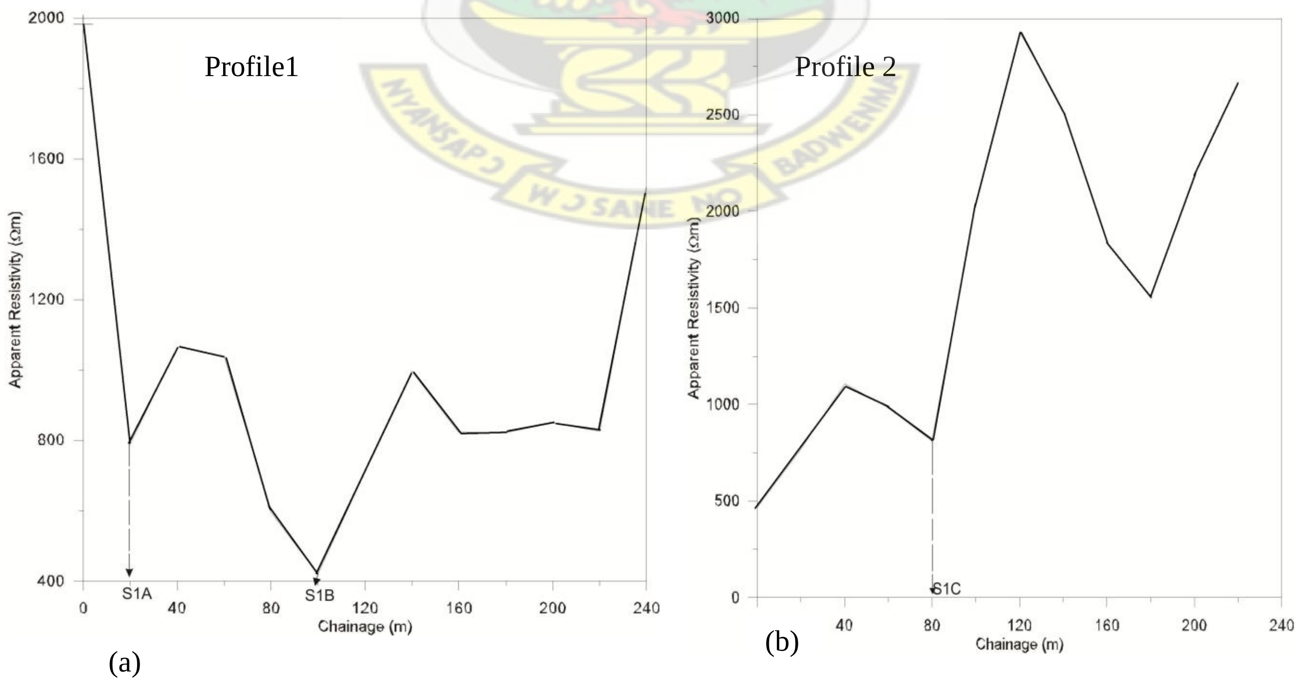

Fig.4.1 Resistivity Profiles 1 and 2 at 40m depth- Adom Koforidua

Resistivity Profiling:

The result for the figure 4.1a showed a decrease in resistivity from 2000Ωm at the beginning to about 800Ωm at 20m. The curve increased to 40m and then droppedto about 420Ωm at 100m. Subsequently, the resistivity value increased to the end of the profile.Two potential drilling points S1A and S1B at 20 and 100m were selected for sounding.

Figure 4.1b shows an increase in apparent resistivityof 500 Ωm from the start. The resistivity dropped slightly curve decreased slightly to 80 m with value of 812 Ωm, afterwards it rose suddenly to 2900 Ωm. It dropped to about 1600 Ωm at 180m and increased toabout 2650 Ωm at 220m. One low resistive point S1C at 80m was selected for sounding.

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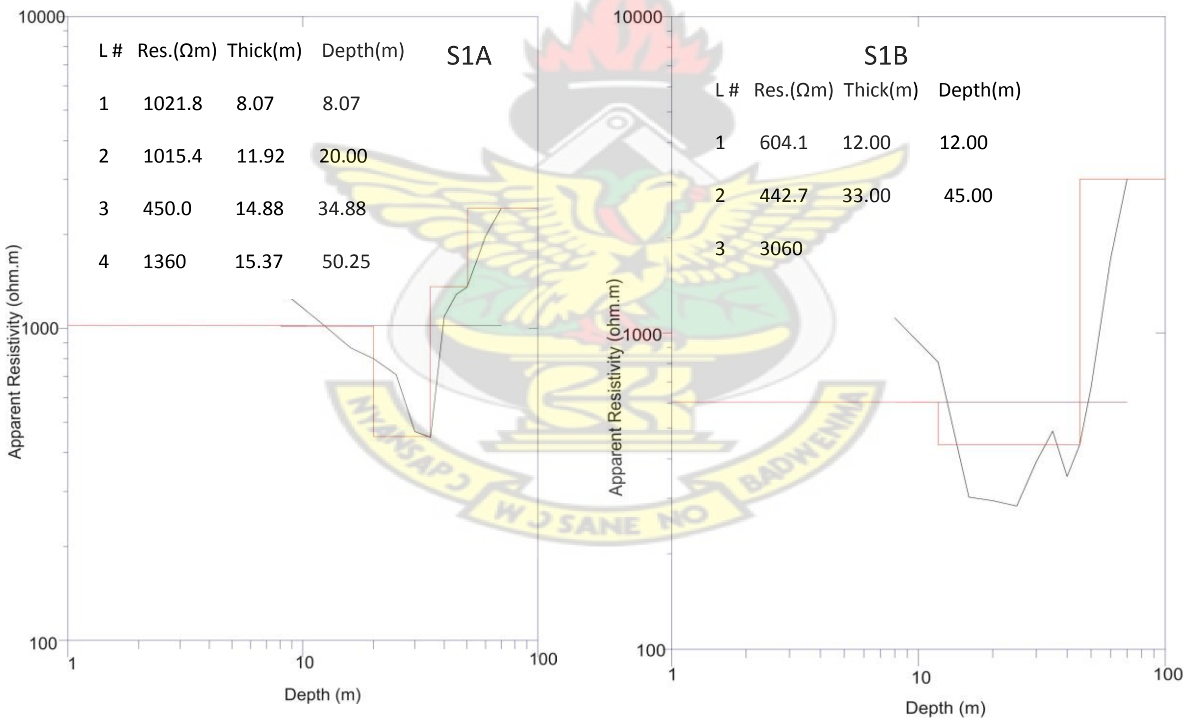

(a)

Fig.4.2 Vertical Electrical Soundings S1A and S1B- Adom Koforidua

Vertical Electrical Sounding:

Fig.4.2arevealed four layers withoverburden resistivityof 1022Ωm from the top to a depth of 8m; this was followed by bedrock with resistivity 1015Ωmfrom 8 to 20m.The third layercould be afractured or weathered zone witha value of 450Ωm between 20 and 35m. The fourthlayer could be fresh bedrock withresistivity valueof 1360Ωm which spanned from 35 to 50m followed byhard bedrock of resistivity2430Ωm from 50m downward. The proposed drilling depth was 35m.

Fig.4.2bconsist of three layers with a top layer of resistivity 604Ωm from the top to 12m, followed by thick fractured or weathered zone within the bedrock with resistivity value of448 Ωmfrom 12 to 45m and may yield some groundwater. Third layer wasbedrock of resistivity 3060 Ωm from 45m downward. The proposed drilling depth was 45m.

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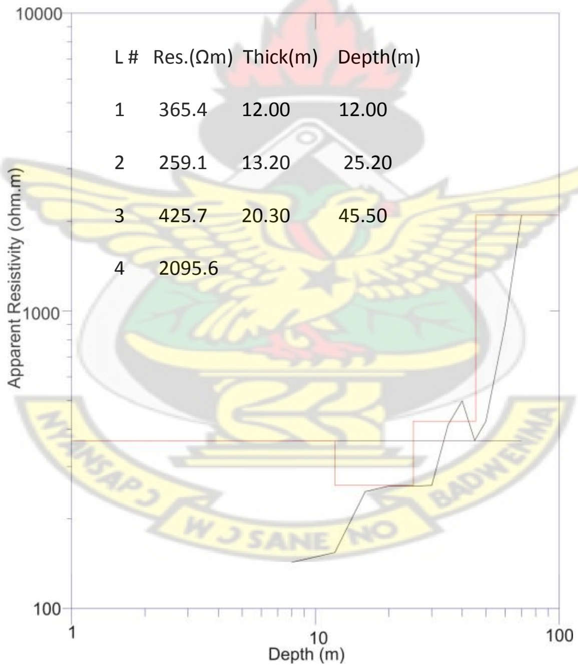


Fig.4.3 Vertical Electrical Sounding S1C- Adom Koforidua

Fig.4.3 shows a four layer system with top soil of resistivity 365 Ωm down to a depth of 12 m, this was followed by two adjacent fracture/weathered zones with resistivityvalues of259and426Ωm. The fourth layer was bedrock of resistivity 2096 Ωm from 46m downward.The point S1C was selected for drilling and the borehole depth was 40 m. The static water level (SWL) and yield were 4 m and 60 lpm respectively. The formation was granite.

4.3 AHINSAN NEWTOWN

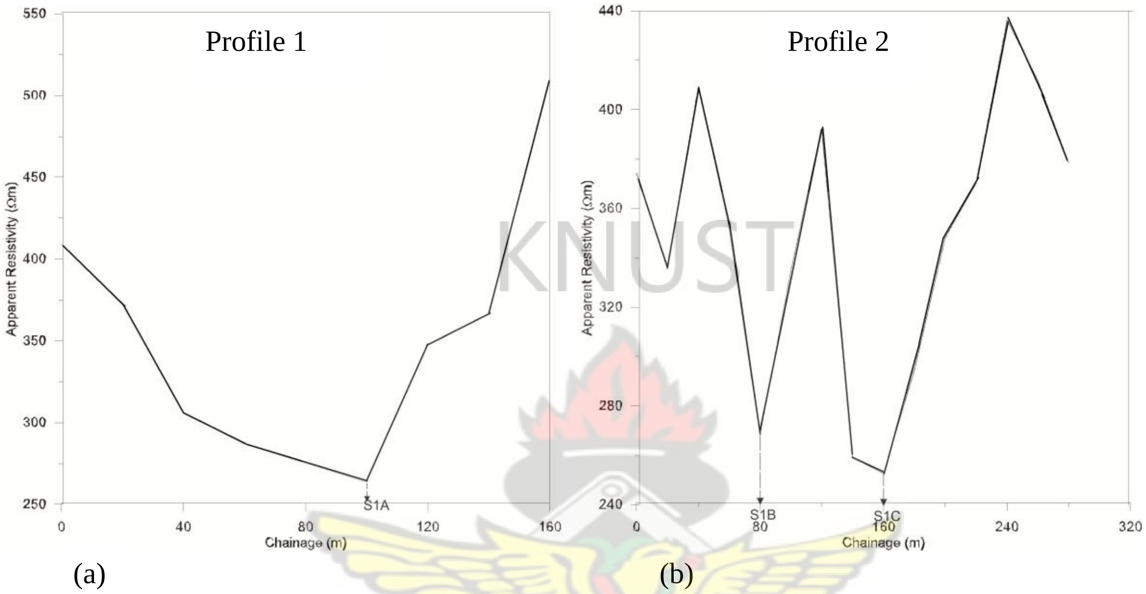


Fig.4.4 Resistivity Profiles 1 and 2 at 40m depth- Ahinsan Newtown

Resistivity Profiling:

Fig. 4.4a indicates adecrease in resistivity of 410 Ωm from the start to100m point with a value of 264Ωm. This low resistivity value could be weathered zone. There is an increasing resistivity trend between 100 m and the end of the profile at 160m.One low resistive point S1A at 100m was selected for sounding.

The result for Fig. 4.4b was erratic. Relatively higher resistivity values at 40, 120 and 240m could be due to intrusions which may be dikes,whereas the lower resistivity points at 80 and 160m with values 268 and 253 Ωm may bedue to weathering. Two suitable points S1B and S1C at 80 and 160mrespectively were selected for further investigation.

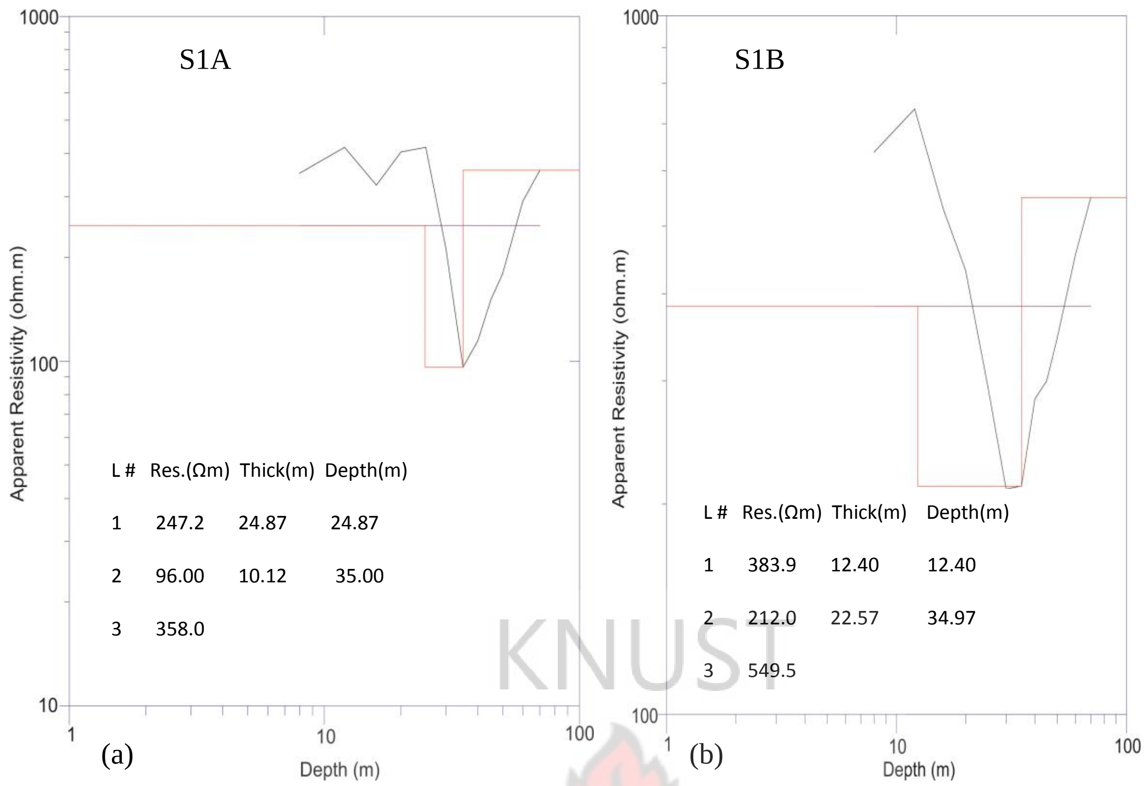
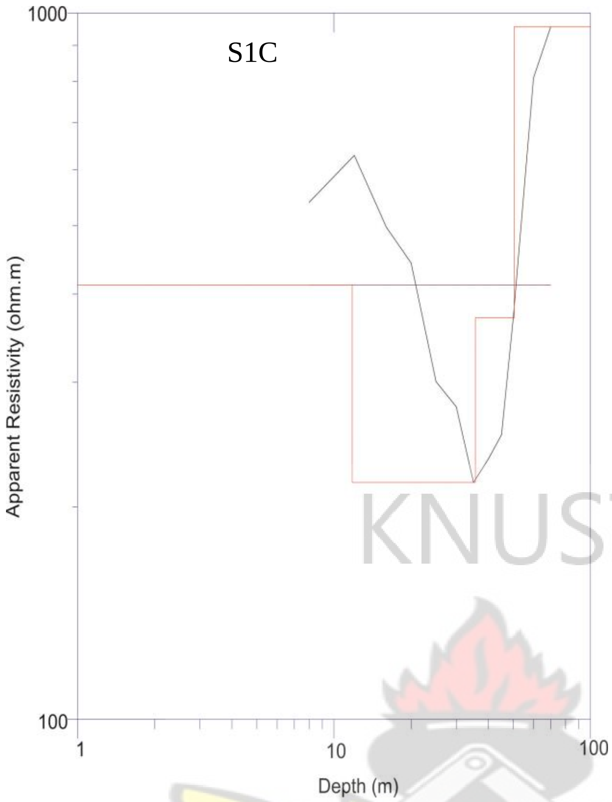


Fig.4.5 Vertical Electrical Soundings S1A and S1B- Ahinsan Newton

<u>Vertical Electrical Sounding:</u>

Fig.4.5aconsists of three layers with a thick upper layer of resistivity 247Ωm from the top to 24m. This was followed by a fractured or weathered zone of resistivity 96Ωm from 25 to 35m. The third layer could be hard bedrock of resistivity 358Ωm from 35m downward. The proposed drilling depth is 35m. Drilling was done at the S1A and borehole depth was 40 m. The static water level (SWL) and yield were 8 m and 40 lpm respectively. The formation was granite.

For Fig.4.5b the first layer recorded avalue of 384Ωm from the top to 12m; this was followed by a fractured or weathered zone with resistivity of 212Ωm from 12to 35 m. Third layer was bedrock of resistivity 550 Ωm from 35m downward. The proposed drilling depth is 35m.



L #	Res.(Ωm)	Thick(m)	Depth(m)
1	412.0	11.77	11.77
2	216.5	23.78	35.56
3	370.0	14.48	50.40
4	956.0		

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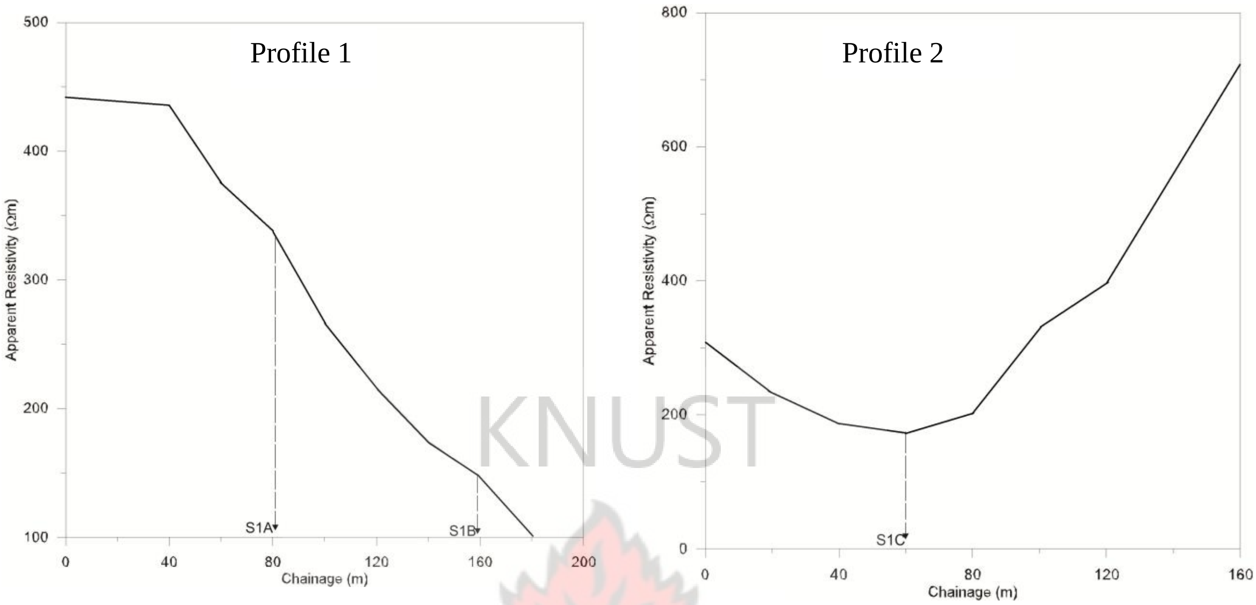
Fig.4.6 Vertical Electrical Sounding S1C- Ahinsan Newton

Fig.4.6 shows a four layer model with overburden resistivity value of 412Ωm down to a depth of 12m. This was followed by two adjacent zones with resistivities 217 and 370 Ωm and thickness of 24 and 14 m respectively. The low resistivities could be as a result of weathering and/or fracturing. The fourth layer was bedrock of resistivity 956Ωm from 50m downward. The aquifer zone could be located around 50m. The formation was likely to be granite.

4.4 AHINSAN PRISON CAMP



(a) (b)

Fig.4.7 Resistivity Profiles 1 and 2 at 40m depth- Ahinsan Prison Camp

<u>Resistivity Profiling:</u>

The curve for fig.4.7a revealed a decrease in resistivityalong the entire profile. The80 and 160 m points with values of 338Ωm and147Ωm were selected for sounding. The end of the profile had the lowest resistivity of 102 Ωm but was not selected because it was close to an existing borehole which may affect its yield.

The results for fig.4.7b revealed a decrease in subsurface resistivity from the beginning of the profile to 60m with a value of 171Ωm. This low resistivity could be a fractured/weatheredzone followed by an increase in resistivity to the end of the profile at 160m. One low resistive point S1C at 60m was selected for further probing.

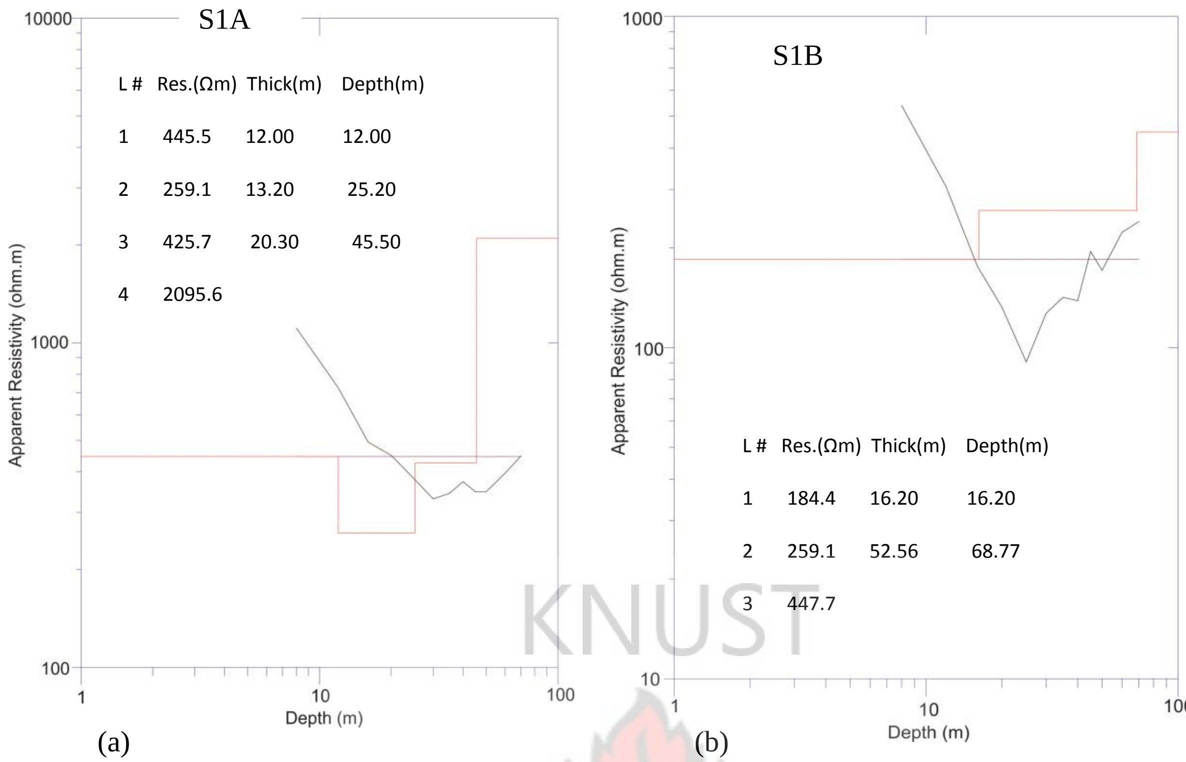


Fig.4.8 Vertical Electrical Soundings S1A and S1B- Ahinsan Prison Camp

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<u>Vertical Electrical Sounding:</u>

Fig.4.8a had four layers with top layer of resistivity 446Ωm down to a depth of 12m. The next two layers had resistivities of 259 and 426 Ωm and widths of 13 and 20 m respectively. The fourth layer was hard bedrock of resistivity 2096Ωm from 46m downward. The proposed drilling depth is 46m.

Fig.4.8bconsist of three layers with overburden resistivity value of 184Ωm from the top to 16m. This was followed by a thick weathered zone with resistivity of 259Ωm from 16 to 69 m. The meter read 448Ωm from 69m downward for the hard bedrock layer. The proposed drilling depth is 69m.

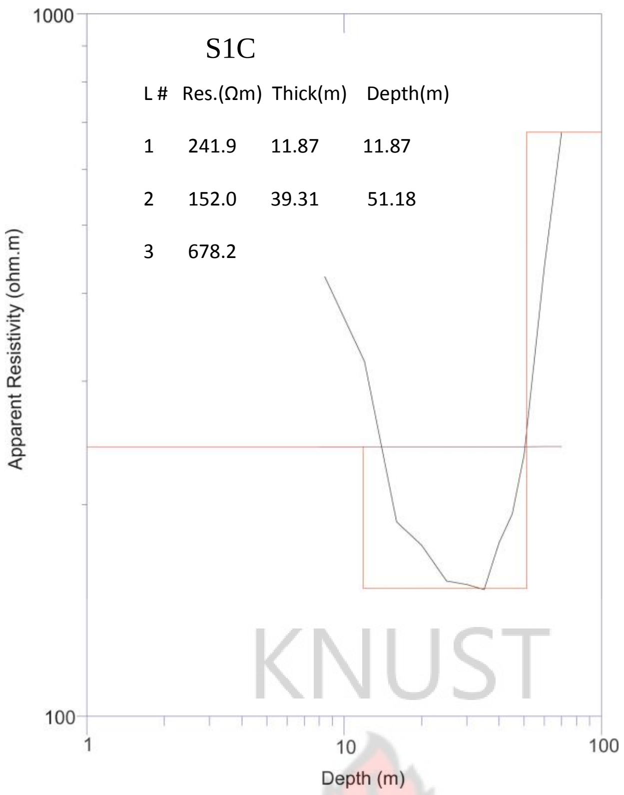
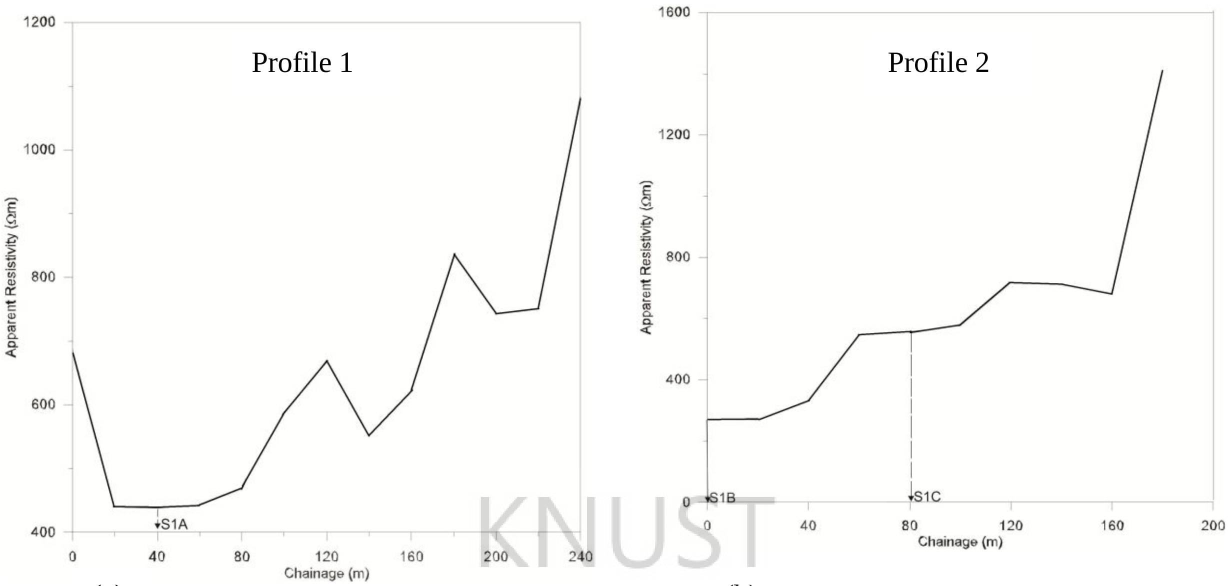


Fig.4.9 Vertical Electrical Sounding S1C- Ahinsan Prison Camp

Fig.4.9 showed three layer model with the first layerhavingresistivityvalue of 242Ωm to a depth of 12m. This was followed by a thick weathered zone with resistivity of 152 Ωm from 12 to 51 m. The third layer ishard bedrock of resistivity 678Ωm from 51m downward.Borehole depth is expected to be 60 m. The static water level (SWL) and yield were 5 m and 50 lpm respectively. The formation was phyllite.

4.5 AKOKORA YAW AMOAH



(a) (b)

Fig.4.10 Resistivity Profiles 1 and 2 at 40m depth- Akokora Yaw Amoah

<u>Resistivity Profiling:</u>

The results for the resistivity profile for fig.4.10a showed that there was a decreasefrom 690 Ωm at the beginning to439 Ωm at 40 m. This low resistivitycould be afractured zone followed by a somewhat sporadic behaviour. Low resistive point S1A at 40m was selected for sounding.

Fig.4.10b recorded an increasing trend from the start with value of 273Ωm to the 60m point with a value of 547Ωm,and dropped by few units at 80m.The resistivity trend continued to the end of the profile at 180m. The low resistivity could be a fractured or weathered zone, whilst the high value of 1411Ωm at 180m could be due to fresh bedrock. Two low resistive points S1Band S1C at zero and 80mwere picked for sounding.

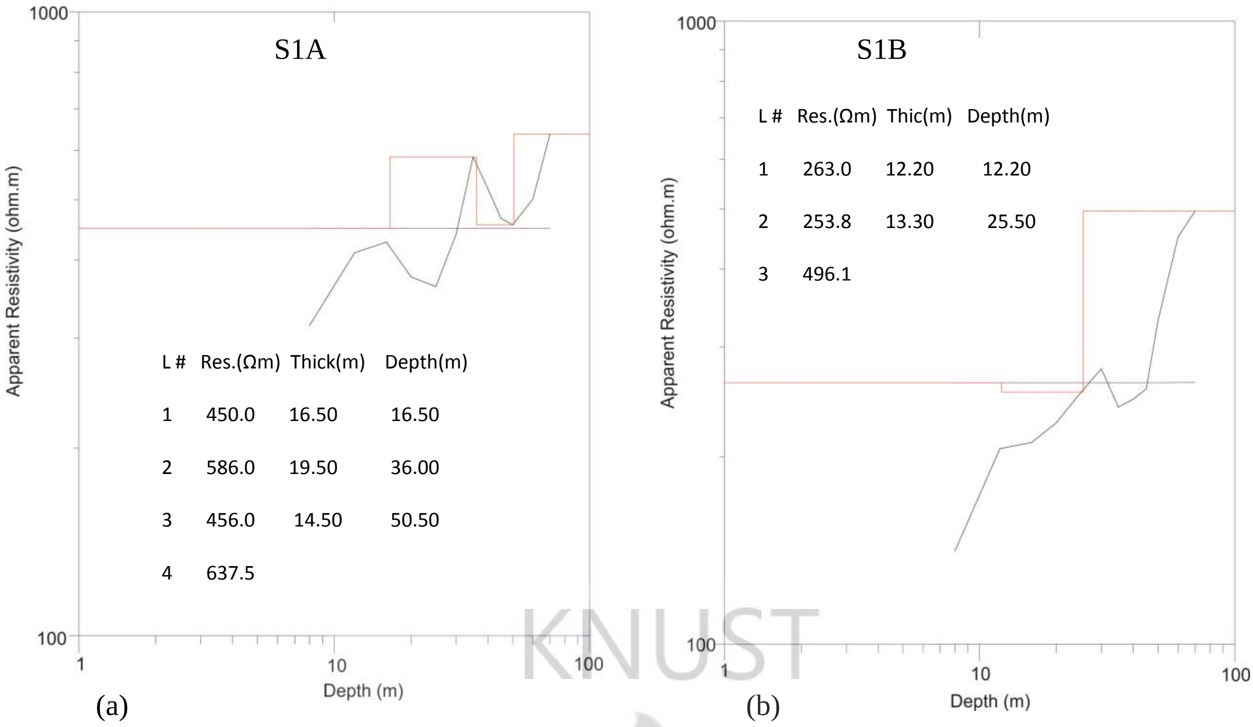


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Fig.4.11 Vertical Electrical Soundings S1A and S1B- Akokora Yaw Amoah

<u>Vertical Electrical Sounding:</u>

The first fig.4.11ashowed four zones with overburden of resistivity 450Ωm down to a depth of 17m.The second and third layers had resistivity values of 586Ωm from 17 to 36m and 456Ωm from 36 to 51m respectively. The fourth layer was hard bedrock of resistivity 638Ωm from 51m downward.Borehole depth at this point was 46 m. The static water level (SWL) and yield were 12 m and 17 lpm respectively.

The investigation revealed three layers forfig.4.11bwith overburden resistivity of 263Ωm from the top to 12m. This was followed by a fractured/weathered zone with resistivity of 254Ωm between the depth range of 12 - 26m. Third layer is bedrock of resistivity 496Ωm from 26m downward. The aquifer zone waslikely to be at 26 m.

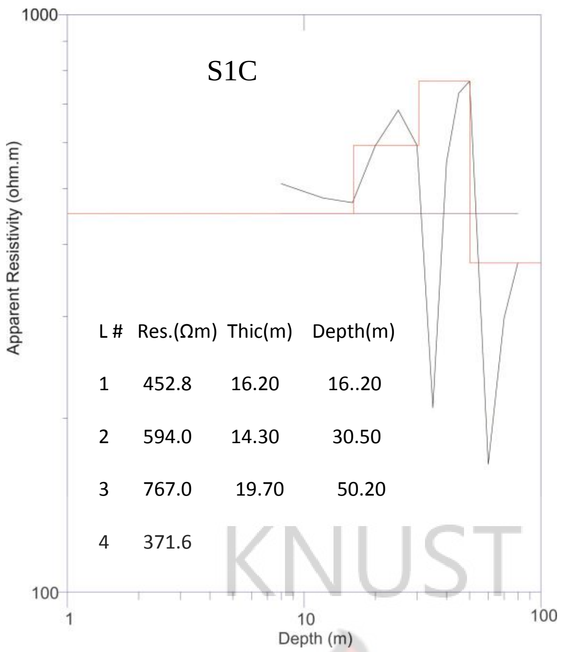
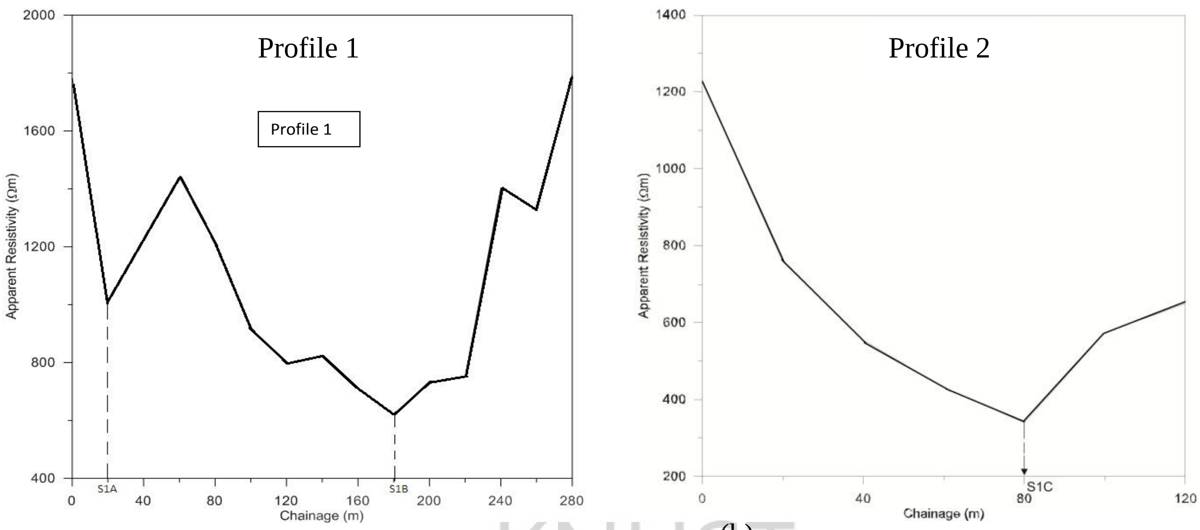


Fig.4.12 Vertical Electrical Sounding S1C- Akokora Yaw Amoah

VES results for S1Cshowed four layers and showedan erratic nature withoverburden resistivityof 453 Ωm down to a depth of 16 m. This was followed by two fracture sections at depths 31 and 50 m with resistivity values of594and 767Ωm respectively. The fourth layer has very low resistivity 372Ωm from 50m downward. This could be hard bedrock. The proposed drilling depth is 80m. The formation was phyllite.

4.6 AKROKERRI JHS



(a) (b)

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Fig.4.13 Resistivity Profiles 1 and 2 at 40m depth- Akrokerri JHS

<u>Resistivity Profiling:</u>

The results for fig.4.13a revealeda decrease in resistivity from the beginning of the traverse to the 20m point with a value of 1008Ωm. This was followed by an appreciable drop to 623 Ωm at 180m.The low resistivity could be a fracture zone. Higher resistivity values at the end of profile may be due to consolidation of the subsurface.Two low resistive points S1A at 20mand S1B at 180m wereselected for further probing.

The survey line 2 for fig.4.13b showed that there was a decrease in resistivity from zero to80 m, which recordeda value of 340Ωm. This low resistive point could be a fracture zone. The resistivity thenshowed an increasingtrend tothe end of the profile at 120 m. High readings at the beginning of the profile may be due to boulders. One low resistivity anomaly point S1C at 80 m was selected for sounding.

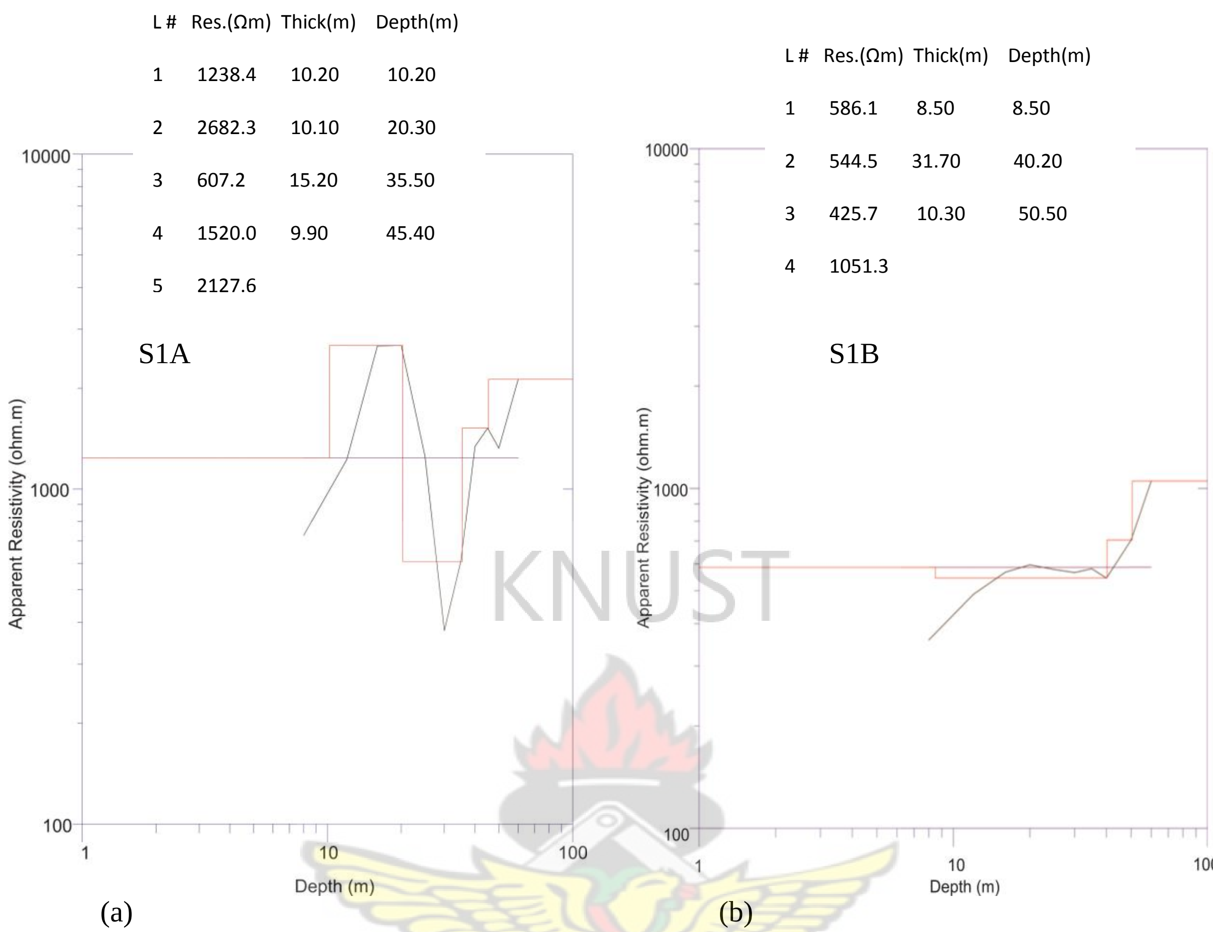


Fig.4.14 Vertical Electrical Soundings S1A and S1B- Akrokerri JHS

<u>Vertical Electrical Sounding:</u>

Fig.4.14a had five layers with the first having resistivity of 1238Ωm down to a depth of 10 m. This isfollowed by a more resistive rock formation with resistivity of 2682Ωm from 10 to 20m.The third layer could be a weathered zone within the bedrock whichmay be an aquifer and had resistivity of 607Ωm from 20 to 36 m. The fourth layer could be fresh bedrock with resistivity 1520Ωm from 36 to 45m followed by hard bedrock of resistivity 2128Ωm from 45m downward. Borehole could be drilledat 36m.

For fig.4.14b there were four layers with an upper layerresistivity of value 586 Ωm down to a depth of 9m, followed by a thick weathered zone with resistivity of 544 Ωm from 9to 40m. The third layer could be fresh bedrock with resistivity 705Ωm from 40to 51m followed by hard bedrock of resistivity 1051 Ωm from 51 m downward.Drilling was done at this point to a depth of 53 m. The static water level (SWL) and yield were 11 m and 20 lpm respectively. The rock penetrated was granite.

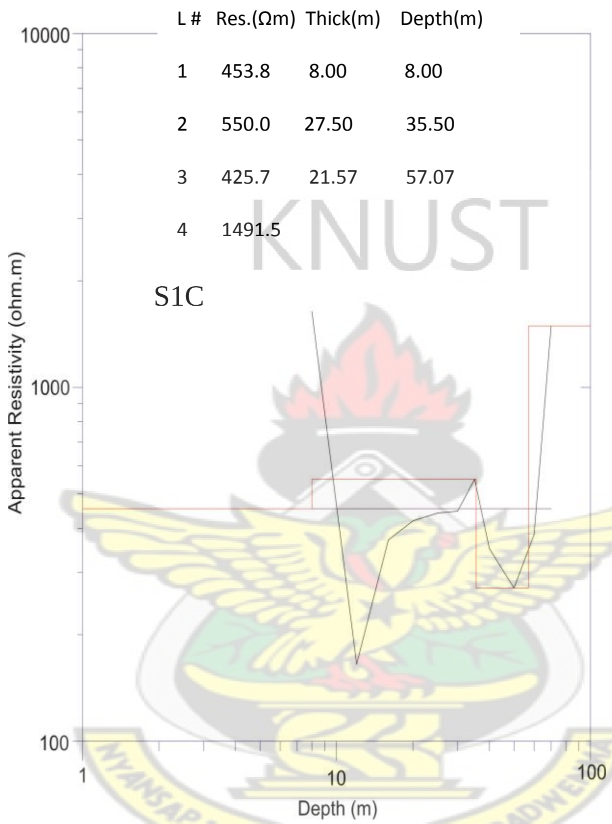


Fig.4.15 Vertical Electrical Sounding S1C- Akrokerri JHS

The survey results at point S1C showed four layers with overburden resistivity value of 454Ωm down to a depth of 8 m, this was followed by a resistive layer with value 550Ωm from 8 to 36m. The third layer could be fracturedbedrock with resistivity value of 271Ωm from 36 to 57m. The fourth layer could be hard bedrock of resistivity 1492Ωm from 57m downward. The expected drilling depth is 57m. The formation could possiblybe granite.

4.7 AKWANSIREM

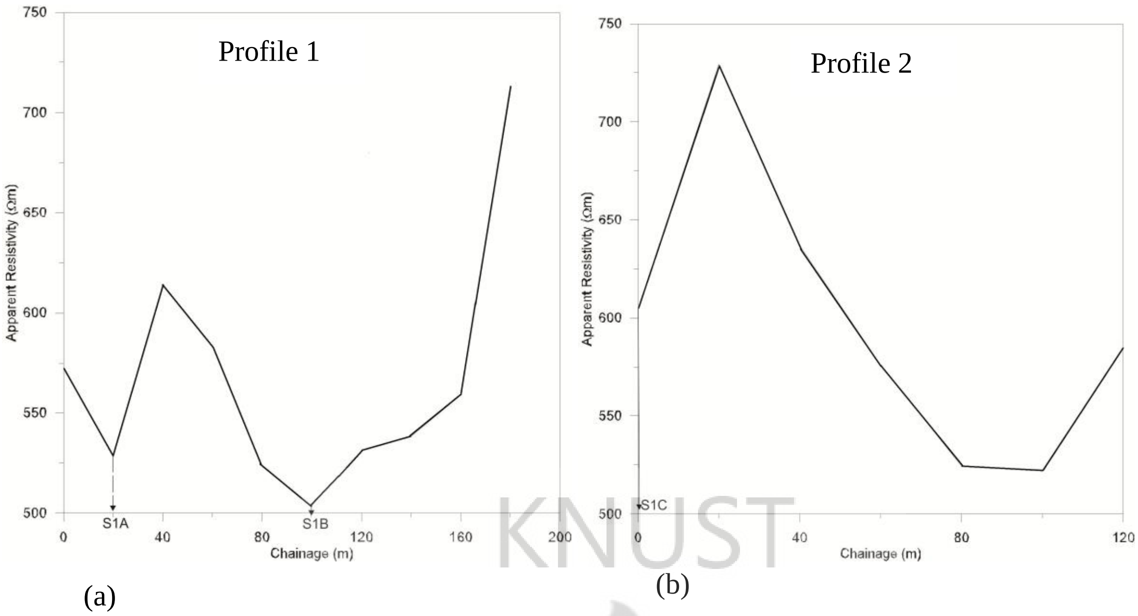
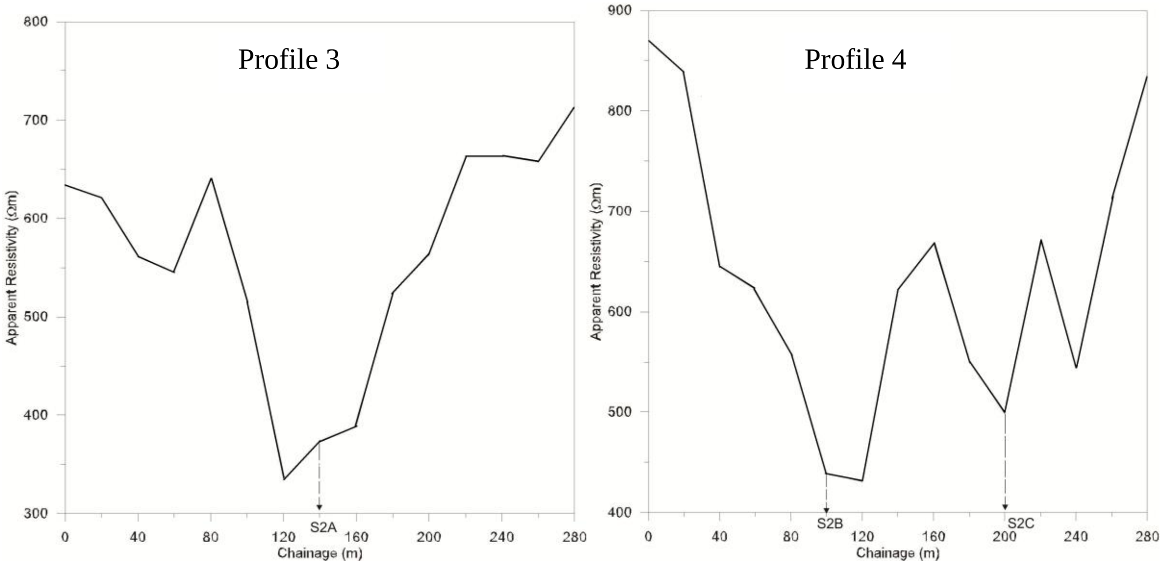


Fig.4.16 Resistivity Profiles 1 and 2at 40m depth- Akwansirem

<u>Resistivity Profiling:</u>

The outcome for fig.4.16a indicated that there was a decrease in resistivity from the beginning to 529Ωm at 20 m. It increased to 40m and then decreased through to 100m with resistivity of 503Ωm; the curve increased to the end at 180m. The low resistivity at 100 m could be fractured or weathered zone. S1Aand S1B at 20 and 100m were picked for sounding.

Fig.4.16b showed that there was an increase in resistivity from point zero with value 605Ωm to20m point, the curve decreased through to 100m point with value 523Ωm, then rose to the end of the profile at 120m,but this low resistive pointat 100 m was closeto a refuse dump. The low resistivity could be due to seepages from the refuse dump. One low resistivity anomaly point at zero was selected for further investigation.



(a) (b)

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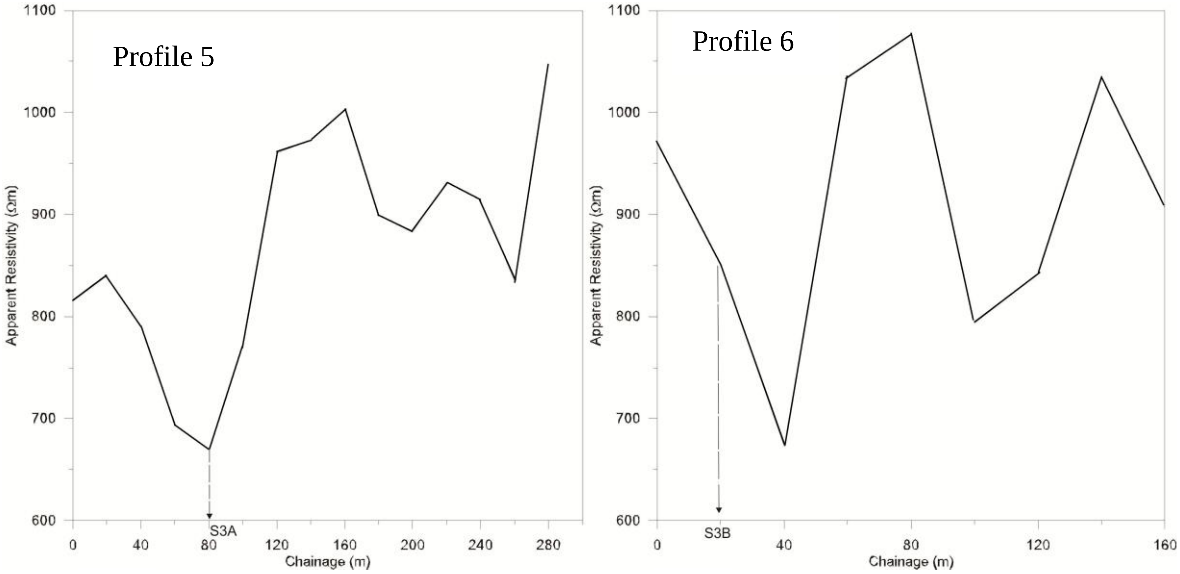
Fig.4.17 Resistivity Profiles 3 and 4 at 40m depth- Akwansirem

<u>Resistivity Profiling:</u>

Fig.4.17a indicated a decrease in resistivity from the start to 60 m, the curve increased slightly to 80m. There was asignificant decrement to 120 m after which it rose through to the end at 280m. The low resistive points at 60 and 120m were not selected because of their closeness to houses. These low resistivities could be due to weathering. One suitable point S2A at 140 m was marked for sounding.

The result for fig.4.17b revealed a decrease in resistivity from zero to120m;it became erratic to the 280m mark. The low resistive point at 120m was not selected because of its nearness to a cluster of houses. The low resistivity value could be due to weak fracture or weathering. Two points S2B and S2C at 100 and 200m with values 439and 498Ωm respectively were selected for sounding.



(a) (b)

Fig.4.18 Resistivity Profiles 5 and 6 at 40m depth- Akwansirem

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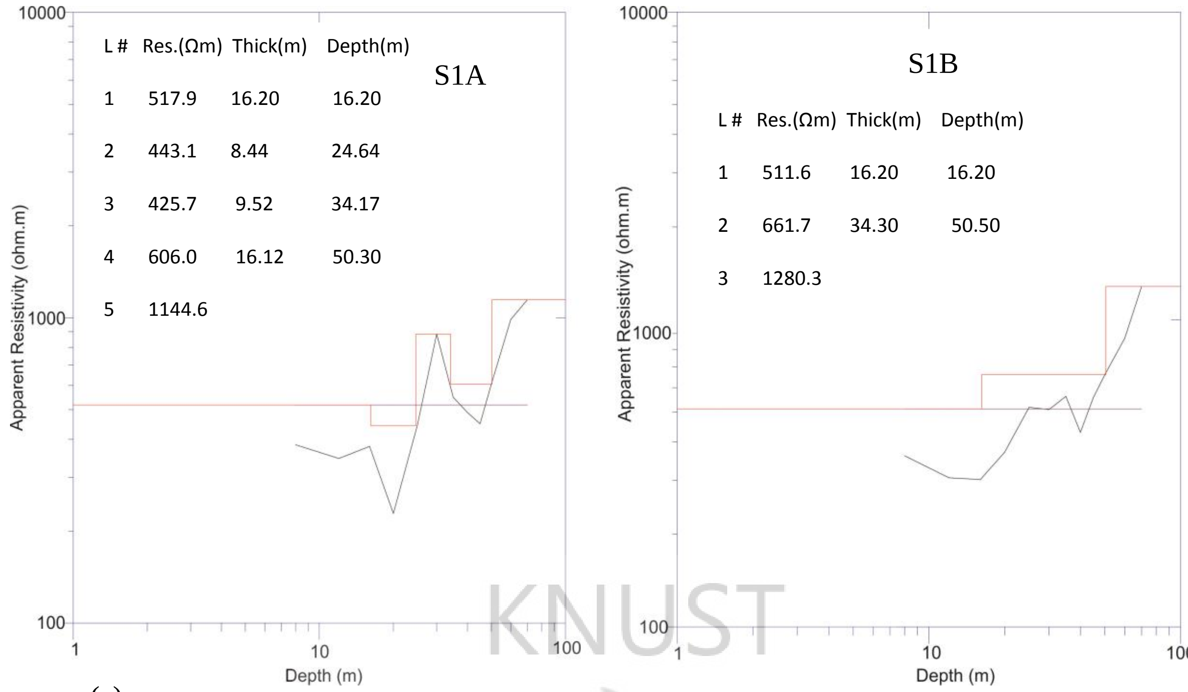
<u>Resistivity Profiling:</u>

Fig.4.18a showed an increase from point zero to 20 m; the curve dropped to 80m with value 670 Ωm and then increased through to the end at 280 m. The low resistivity at 80 m could be a fracturedor weathered zone which contained mineralization or groundwater whereas the high resistivity at the end of the profile is probably due to the compact nature of the subsurface. One low resistive point S3A at 80m was selected for sounding.

Fig.4.18b was zigzagin nature throughout. The low resistivities could be fractured zone which contain some groundwater. One low resistive point S3B at 20m with a valueof 851Ωm was selected for sounding instead of 673Ωm at 40 m which was close to a toilet and pollutants couldseep and contaminate the groundwater.



(a) (b)

KNUST

Fig.4.19 Vertical Electrical Sounding S1A and S1B- Akwansirem

Vertical Electrical Sounding:

Analysis for fig.4.19a showed afive layer model with overburden of resistivity 518Ωm down to a depth of 16m, this was followed by a weathered zonewith value 443Ωm from 16 to 25m. The third layer could be fresh bedrock with resistivity of 884 Ωm from 25 to 34 m.The fourth layer could be a weathered zone beneath the fresh bedrock and it had resistivity of 606Ωm from 34 to 50m. The fifth layer ishard bedrock of resistivity 1145Ωm from 50m downward. The borehole was drilled at this point to a depth of 44 m. The static water level (SWL) and yield were 3 m and 40 lpm respectively.

Fig.4.19b wasa three layer model with overburden resistivity of 512Ωm from the top to 16m, this was followed by fresh bedrock of resistivity 662Ωm from 16 to 51m. Third layer was hard bedrock of resistivity 1280Ωm from 51m downward. Drilling at this point was not recommended because no fractures were detected.

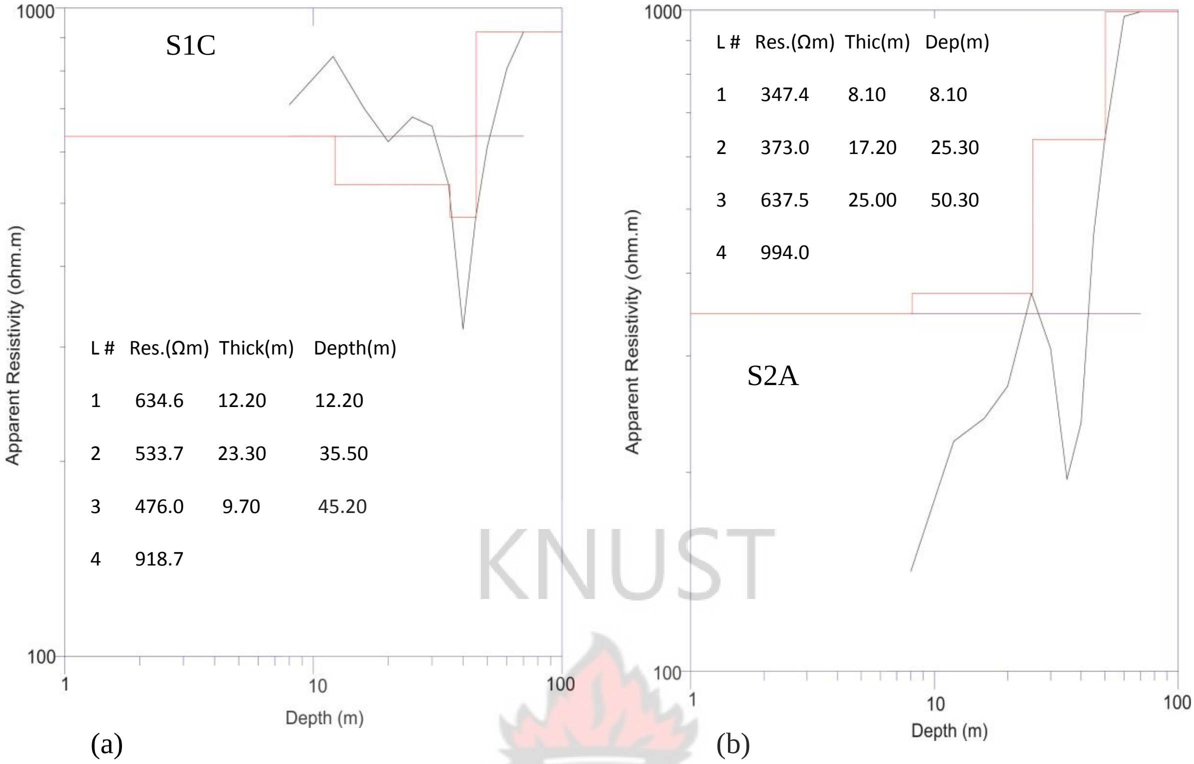


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Fig.4.20 Vertical Electrical Sounding S1C and S2A- Akwansirem

<u>Vertical Electrical Sounding:</u>

Fig.4.20a had four layers with top layer having resistivity of 635Ωm down to a depth of 12m; this was followed by bedrock with fractured or weathered materials which had resistivity of 534Ωm from 12 to 36m.The third layer could be a deep fracturewithin the bedrock and had resistivity of 476Ωm from 36 to 45m. The fourth layer could be hard bedrock of resistivity 919Ωm from 45m downward. The proposed drilling depth is 45m.

The survey for fig.4.20brevealed four layers with upper layer resistivity of 348Ωm down to a depth of 8m, and was followed by bedrock with resistivity 550Ωm from 8 to 25m.The third layer could be a fracture within the bedrock having low resistivity values of 195Ωm at 35m and 238 Ωm at 40m respectively but a resistivity of 638Ωmat its boundary (50m). The thickness of this layer was from 25 to 50m. The fourth layer could be hard bedrock of resistivity 994 Ωm from 50m downward. The estimated borehole depth was 48 m. The static water level (SWL) and yield were 4 m and 80 lpm respectively. The formation was likely to be phyllite.

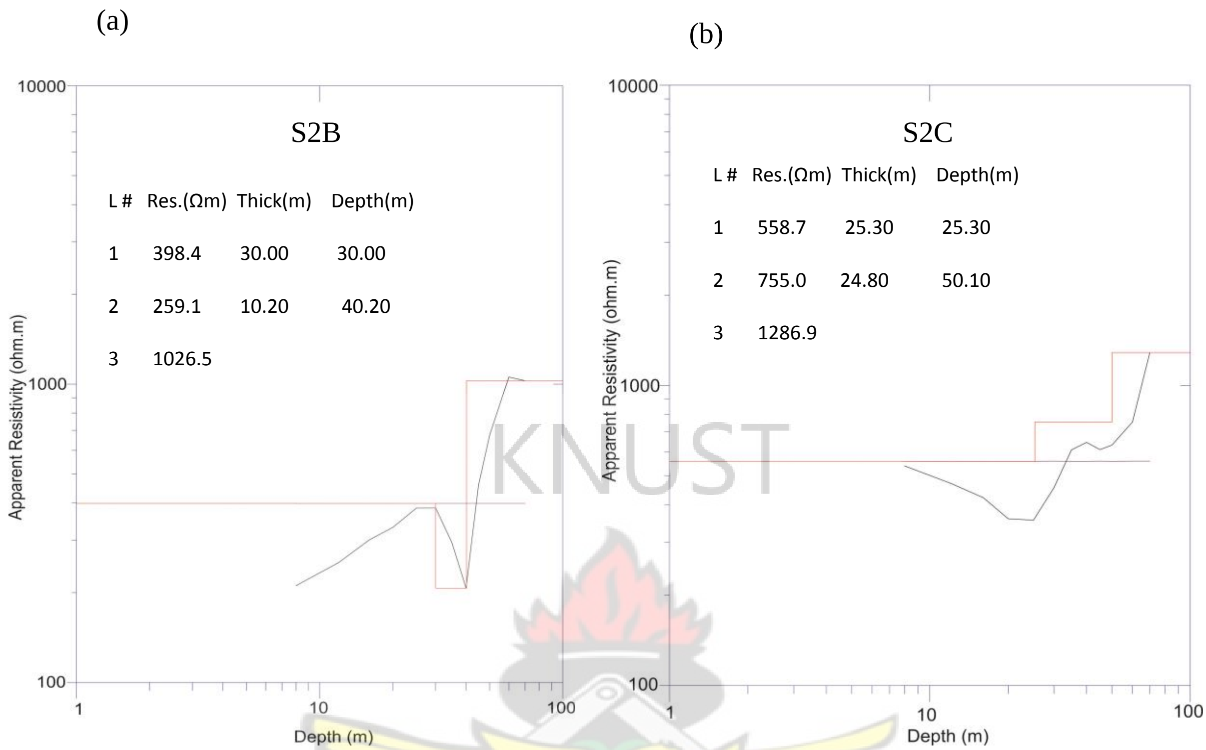

Fig.4.21 Vertical Electrical Soundings S2B and S2C- Akwansirem

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The survey showed three layers for fig.4.21awith overburden resistivity of 398Ωm from the top to 30 m, this was followed by a weathered zone which could accommodate groundwater or mineralization and had resistivity value of 254Ωm from 30 to 40m. Third layer was hard bedrock of resistivity 1027Ωm from 40m downward. Drilling at this point was recommended at 40m.

The investigation for fig.4.21b revealed three layers with upper layer of resistivity 559 Ωmfrom the top to 25 m, this could be followed by a weathered or fractured zone which accommodated groundwater or mineralization from 25 to 50m withresistivity value of 775Ωm. Third layer was hard ... 3SA 50 m dc ... S3B ...ld be expec...

L #	Res.(Ωm)	Thick(m)	Depth(m)
1	713.4	12.10	12.10
2	1116.1	8.10	20.20
3	615.2	30.00	50.20
4	1169.3		

L #	Res.(Ωm)	Thick(m)	Depth(m)
1	571.3	16.00	16.00
2	735.2	19.30	35.30
3	206.8	9.90	45.20
4	1203.0	14.90	60.10
5	819.0		

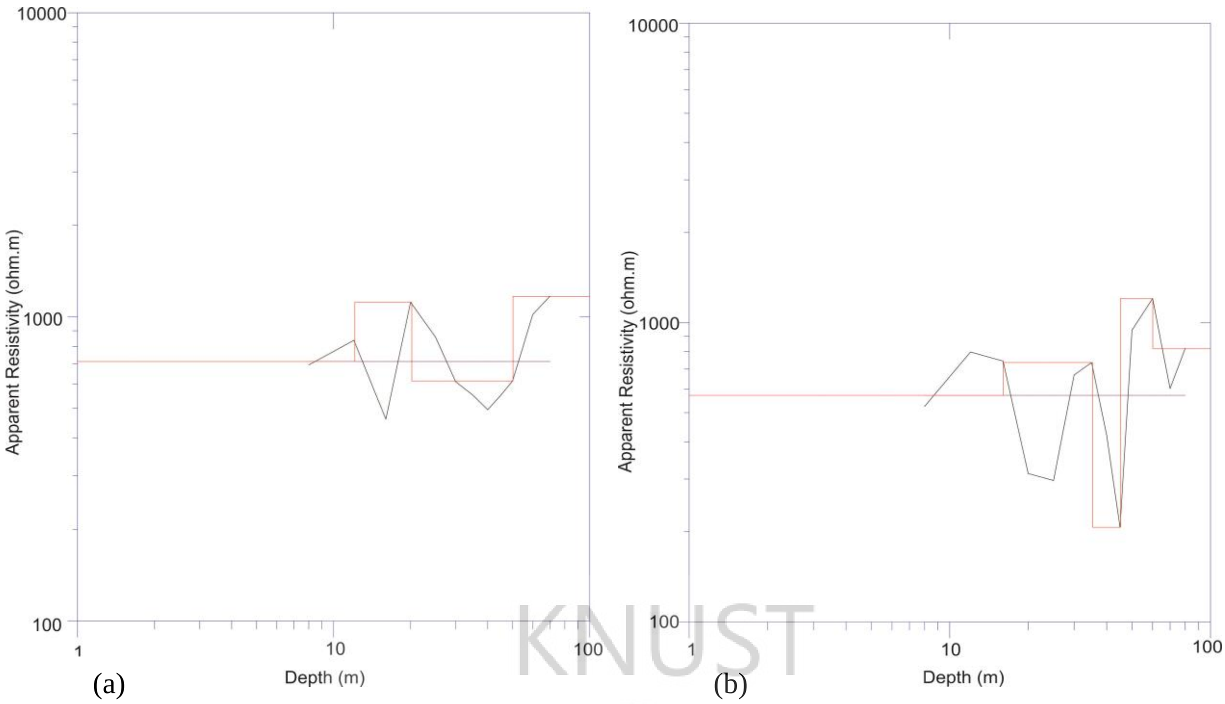
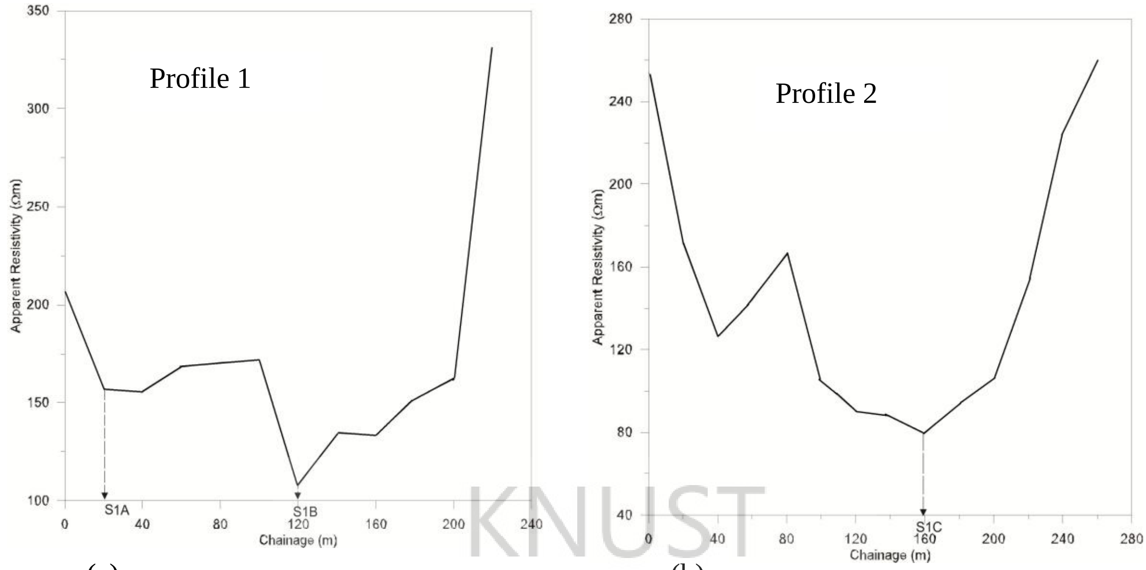


Fig.4.22 Vertical Electrical Sounding S3A and S3B- Akwansirem

Fig.4.22ahad four layers with overburden resistivity of 713 Ωm down to a depth of 12m, and it is followed by a resistive layer of 1116Ωm at 20m. The third layer could be a fractured/weathered zone which could contain groundwater deposits within the bedrock and had a value of 615Ωm andthickness of 30m. The fourth layer could be hard bedrock of resistivity 1169Ωm from 50m downward. The proposed drilling depth is 50 m.

Fig.4.22bindicatedfive layers with top layer resistivity of 571 Ωm to a depth of 16m, and was followed by a layer of resistivity 735Ωm from 16 to 35m. The third layer could be a weathered zone which could result from deep chemical weathering beneath the fresh bedrock and it had resistivity of 207Ωm from 35 to 45m, this could be groundwater- bearing zone. The fourth layer is hard bedrock of resistivity 1203Ωm from 45to 60m; this is followed by another layer probably with fractures. Drilling was done to a depth of 50 m. The static water level (SWL) and yield were 11 m and 30 lpm respectively. The formation penetrated was likely to be phyllite.

4.8 ANITOA



(a) (b)

Fig.4.23 Resistivity Profiles 1 and 2 at 40m depth- Anitoa

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<u>Resistivity Profiling:</u>

The result for fig.4.23ashowed a decrease in resistivity from point zeroto 155 Ωm at 40 m. The resistivity value decreased slightly to 100m to 107Ωm at 120m. Subsequently, it rose through to the end of the profile at 220m. The 40m point was not selected because itwas close to a church. The low resistive layer could be due tofracturing or weathering. Two potential points S1Aand S1B at 20 and 120mwere probed further.

The result for fig.4.23b indicated a decrease in resistivity from zeroto 40 m with a valueof 255 Ωm and then it decreasedto79Ωm at 160 m. The resistivity increased through to the end of the profile at 260m. The 40m point was not selected because itwas close to S1B. The low resistivity could be a fractured zone which contained groundwater. S1C at 160m was selected for sounding.

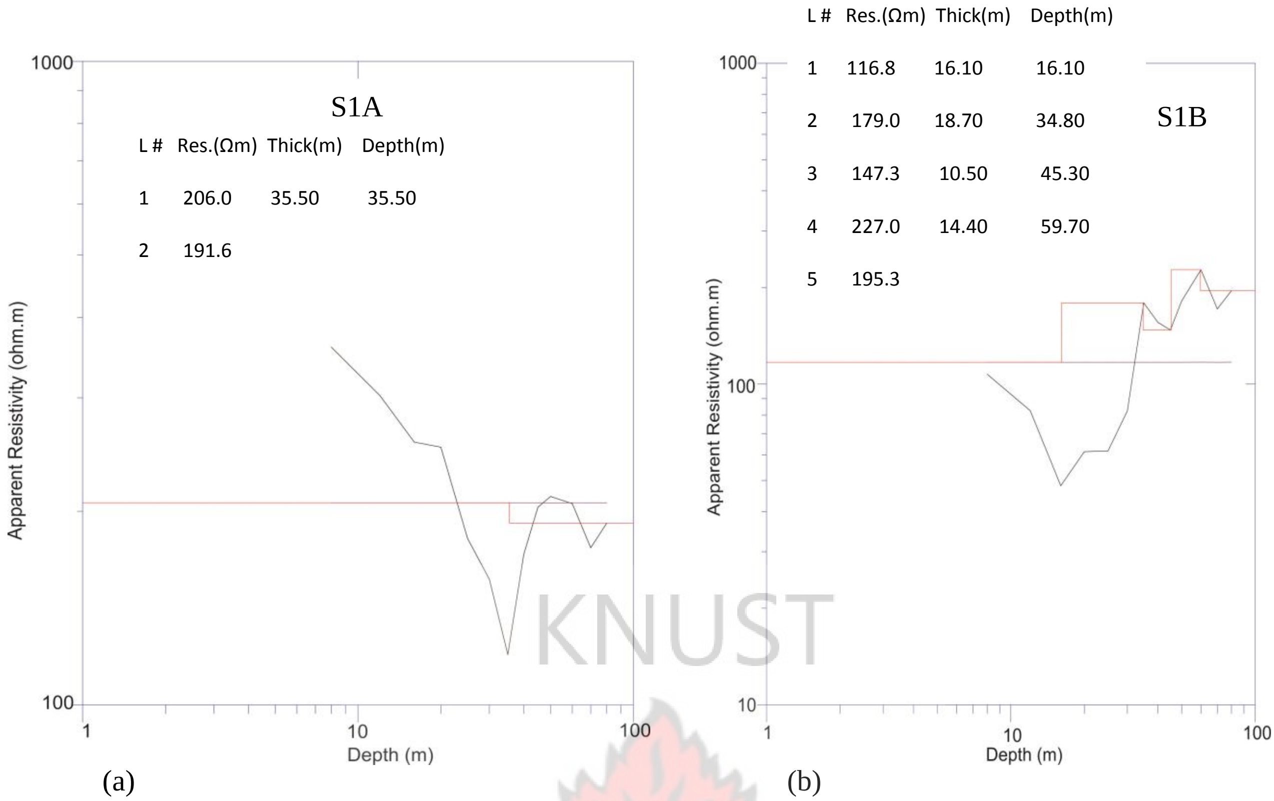


Fig.4.24 Vertical Electrical Sounding S1A and S1B- Anitoa

Vertical Electrical Sounding:

The surveyfor fig.4.24ashowed two layers with highoverburden resistivity of 206Ωm down to a depth of 36m. The second layer is a fractured zone within the bedrock and it had resistivity of 192Ωm from 36m downward. This zone may contain groundwater, the recommended drilling depth is 80m.

Fig.4.24b showed five subsurface geological layers with top layer having resistivity value of 117Ωm fromthe top to a depth of 16m. This is followed by twofractured zones with resistivities 179Ωm and 147 Ωm. The fourth and fifth layers with resistivity of 227Ωm from 45 to 60m and 195 Ωm from 60m downwards could be bedrock withfracture. The proposed drilling depth is 80m.

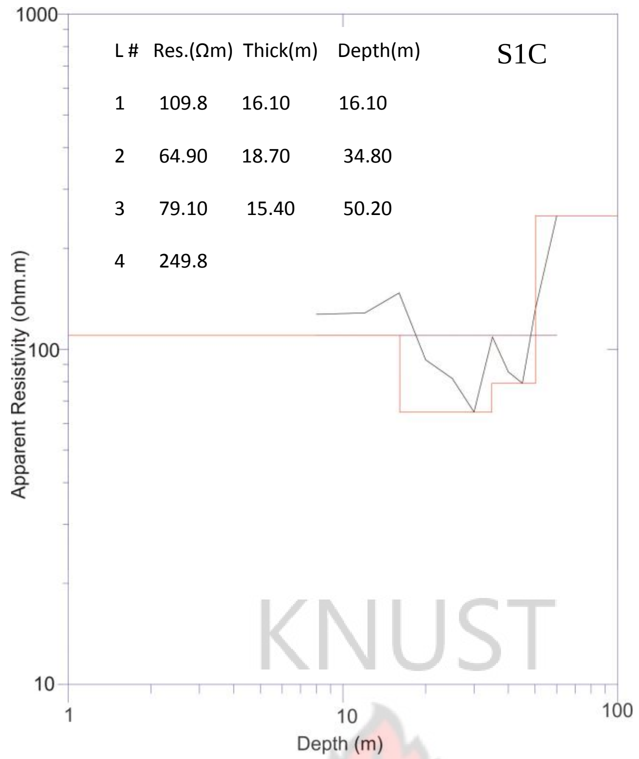
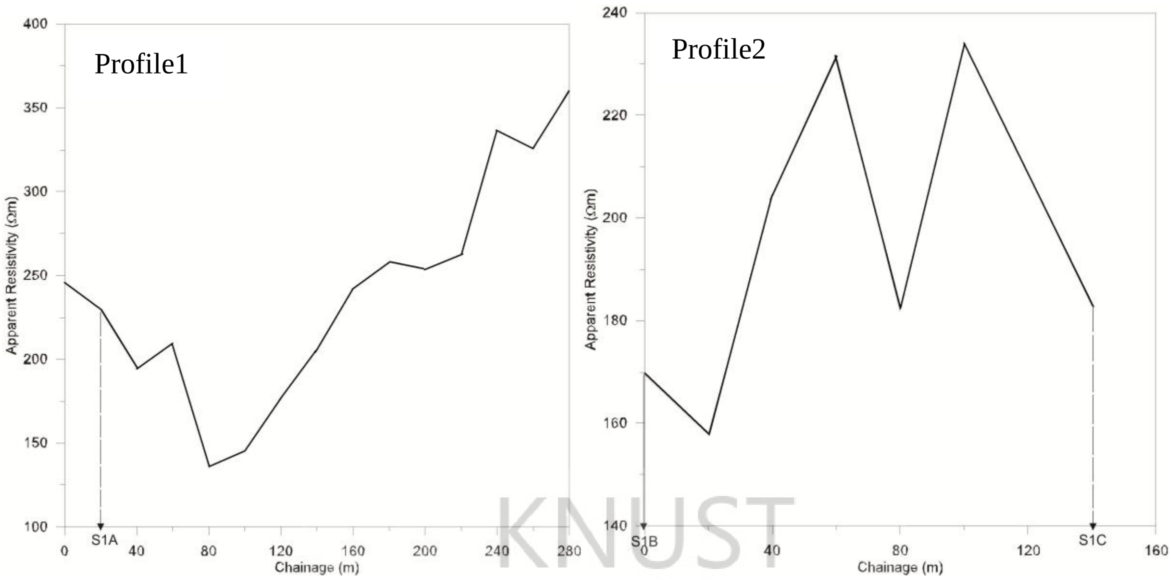


Fig.4.25 Vertical Electrical Sounding S1C- Anitoa

At point S1C, four layerswere detected. The upper layerhas resistivity of 110Ωm down to a depth of 16m, and was followed by a fractured orweathered zonewith resistivity of 65Ωm from 16 to 35m. Thethird layer could be fresh bedrock with resistivity of 79Ωm and thickness of 15 m. The fourth layer might behard bedrock of resistivity 250Ωm from 50m downward. The proposed drilling depth is 50m.The subsurface rock was likely to be phyllite.

4.9 ANWONA



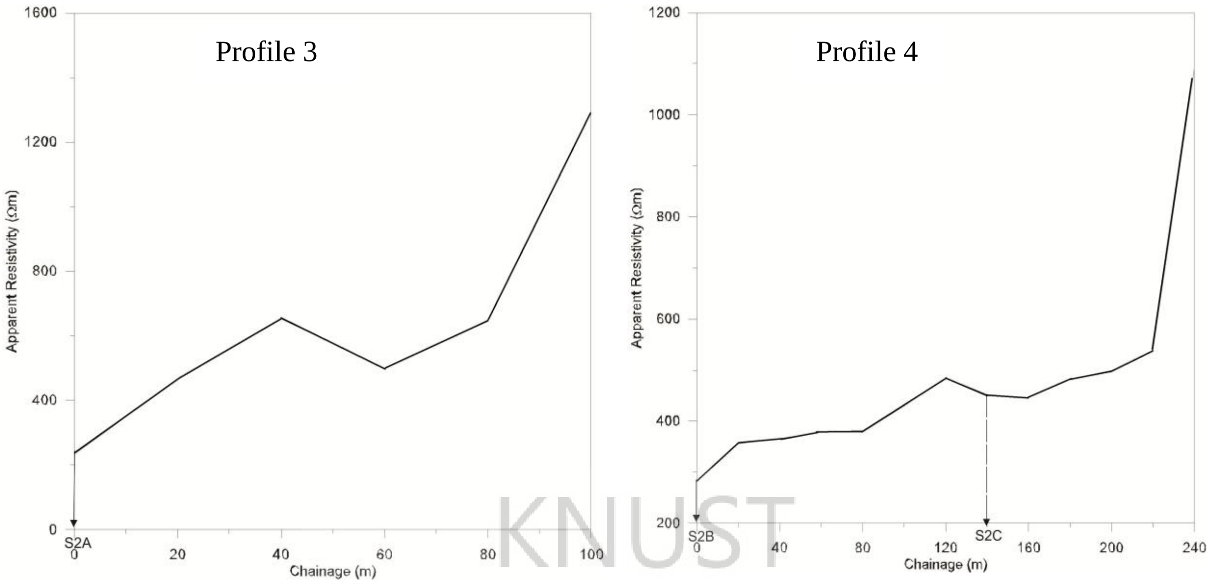
(a) (b)

Fig.4.26 Resistivity Profiles 1 and 2 at 40m depth- Anwona

<u>Resistivity Profiling:</u>

The results on fig.4.26a indicated a decrease in resistivity from zero to 40m.The resistivity value increased shortly to 60m and dropped further at 80 m. Subsequently, the resistivityroseabout 370 Ωm at 280m. The low resistive point at 40m and 100m were not selected because it is close to S1B and marshy arearespectively. Point S1A at 20m with resistivity of 230 Ωm was selected for further investigation.

Fig.4.26b revealed a slightdecrease in resistivity from the beginning of the traversewith value 170Ωm to 20m. The resistivity value increased to 230 Ωm at 60 m and dropped significantly to 180 Ωm at 80 m.Subsequently, it rose to 100 mand then dropped againto the end of the profile at 140m with a value of 183Ωm. The low resistive points at 20m and 80m were not selected for further investigation because it was close to houses. The high resistivity points at 60 m and 100 m could be due to hard rock of the subsurface. Two points S1Band S1C at zero and 140mrespectively were selected for sounding.



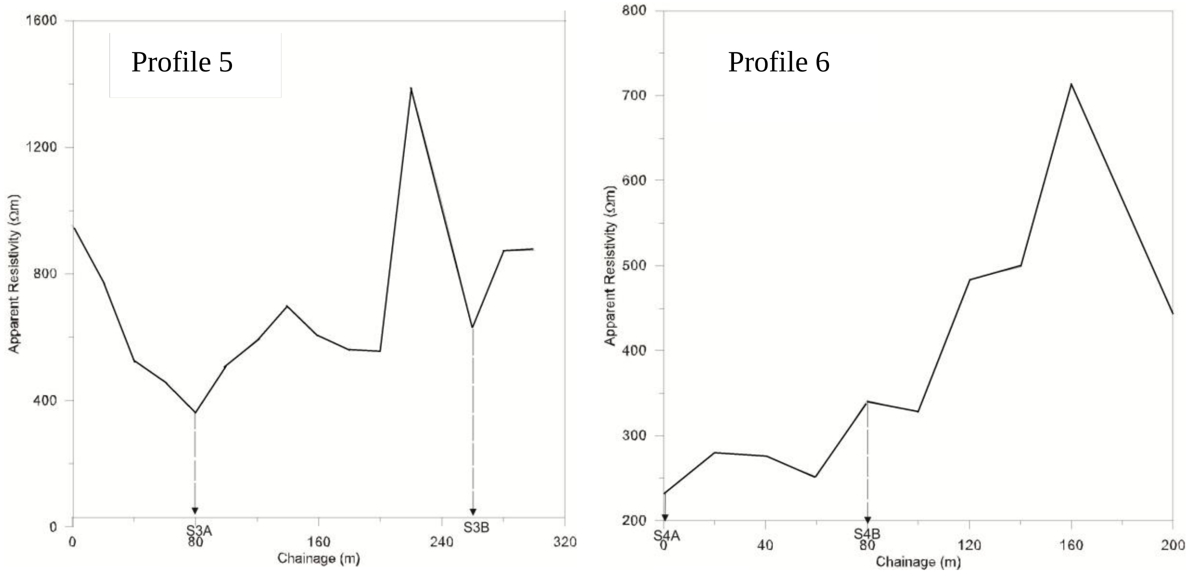
(a) (a)

Fig.4.27 Resistivity Profiles 3 and 4 at 40m depth- Anwona

Resistivity Profiling:

The workfor fig.4.27ashowed an increase in resistivity from zero with a value of 234 Ωm to 40m. The resistivity value decreased slightly at 60m and then increasedupto 100m with a value of 1294Ωm. The low resistivity at zerocould be a fractured zone with groundwater whereas high resistivity at 100m could be due to boulders. Point S2A at zero was selected for sounding.

The result for fig.4.27b indicated a gradual increase in resistivity from zero with a value of 284Ωm to120 m. The curve dropped slightly at 140m with a value of 451 Ωm and then rose to the end of the profile. The low resistivity could be a weathered zone which contained minerals whereas the high resistivity at 240m could be due to compaction of the subsurface. Station S2Band S2C at zero and 140mwere marked for further investigation.



(a) (b)

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Fig.4.28 Resistivity Profiles 5 and 6 at 40m depth- Anwona

Resistivity Profiling:

Fig.4.28a indicated a decrease in resistivity from zero to 365Ωm at 80 m. The resistivity values roseand dropped again at 260m with a value of 629Ωm; afterward there was a slight rise to the end at 300m. The point 200m was not selected because of it was close to a toilet. The high resistivity at zero and 220-240 m could be due to compaction of subsurface. Two low resistive points S3A and S3B at 80 m and 260m respectively were probed further.

Fig.4.28b gradually increased to 160 m and then dropped to the end of the profile at 200m. The low resistive point at 60m was not selected because it was close to S4A and there could be interference during pumping. The low resistivity could be a fractured/weathered zone which could contain groundwater whereas the high resistivity at 160 m might also be due to a boulder. Two points S4A and S4B at zero and 80m were selected for further investigation.

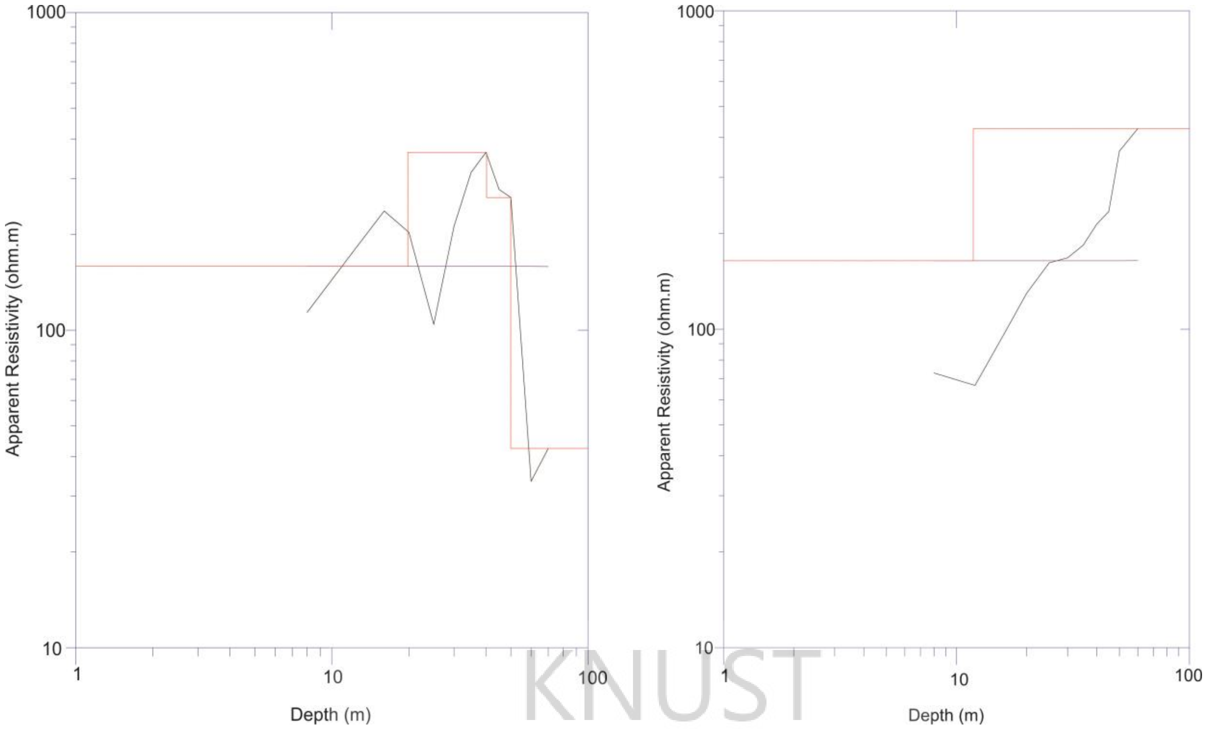

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Fig.4.29 Vertical Electrical Soundings S1A and S1B- Anwona

Vertical Electrical Sounding:

Fig.4.29a showed four layers with overburden resistivity of 159Ωm down to a depth of 20m.Twofractured/weathered zones with resistivity values of 36 and 262Ωm with thickness of 20 and 10m respectively were detected.The fourth layer may possibly be fresh bedrock with a value of 42Ωm from 50m downward. The anticipated drilling depth is 50m.

Fig.4.29b had two layers with upper layer whoseresistivity was164Ωm and thickness of 12m.The second layer may possiblybe a fractured/weathered layer with resistivity of 427Ωm at 60m. This layer might contain some fracture with groundwaterat a depth of 45 m.

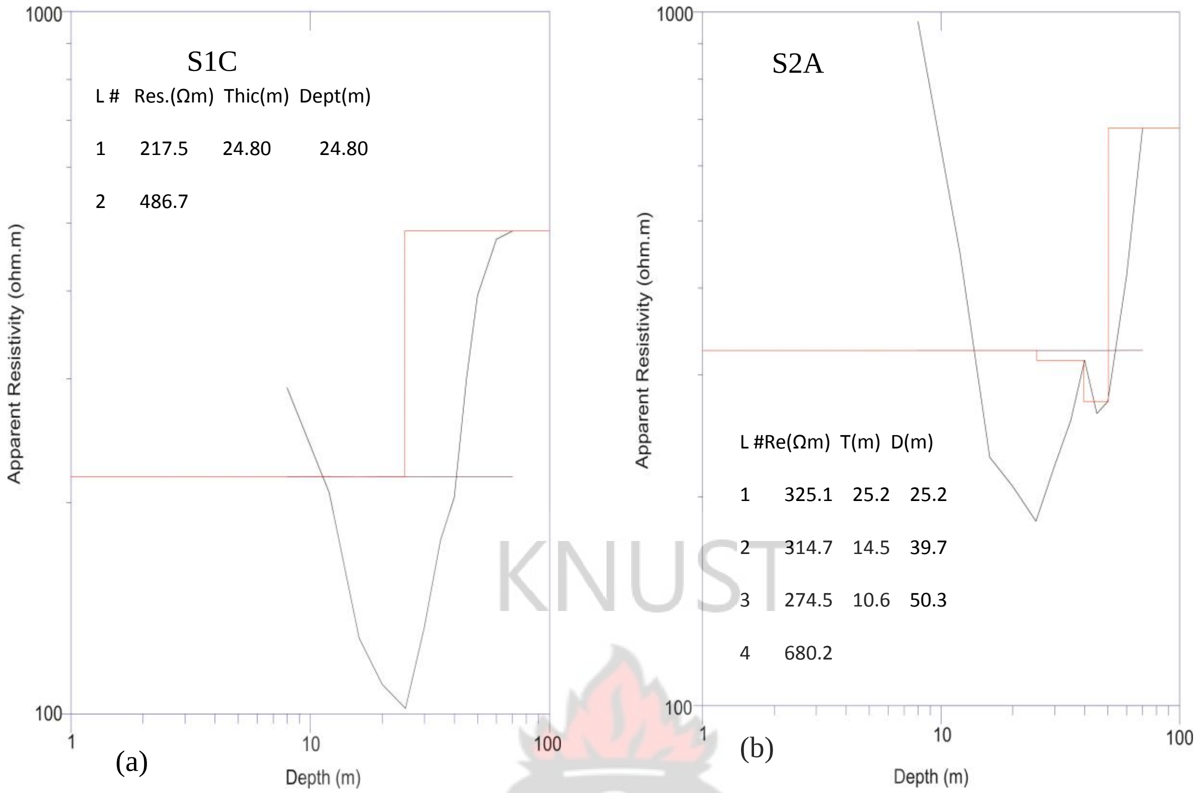

Fig.4.30 Vertical Electrical Sounding S1C and S2A- Anwona

Fig. 4.30a had two layers with thick overburden of resistivity 218Ωm from the top to a depth of 25m, the second layer could be a fractured or weathered zone and it had resistivity of 203Ωm at 40 m and 487Ωm at 70 m. The borehole depth was estimated to be 47 m. The static water level (SWL) and yield were 1 m and 18 lpm respectively.

The VES showed four layers for fig. 4.30b with overburden resistivity of 325Ωm down to a depth of 25m.There were two separate fracture zones with resistivity of 315Ωm and 275Ωmand thicknesses 15 and 10 m respectively. This fractured/weathered zone mighthave some potential for groundwater occurrence; and was followed by hard bedrock with resistivity value of 680Ωm from 50 m downward. The proposed drilling depth is 50 m.

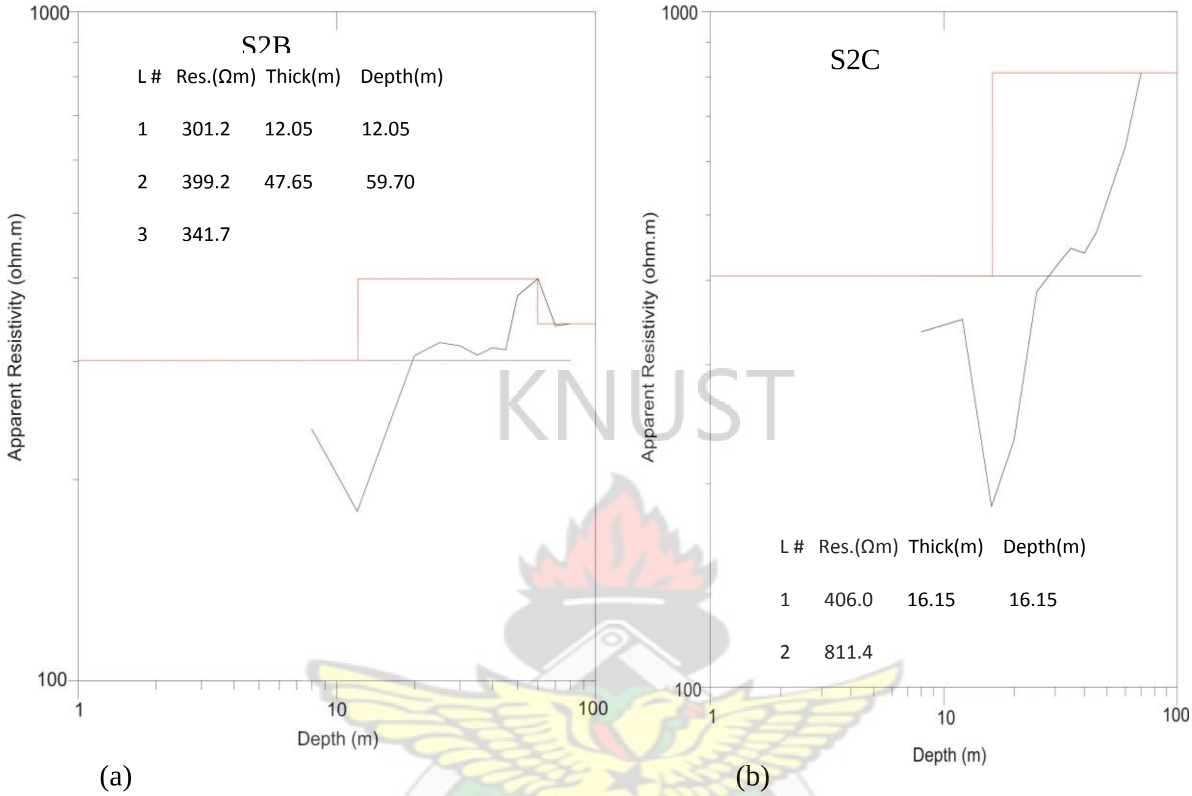

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Fig.4.31 Vertical Electrical Sounding S2B and S2C- Anwona

Fig.4.31ashowed three layers with overburden resistivity of 301Ωm from the top to 12m. This was followed by fresh bedrock of resistivity value 399Ωm from 12 to 60m. Third layer could be hard bedrock whose resistivity was 342Ωm from 60m and showed signs of reducing resistivity trend after 60 m depth. The borehole drilled at this point terminated at a depth of 52 m. The static water level (SWL) and yield were 16 m and 51 lpm respectively.

Point for figure 4.31bhad two layers with an upper layer of value 350 Ωm at 12 m. Low resistivity values between 185-232 Ωmat 16 m might be due to existence of fractures. The resistivity of the bedrock showed increasingtrend with depth therefore drilling at this point was not recommended.The subsurface rock is likely to be phyllite.

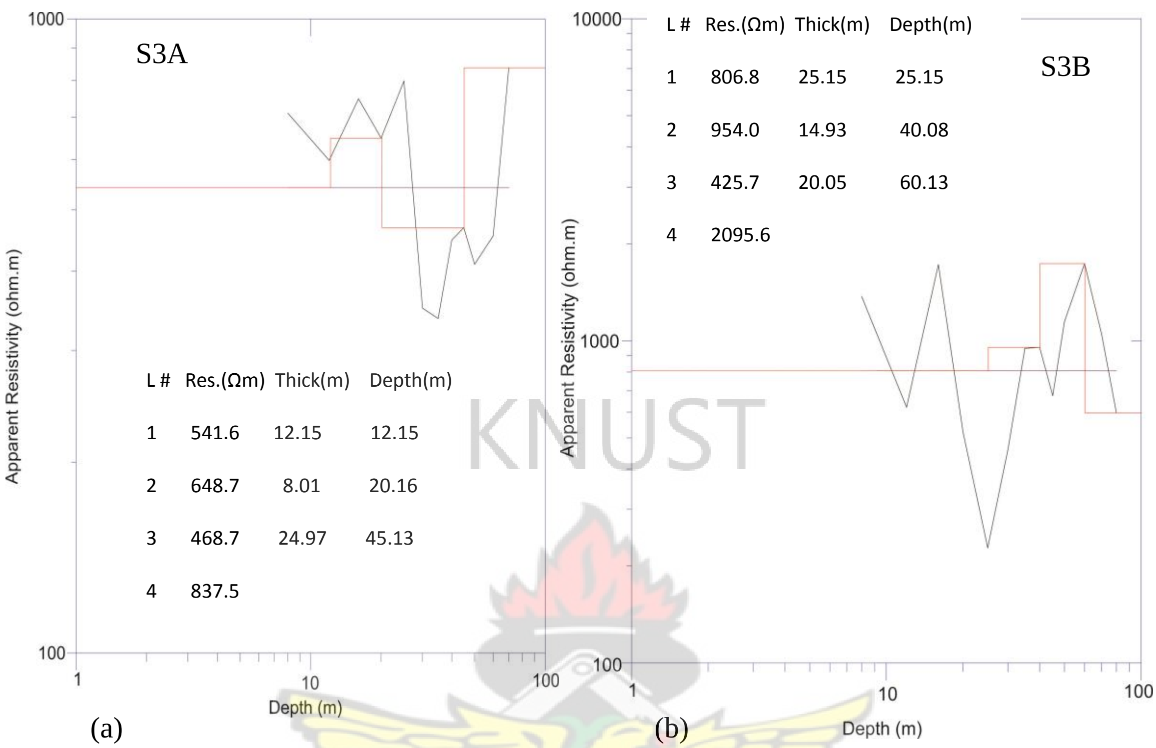

Fig.4.32 Vertical Electrical Sounding S3A and S3B- Anwona

The vertical probefor figure 4.32ashowed four layers with top layerresistivity of 542Ωm down to a depth of 12m.It was followed by a layer with resistivity of 649Ωm from 12 to 20m.The third layer with resistivity of 469Ωm spanned 25m and could be a fractured bedrock having the potential to store groundwater. The fourthlayer might possibly behard bedrock with resistivity value of 838Ωm from 45m downward. The proposed drilling depth is 45 m.

The sounding showed four layers for figure 4.32b withoverburden resistivity of 807Ωm down to a depth of 25m. The second layer had a value of 954Ωm from 25 to 40m. The third layer hasresistivity valueof 1738Ωm and thickness of 20m. The fourth layer might befracturedwith low resistive materials which reduced its apparent resistivity value to598 Ωm from 60m

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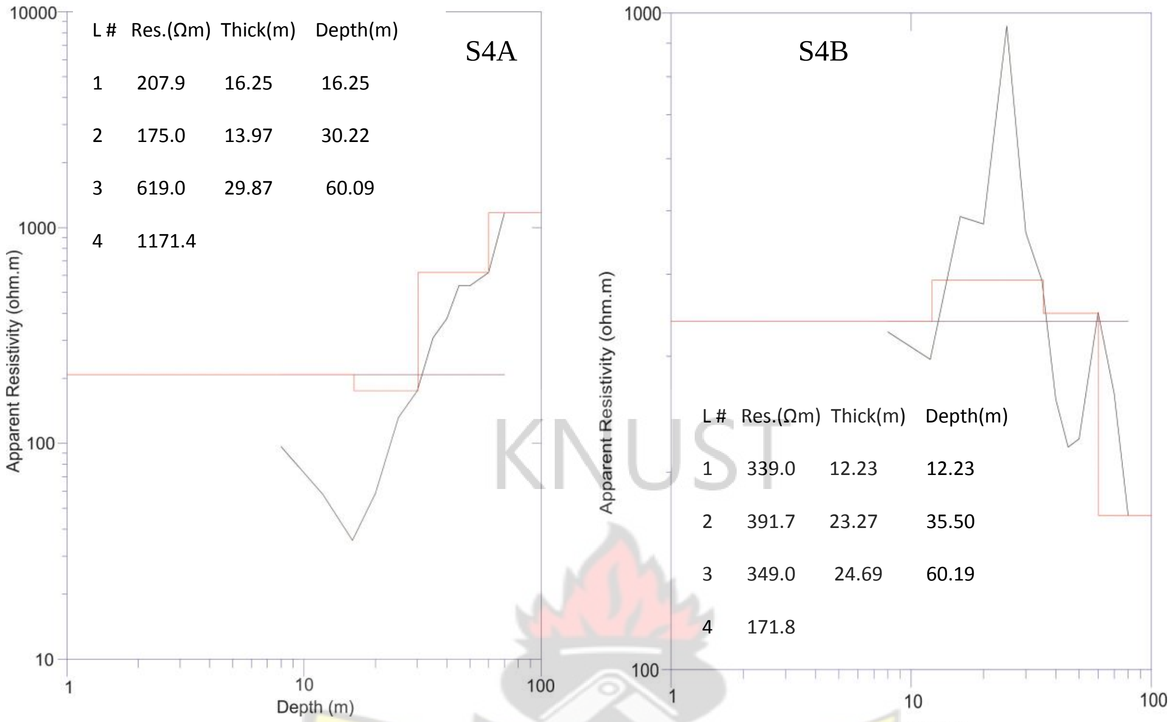
downward. The borehole drilled at this point terminated at 32 m deep. The static water level (SWL) and yield were 2 m and 30 lpm respectively.



(a) (b)

Fig.4.33 Vertical Electrical Sounding S4A and S4B- Anwona

Four layers with overburden which could be clayey down to a depth of 16m were seen in figure 4.33a. The second layer could be a fractured/weathered zone, which could containgroundwater and had resistivity of 175Ωm from 16 to 30m. The third layer could be fresh bedrock with value of 619Ωm from 30 to 60m. The fourth layer might possibly be hard bedrock of resistivity 1171Ωm from 60m downward. The drilling depth is estimated to be 30m.

Fig.4.33b had four layers with upper layer of resistivity 339Ωm down to a depth of 12m. The second layer had a value of 392Ωm and with thickness of 24 m. The third layer could be a fractured zone with high groundwaterpotential. The thickness of this layer is about 24 mand has resistivity of 349Ωm. The fourth layer could also be fractured bedrock with resistivity of 172

Ωm from 60m downward. Borehole was drilled at this point to a depth of 64 m. The static water level (SWL) and yield were 2 m and 20 lpm respectively.

4.10 AYOKOA SAVIOUR CHURCH

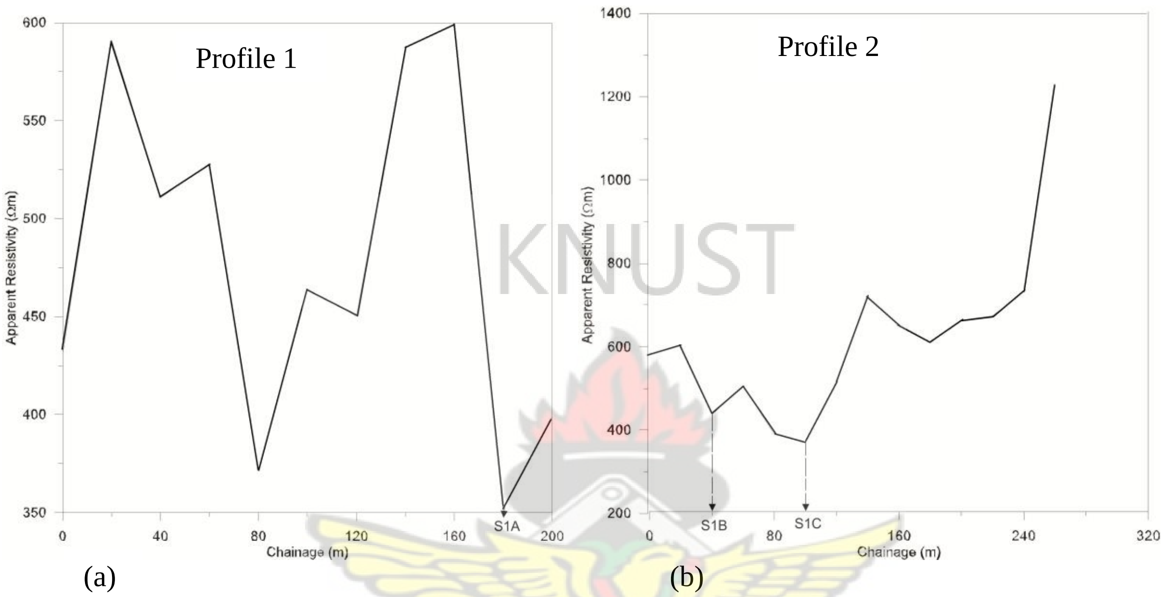


Fig.4.34 Resistivity Profiles 1 and 2 at 40m depth- Ayokoa Saviour Church

Resistivity Profiling:

The profiling results for figure 4.34a indicated an increase in resistivity from zeroto 20m and decrease tothe 80m point.It rose at 160m afterwards dropped at180m with its lowest value 352Ωm.Subsequently it increasedto the end of the profile at200m. Points0 m, 40 mand 80m were not selected because they were close to an existing borehole, a building and S1C respectively. Point S1A at 180mwas selected for further investigation.

The resistivity results forfigure 4.34bwas generally undulatingwith an average value of 600 Ωm to point 240 m, where it rose rapidly to 1300 Ωm at 260 m. Two low anomaly points S1B and

S1C at 40 and100mwith resistivity values of484 and 371 Ωm respectively were selected for further investigation.

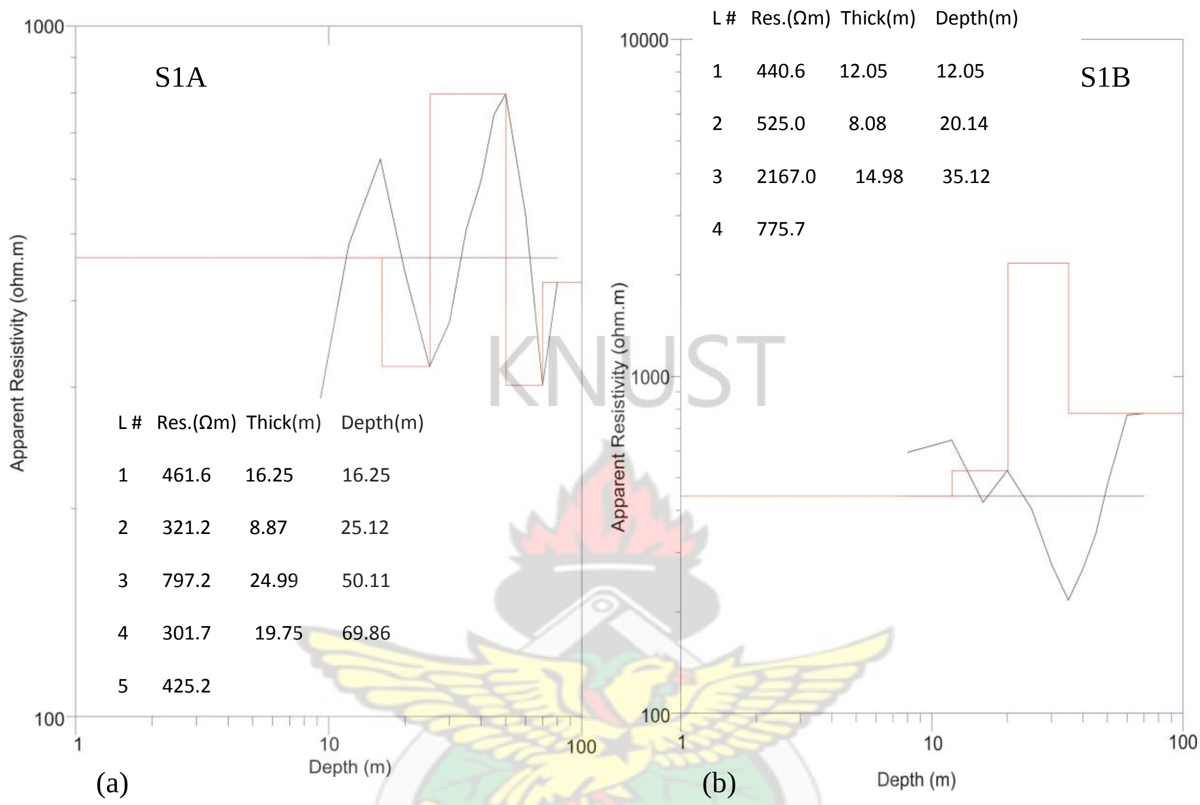


Fig.4.35 Vertical Electrical Soundings S1A and S1B- Ayokoa Saviour Church

<u>**Vertical Electrical Sounding:**</u>

Fig.4.35ashowed a five layer model with overburden resistivity of 462Ωm down to a depth of 16m. This was followed by a fractured or weathered zonewith resistivity of 321Ωm and thickness 9m. The third layer could be a consolidated layer with resistivity of 797Ωm and has thicknessof 25m. The fourth and fifth layers could be two narrowfractures with resistivity values of 301Ωm from 50 to 70m and425Ωm from 70m downward. The proposed drilling depth is 25 m.

Fig.4.35b had four layers with an upper layer resistivity of 339Ωm and thickness of 12m. The second layer was slightly resistive with value of 392Ωm and spanned to a depth of 24 m. The third could be fractured bedrock with high potential to obtain groundwater, with resistivity of 349Ωm from 35 to 60 m. The fourth layer could be fractured bedrock of resistivity 172Ωm which increased from 60m downward. The proposed drilling depth is 35m.

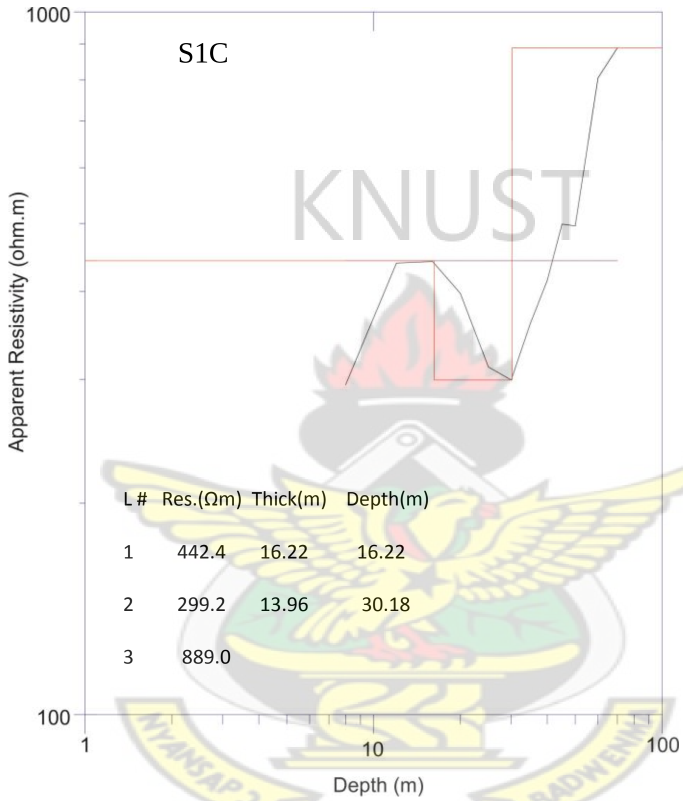


Fig.4.36 Vertical Electrical Sounding S1C- Ayokoa Saviour Church

The VES results showed three layers with overburden resistivity of 442Ωm from the top to 16m. This was followed by fractured rockwith the potential to storegroundwater potential whose resistivity was 299 Ωm and 14m thick.Third layer was hard bedrock with resistivity889Ωm from 30m downward. Drilling depth was recommended to be 30m.Drilling penetrated through quartzite rock. The borehole depth was 48 m. The static water level (SWL) and yield were 10 m and 30 lpm respectively.

4.11DOMEABRA II

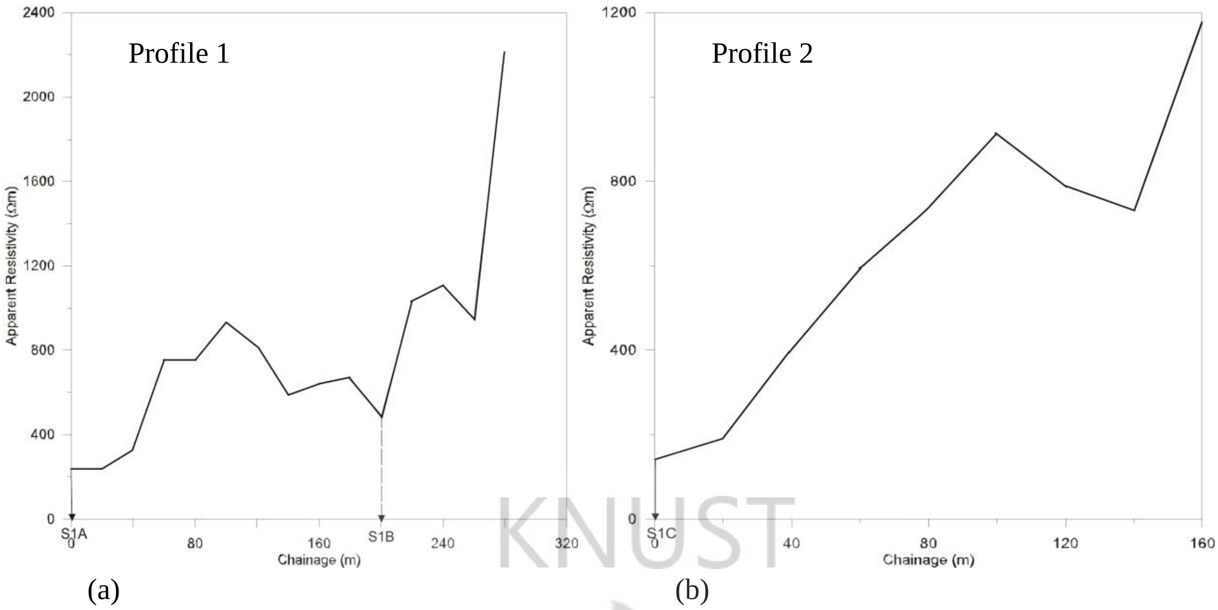


Fig.4.37 Resistivity Profiles 1 and 2 at 40m depth- Domeabra II

<u>**Resistivity Profiling:**</u>

The resultsfor figure 4.37a revealed an increase in resistivity from start with a value of 238Ωm to 100m. The resistivity value fell to 483Ωm at 200 m and then rose to280 m.The low resistivity could be a fractured rock, with high possibility to store groundwater. Two potential drilling sites S1A and S1B at zero and 200m wereselected further probing.

The results for figure 4.37b indicated an increase in resistivity from thebeginning to 100m with a valueof 914 Ωm. The curve decreased slightly to 140m with a value 733Ωm and then rosetothe end of the profile at 160m. The low resistivity could be fractures within the bedrock which contain groundwater, whiles the high resistivity at 100m and 160m could be due to massive rock. S1C at zero was selected for sounding.

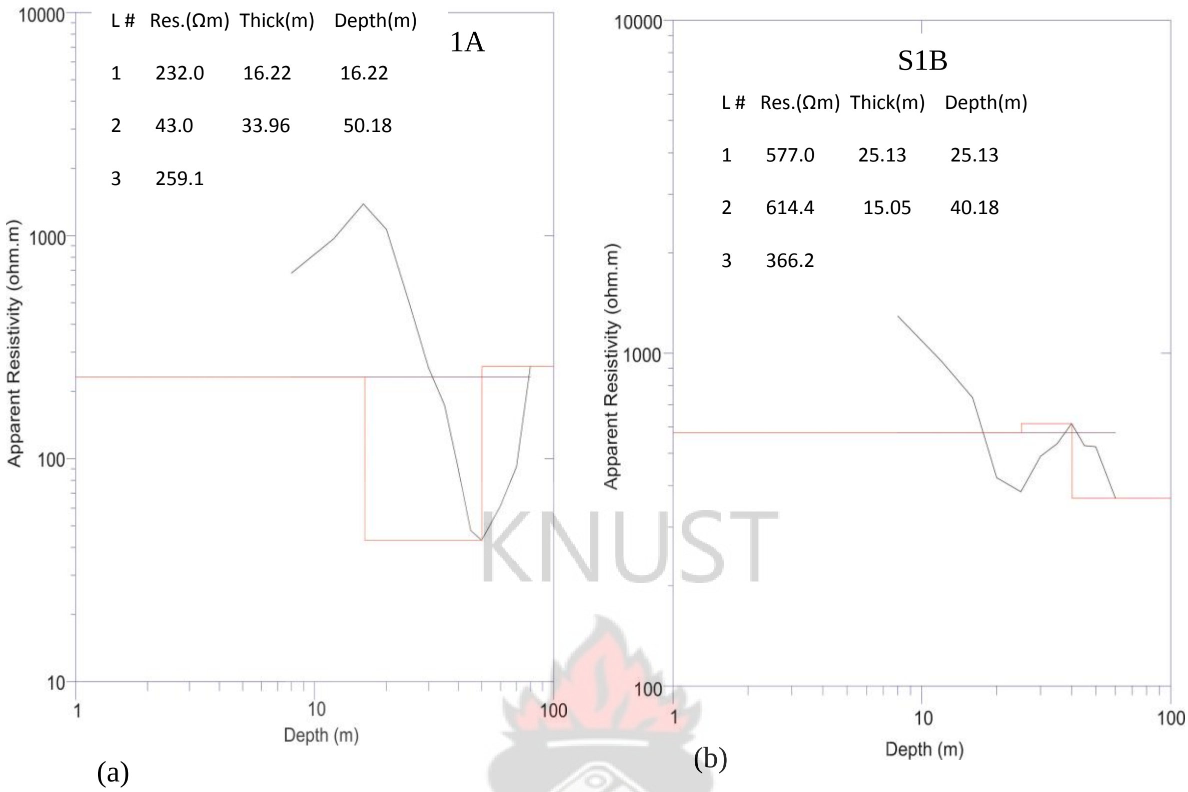


Fig.4.38 VerticalElectrical Sounding S1A and S1B- Domeabra II

<u>Vertical Electrical Sounding:</u>

Fig.4.38ashowed three layers with upper layer resistivity of 232Ωm from the top to 16 m. This might be followed by weatheredlayer whose resistivity value was 43Ωm and 34m thick.The third layer could bedrock with resistivity 259Ωm which increased from 50m downward. Drilling at this point is recommended at 50m.

The sounding at figure 4.38b showed three layers with overburden resistivity of 577Ωm from the top to 25m.This was followed by a more resistive layer of value614Ωm from 25to 40m.The third layer was bedrock with resistivity of366Ωm from 40m downward. Drilling was not recommendedat this point because there was no clear indication of a fractured or weathered zone which could accommodate groundwater.

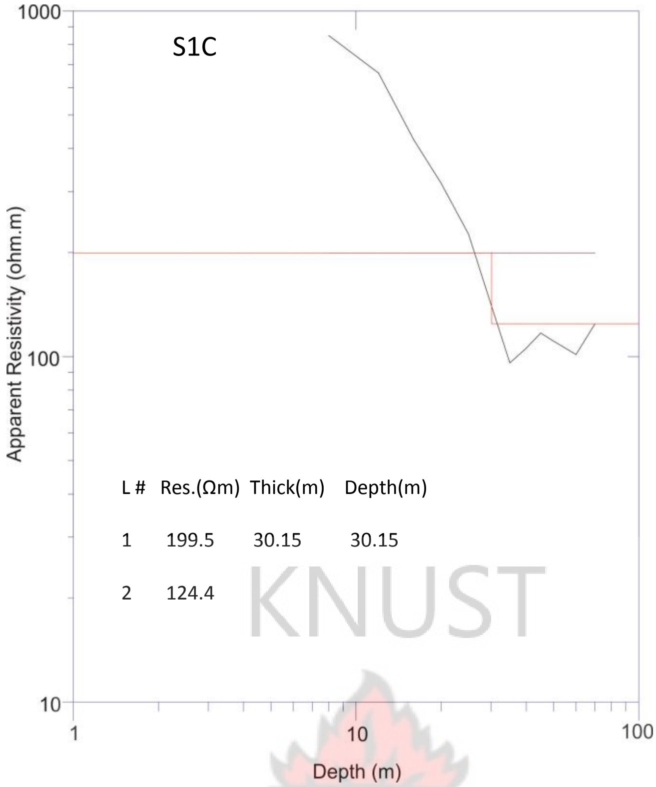


Fig.4.39 Vertical Electrical Sounding S1C- Domeabra II

The VES resultsat point S1C showed two layers with top layer resistivity of 200Ωm from the top to a depth of 30m.The overburden material was more resistive which might indicate dry compact soil. This was followed by highlyweathered zone whose resistivity was 124Ωm from 30m downward. Drilling at this point was recommended at 70m. The formation was likely to be phyllite.

4.12 ETOAKROM

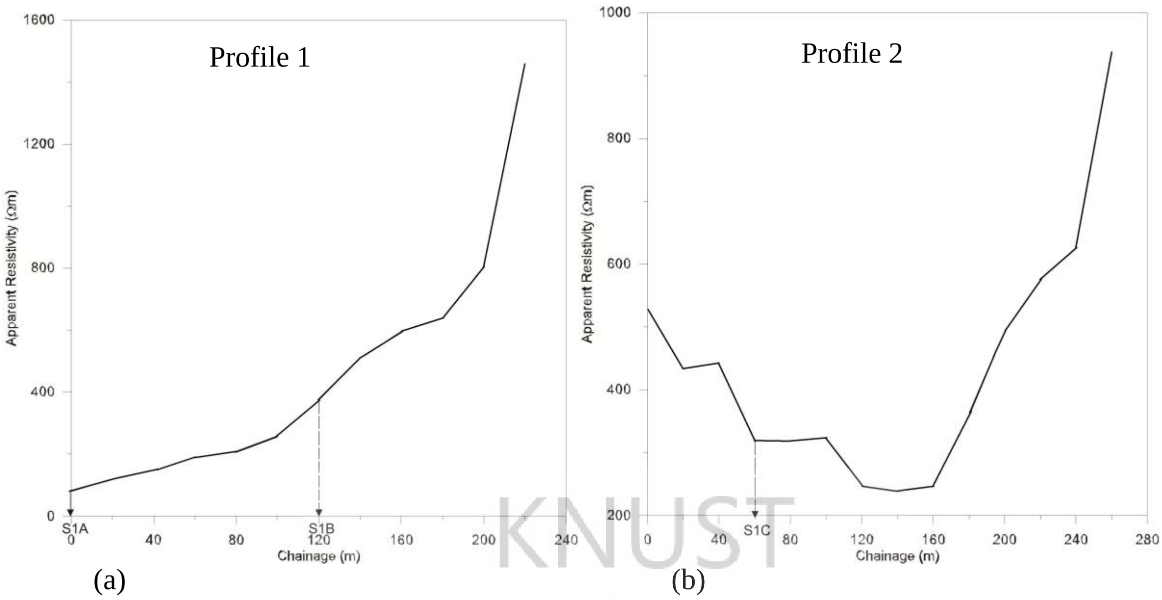


Fig.4.40 Resistivity Profiles 1 and 2 at 40m depth- Etoakrom

<u>Resistivity Profiling:</u>

Theresistivity profiling result forfigure 4.40a revealed an increasing resistivity trend from zero with a value of 79Ωm to 220m with a value of 1461Ωm. Two potential drilling points S1A at zero and S1B at 120m were selected for sounding.

Theresistivity output of the survey for figure 4.40bshowed a decrease in resistivity from point zero to 140m,and then increasedto 260m.The low resistivity could be a fractured or weathered zone which could containsome groundwater whereas the high resistivity between200 and 260m could be due to compaction of the subsurface. Point S1C at 60mwith value 320Ωm was selected for sounding.The 140m point was not chosen because of its closeness to a pit latrine.

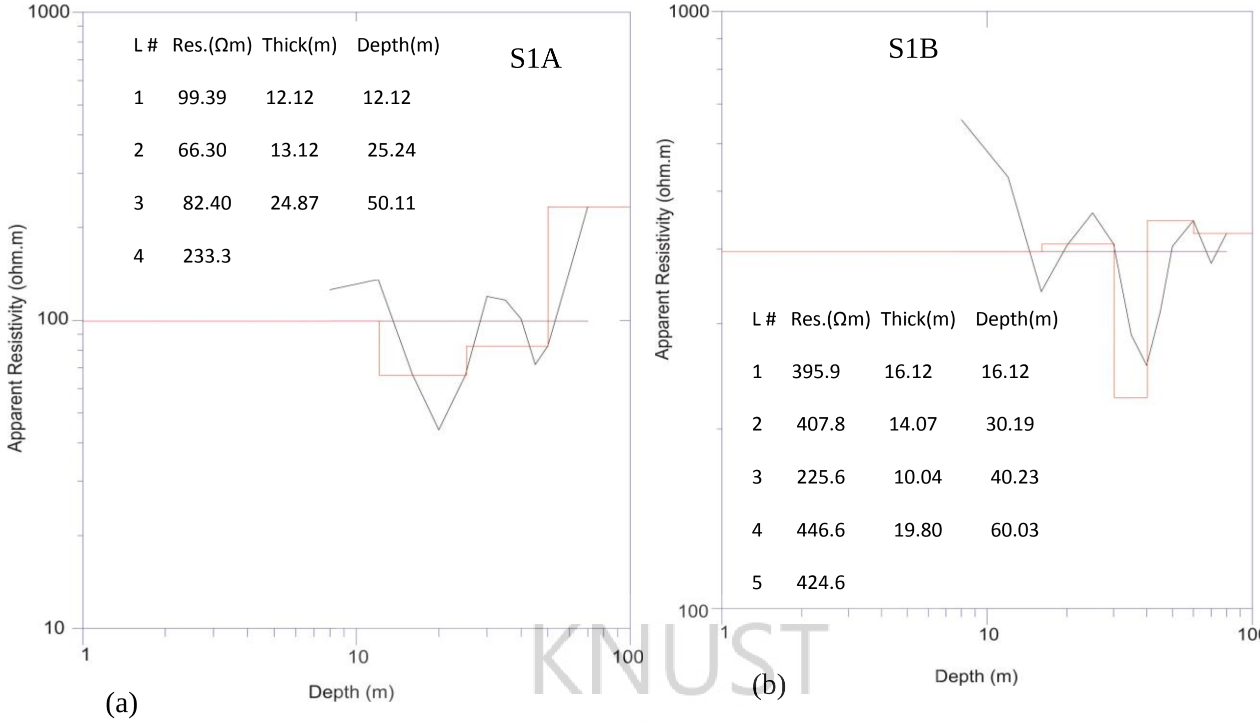


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Fig.4.41 Vertical Electrical Sounding S1A and S1B- Etoakrom

Vertical Electrical Sounding:

Fig.4.41a had four layers with first layer resistivity of 99Ωm which could be clay down to a depth of 12m. The second layer could be fractured bedrock with potential to store groundwaterand with resistivity of 66Ωm from 12 to 25m. The third layer could be fresh bedrock layer with resistivity of82Ωm, which spanned 25 m. The fourth layer could be hard bedrock of resistivity 233Ωm from 50m downward. The proposed drilling depth is 50m.

Fig.4.41b revealed five layerswith overburden resistivity of 396Ωm and thickness 16m. This was followed by bedrock with resistivity 408Ωm from 16 to 30 m. The thirdlayer could befractured bedrock with resistivity value of 226Ωm and thickness 10 m, and it is likely to be an aquifer zone. The fourth and fifth layersmight be two adjacent bedrock formations with slightly different resistivities of 447and 425Ωm and spanned 20 m each. Drilling at this point indicated borehole depth of 48m. The static water level (SWL) and yield were 11 m and 17 lpm respectively. The formation penetrated was phyllite.

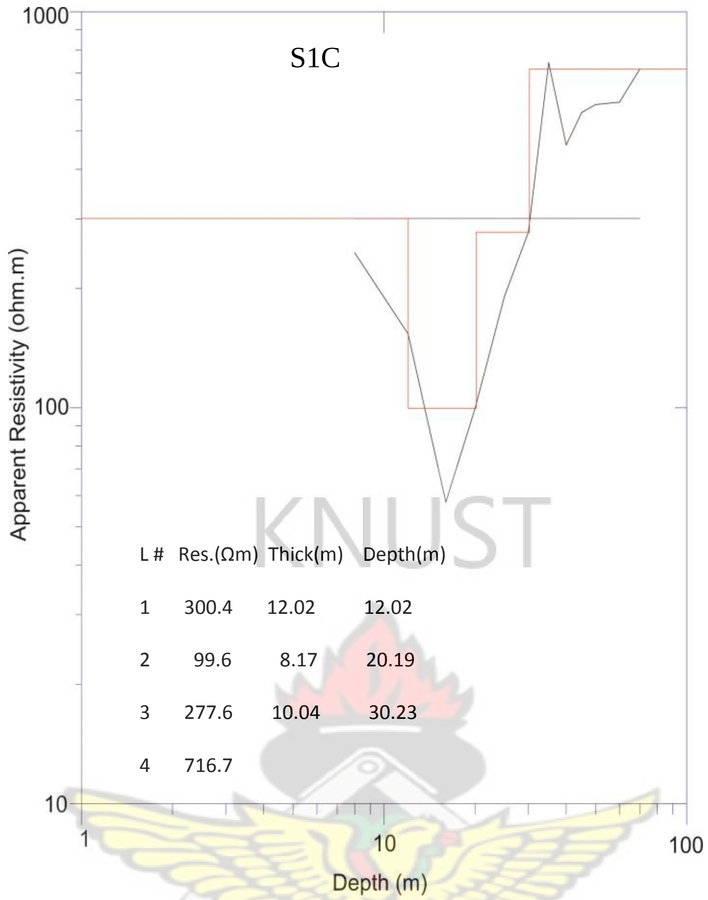
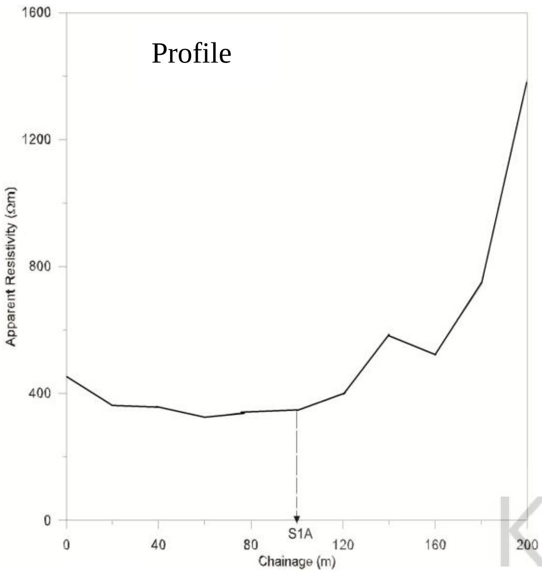


Fig.4.42 Vertical Electrical Sounding S1C- Etoakrom

At point S1C four layers with top layer resistivity of300Ωm down to a depth of 12m was observed. The second layer could be fractures within the bedrock and had resistivity of 100Ωm from 12 to 20m. The third layer could be fresh bedrock with resistivityvalue of 278Ωm and thickness of 10 m; whiles the fourth layer might also be hard bedrock of resistivity 717Ωm from 30m downward. The proposed drilling depth is 30 m. Theformation could probably be phyllite.

4.13FUMSO KETEWA SCHOOL



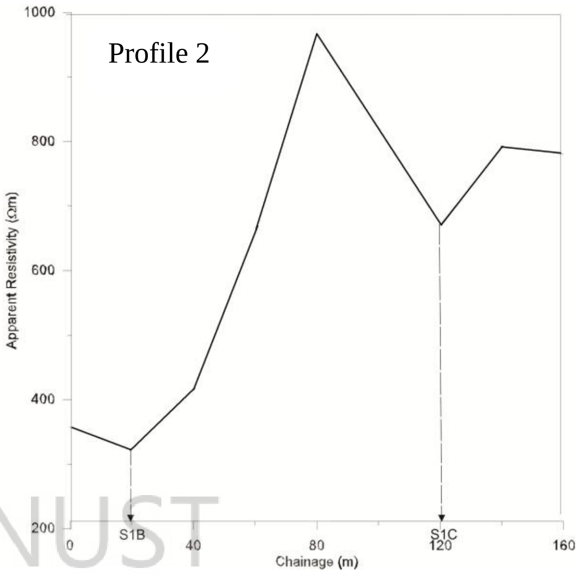
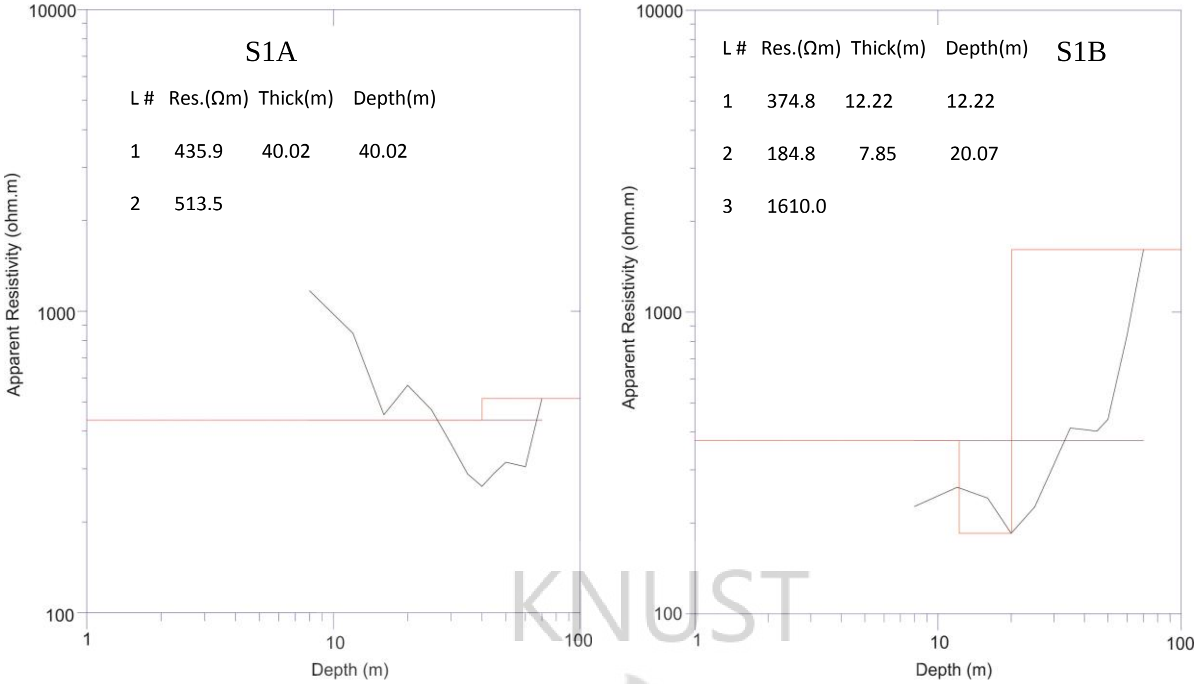


Fig.4.43 Resistivity Profiling 1 and 2 at 40m depth- Fumso Ketewa School

Resistivity Profiling:

The results for figure 4.43a revealed a decrease in resistivity from zero to 60 m, followed by gradual increase in resistivity to 200m.The low resistivity could be a fractured zone which could contain groundwater whereas the high resistivity at 200m with value 1389Ωm might also be due to a vertical intrusion such as a dike. S1A at 100mwith value of 347Ωm was selected for VES.

Along figure 4.43b aslight decreasein resistivity from the start to 20m with a value of 323Ωm was seen. The curve increased to 80m and then dropped to 671Ωm at 120 m.Subsequently, it rose to 160m.The low resistivity could be a fracturedzone which could contain some groundwater whereas the high resistivity at 80m could be due to rock hardness. Two low resistivityanomaly points S1B and S1C at 20and 120mcorrespondingly were investigated further.



(a) (b)

Fig.4.44 Vertical Electrical Soundings S1A and S1B- Fumso Ketewa School

Vertical Electrical Sounding:

The vertical variation in resistivity for figure 4.44a showed two layers with thick upper layer of resistivity 436Ωm from the top to 40m.The soil from the top to 8 m was highly resistive (1168Ωm) whichcould indicate dry compact soil formation. This was followed by bedrock fractures that could contain some groundwater. Groundwater at this point was recommended at 40m.

Figure 4.44b showed three layers with overburden resistivity of 375Ωm from the top to 12m. This was followed by fractureswithin the bedrock with resistivity of 185 Ωm from 12 to 20m. The third layer could behard bedrock with resistivityof 1610Ωm from 70m downward.Drilling was carried out at this point to a depth of 47 m. The static water level (SWL) and yield were 4 m and 20 lpm respectively.

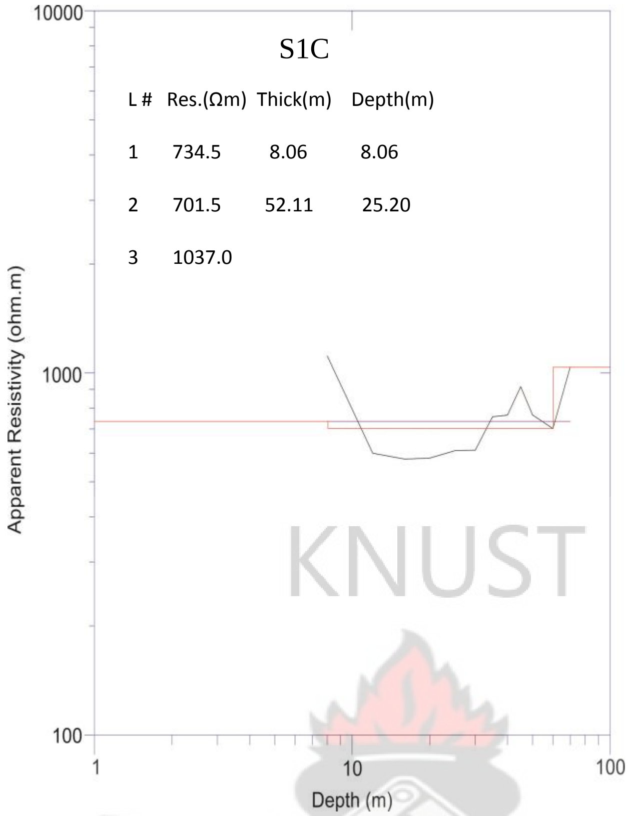


Fig.4.45 Vertical Electrical Sounding S1C- Fumso Ketewa School

VES output at point S1C showed three layers with upper layer resistivity of 735Ωm and thickness 8 m. This was followed by a bedrock whose resistivity was 702Ωm from 8 to 60m.Third layer was hard bedrock with resistivity of 1037Ωm at 70m. Drilling at this point was not recommended because there was no clear indication of a fractured or weathered zone, which could accommodate groundwater. The penetrated rock was quartzite.

4.14 HWIREMOASE

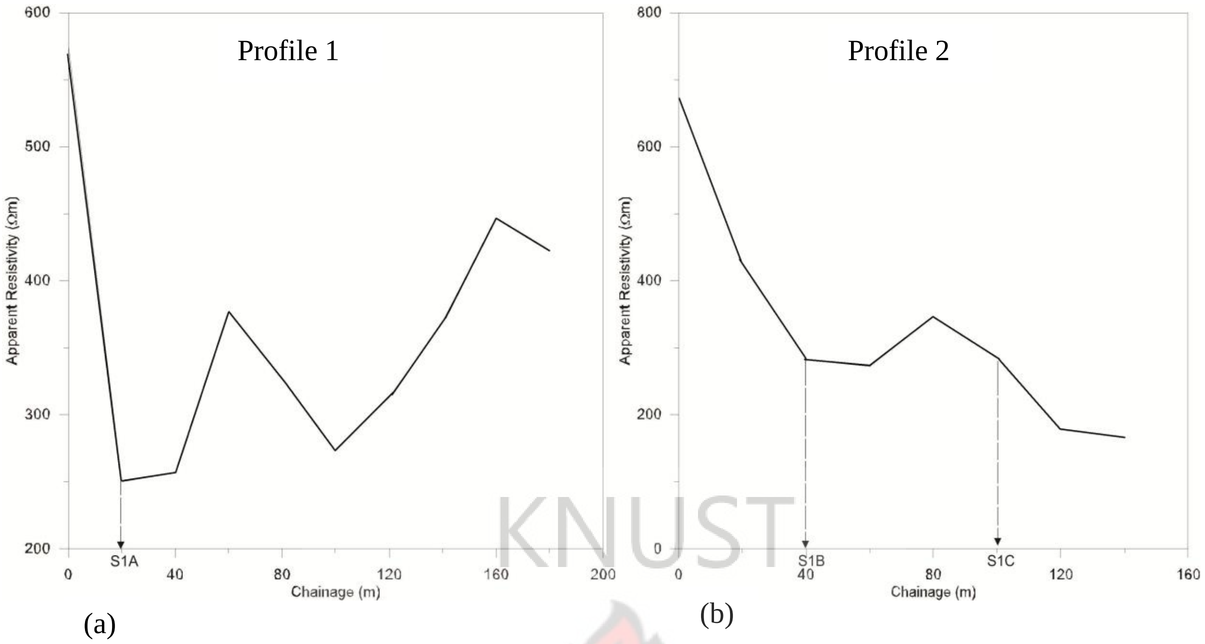


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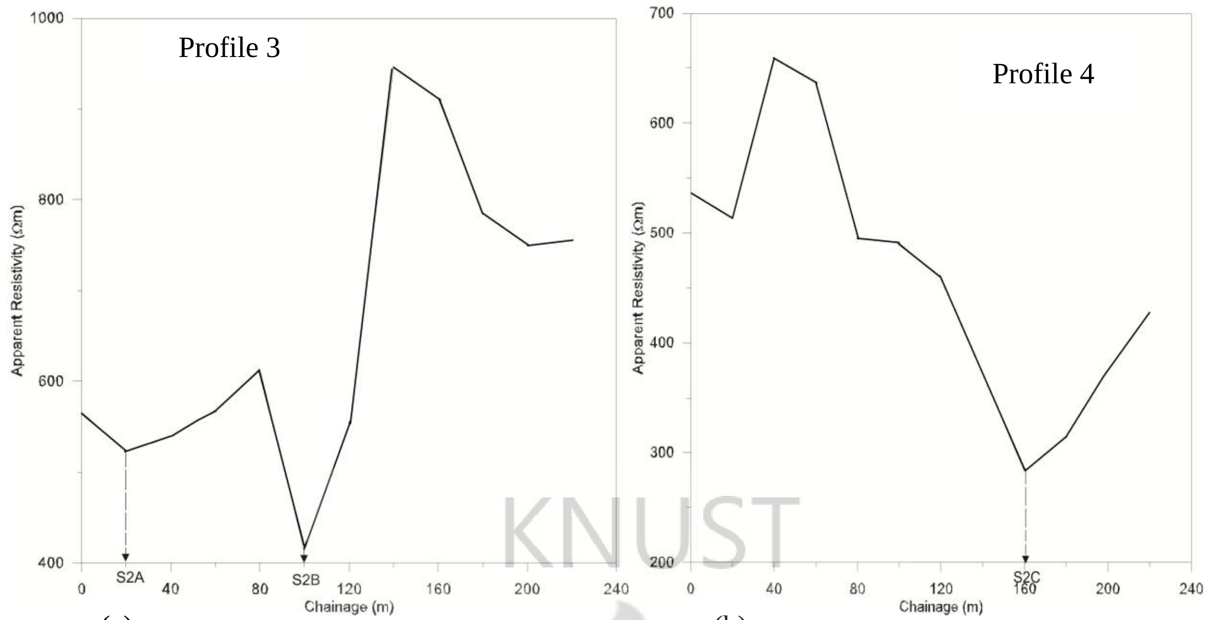
Fig.4.46 Resistivity Profile 1 and 2 at 40m depth- Hwiremoase

<u>Resistivity Profiling:</u>

Fig.4.46a indicated a sharp decrease inapparentresistivity from zeroto 20m with value 250Ωm. The curve roseto 60 m and then subsequently declined at 100m.Afterward there was an increase to 160m and a slight decrease to the end of the profile at 180 m.The low resistivity could be a fractured zone which could contain some groundwater, whereas the high resistivity at zero, 60m and 160m could be due to boulders. One low resistive point S1A at 20m was selected for sounding, whilstthe 100m point was not selected because of poor sanitation.

The result for figure 4.46b showed a decrease in resistivity from zero to 60m with a value of 272Ωm, the curve increased slightly to 80 m and then dropped at the end of the profile at 140m.Low resistivities at 40 and 100 m could beweathered zones which could contain some water, whereas the high resistivity at zero and 80m could be due compaction of the subsurface. Two suitable points S1B and S1C at 40 and 100m correspondingly were probed further.



(a) (b)

Fig.4.47 Resistivity Profile 3 and 4 at 40m depth- Hwiremoase

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<u>Resistivity Profiling:</u>

Profiling results for figure 4.47a indicated a slight decrease in terrain resistivity from zero to 523Ωm at 20 m and then droppedagain at 100m with value 414 Ωm.There was a sharp rise to 140m and then fell to the end at 220m.The low resistivity could be a fractured or weathered zone which could contain groundwater whereas the high resistivity at 80 and 140m could be boulders. Two low resistive points S2A and S2B at 20 m and 100m respectively were selected for further work.

The result for figure 4.47b indicated a slight decrease from the beginning to 20m. The curve increased to 40 m and then dropped significantly to 160m point with a value of 283Ωm. Subsequently, it increased from 160m to the end of the profile at 220m. The low resistivity could be aweathered zone which contained or groundwater, whereas the high resistivity values between 40 and 60m could be due to hardness of the subsurface. One potential drilling point

S2C at 160m was selected for probingbut 20, 80 and 180m points were not selected because of their closeness to S1B(for first two points) and cocoa farm respectively.

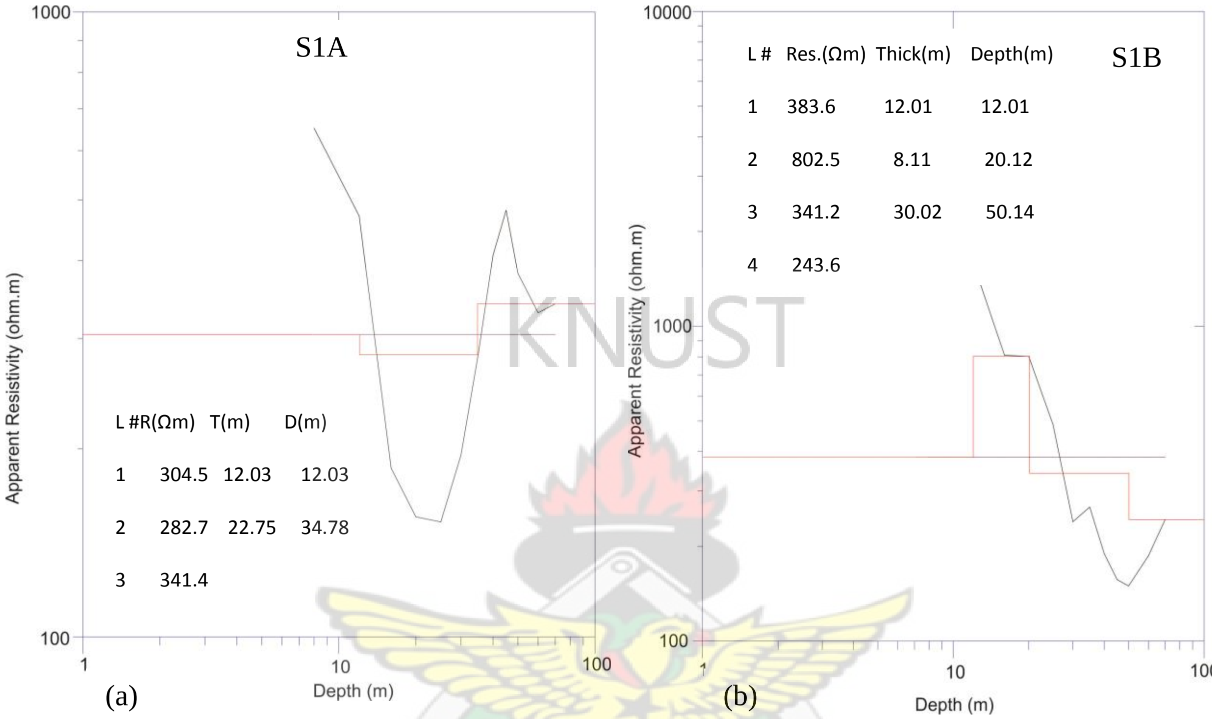


Fig.4.48 Vertical Electrical Soundings S1A and S1B- Hwiremoase

<u>Vertical Electrical Sounding:</u>

The study showed three layers for figure 4.48a with top layer of resistivity 305Ωm from the surface to 12m.This was followed by a fractured/weathered zone, which mightcontain minerals,groundwater or clay deposits within the bedrock whose resistivity was 283Ωm from 12 to 35m.The third layer was bedrock with resistivity of 341Ωm from 35m downward. Drilling at this point was recommended.

Figure 4.48b had four layers with overburden of resistivity 300Ωm down to a depth of 12m. The second layer could be unfractured bedrock with resistivity of 803Ωm and it is 8m thick.The third layer may possibly be a fractured bedrock, which may contain minerals, groundwater or clay deposits within the bedrock and had resistivity of 341Ωm and thickness 30m. The fourth layer could be hard bedrock with resistivity of 244Ωm from 50m which increased downward. The borehole drilled at this point terminated at a depth of 56 m. The static water level (SWL) and yield were 9 m and 150 lpm respectively.

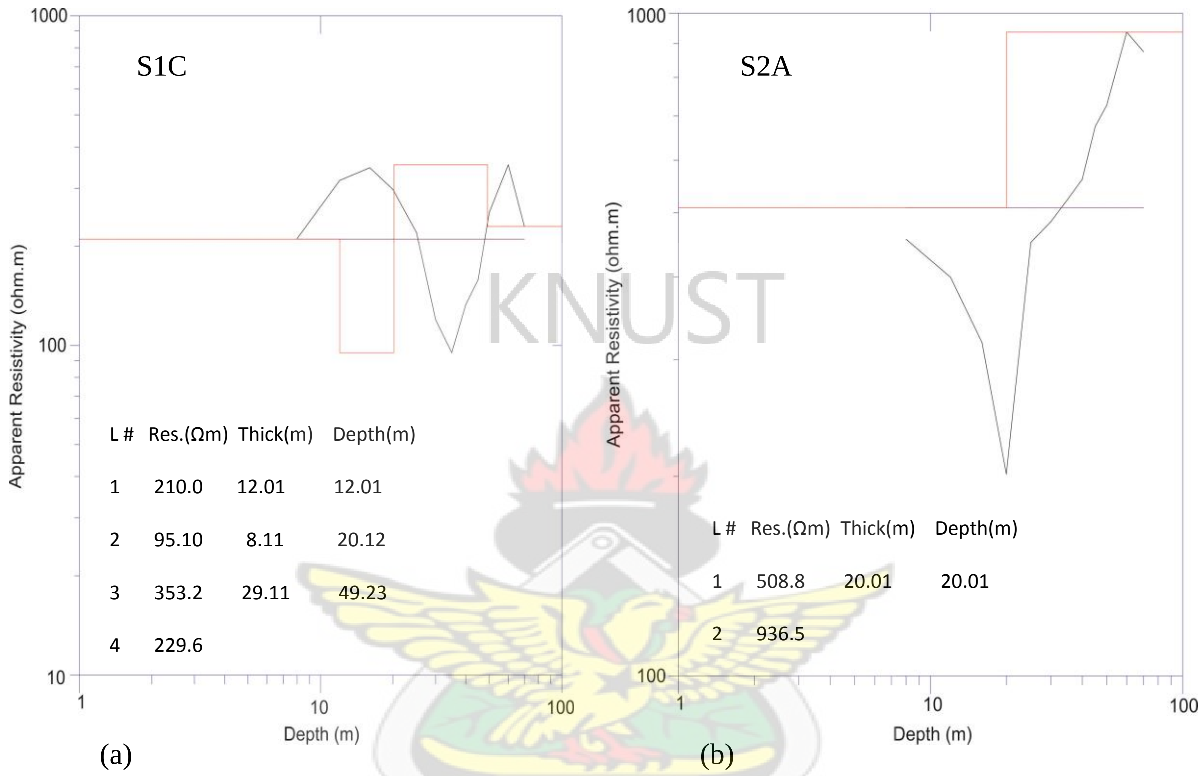


Fig.4.49 Vertical Electrical Soundings S1C and S2A- Hwiremoase

Figure 4.49a showed four layers with overburdenof resistivity 210Ωm down to a depth of 12m. The second layer could be a fractured or weathered zone, and may yield somegroundwater. It has resistivity of95Ωm between 12 and 20m. The third and fourth layers could be bedrockwith varying resistivity valuesof 353Ωm from 20 to 49m and 230Ωm from 49m downward respectively. The proposed drilling depth is 35 m.

Figure 4.49b showed two layers with an upper layer resistivity of 509Ωm from the top to a depth 20m. This is followed by bedrock with resistivity of 514Ωm from 20m downward. At 20 m, the meter recorded a relatively lower resistivity value of 202 Ωm. This could possibly be a narrow fracture. Drilling at this point was not recommended because detected fracturewas narrow and at shallow depth.

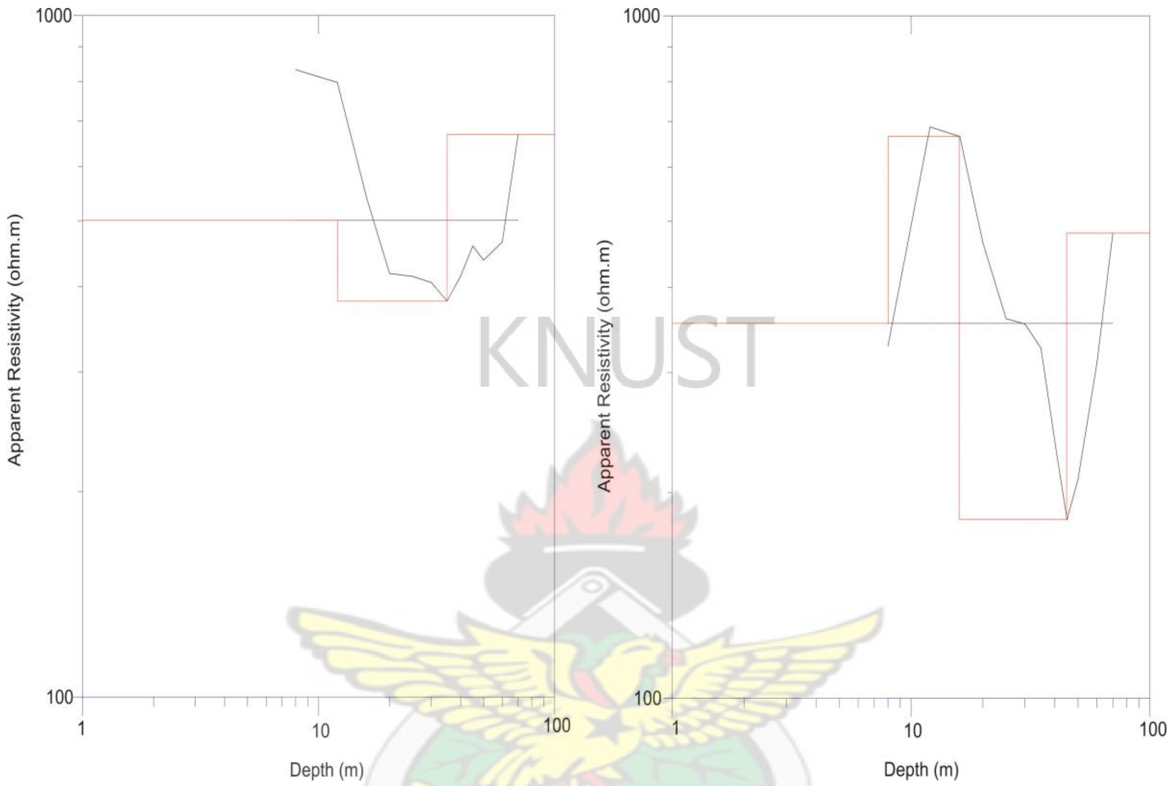


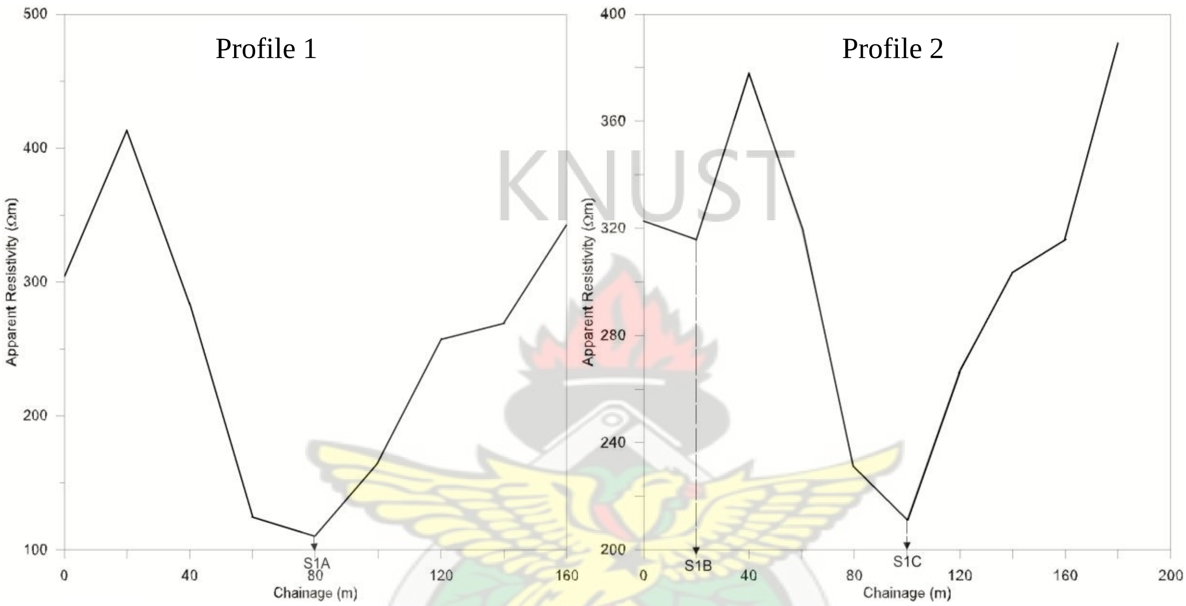
Fig.4.50 Vertical Electrical Sounding S2B and S2C - Hwiremoase

The analytical results for figure 4.50a showed three layers with overburden resistivity of 501Ωm from the top to 12 m. This could be followed by fractured or weathered zone which accommodate, groundwater or clay deposits within the bedrock whose resistivity was 381Ωm from 12 to 35m. The third layer might be hard bedrock with resistivity of 668Ωm from 35m downward.Borehole was drilled at to a depth of 68 m. The static water level (SWL) and yield were 10 m and 30 lpm respectively and formation penetrated was phyllite.

Figure 4.50b exhibited four layers with overburden resistivity of 210Ωm down to a depth of 12m. The second layer could be slightly-weathered bedrock with resistivity value of 665Ωm from 8 to 16m. The third layer could be a fractured rock with the potential to store groundwater;

and had resistivity of 183Ωm from 16 to 45m. The fourth layer could be hard bedrock with resistivity 480Ωm from 45m downward. The proposed drilling depth is 45m andthe bedrock was likely to be phyllite.

4.15 KOJO NKWANTA



(a) (b)

Fig.4.51 Resistivity Profiles 1 and 2 at 40m depth- Kojo Nkwanta

Resistivity Profiling:

Figure 4.51a indicated an increase in resistivity from 310 Ωm at zero to 420 Ωm at 20m. The resistivity dropped appreciably from this point to 80mwith resistivity of 110 Ωm and continued to ascend to the end of the profile. One low resistive point S1A at 80mwas handpicked for sounding but the zero point was not selected because of its closeness to a car park.

The result indicated a slight decrease in resistivity for figure 4.51b from 315 Ωm at zero to 375 Ωm at 20m. It decreased significantly to 100m with resistivity of211Ωm and further increased to the end of the profile at 180 m.The low resistivity could be a fractured zone, which could

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contain some groundwater whereas the high resistivity zones at 40 and 180m could be due to unfractured rock. Two potential drilling points S1B and S1C at 20 and 100m correspondingly were selected for probing.

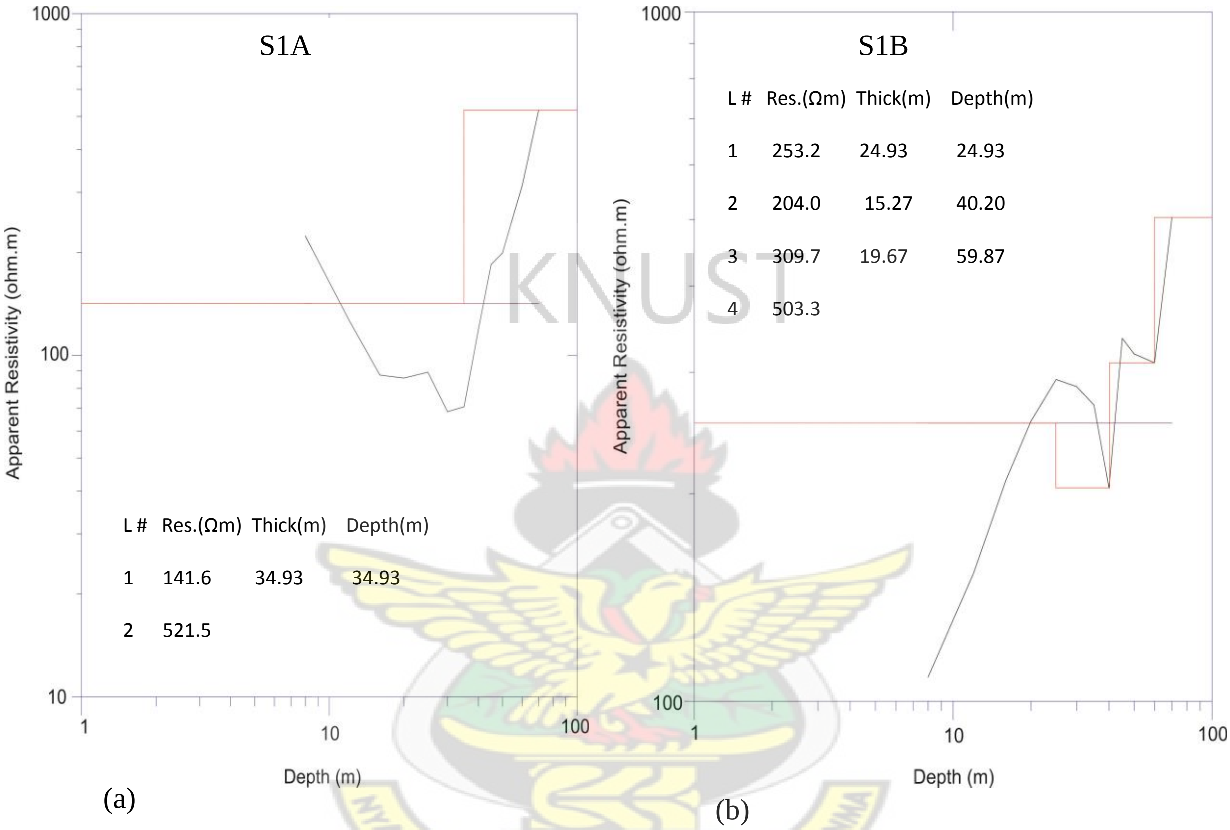

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Fig.4.52 Vertical Electrical Soundings S1A and S1B- Kojo Nkwanta

<u>Vertical Electrical Sounding:</u>

The analysis showed two layers for figure 4.52awith overburden resistivity of 142Ωm from the top to 35m. This is followed by bedrock with fractured/weathered layer with possibility of storing minerals or groundwater; and had resistivity of522Ωm from 35m downward. Drilling wasnot recommended at this point.

Figure 4.52b showed four layers with overburden resistivity of 253Ωm down to a depth of 25m. The second layer could be a weathered zone with high clay content resistivity of 204Ωm from 25 to 40m. The third layer might be slightly-fractured bedrock with resistivityvalueof 310Ωm from 40 to 60m. The fourth layer might be hard bedrock with resistivity 503Ωm from 60m downward. The proposed drilling depth was 40 m.

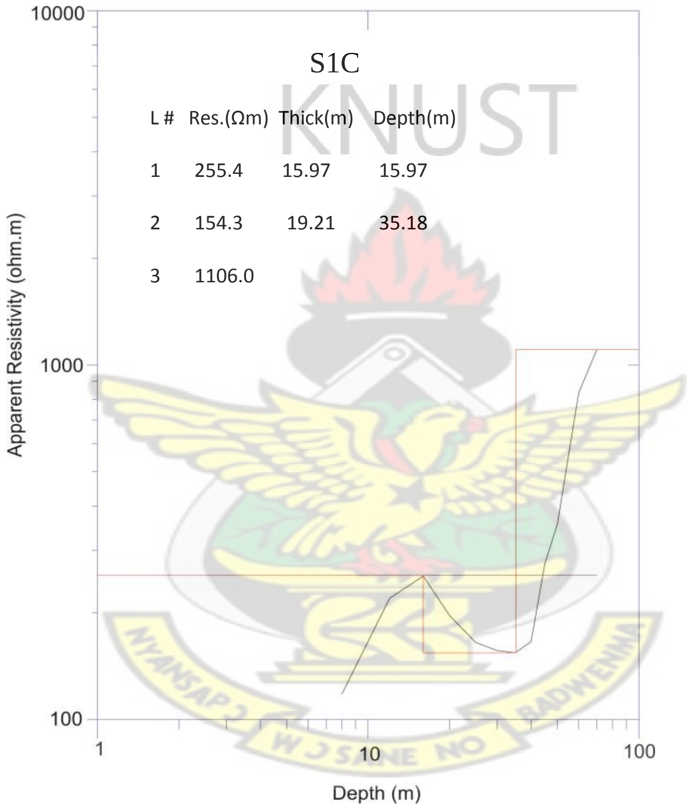


Fig.4.53 Vertical Electrical Sounding S1C- Kojo Nkwanta

The analysis for figure 4.53 revealed three layers with overburden resistivity value of 255Ωm from the top to 16m, followed by a fractured/weathered zone, having argillaceous and moisture content with resistivity of154 Ωm from 16 to 35 m. Third layer is bedrock with resistivity of 1106Ωm from 35m downward. The borehole drilled at this point was 56 m deep. The static water level (SWL) was 15 m whilst yieldwas 18 lpm.The rock penetrated was phyllite.

4.16 ODEM

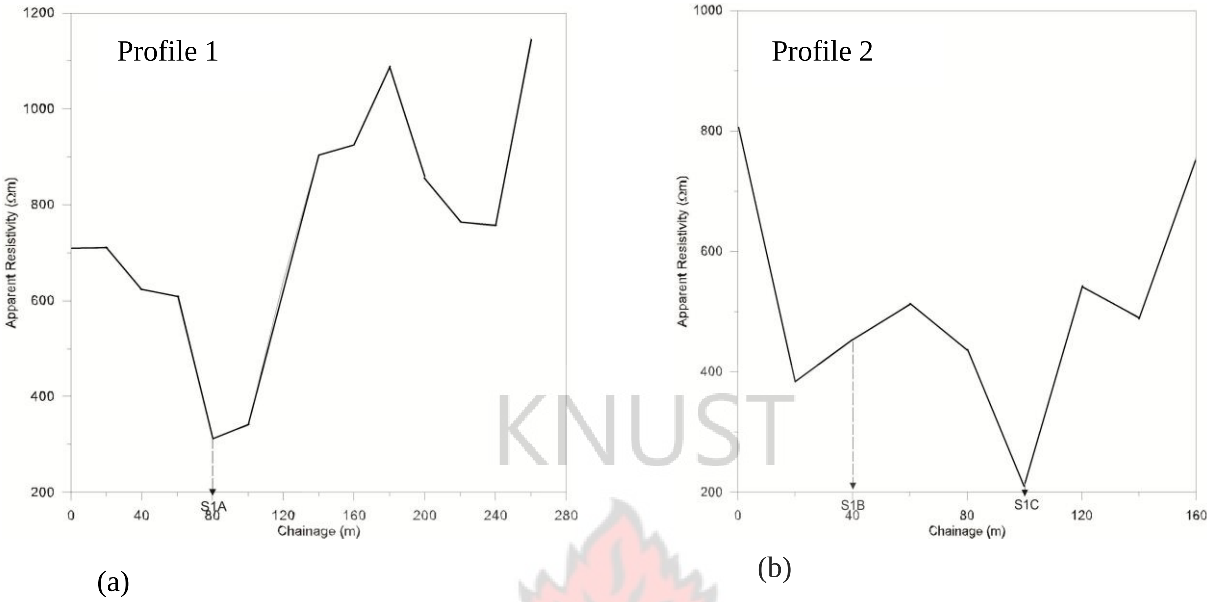


Fig.4.54 Resistivity Profiling 1 and 2 at 40m depth- Odem

Resistivity Profiling:

Fig.4.54ashowed a profile of length 280 m. There was decrease in resistivity from the start with value 720 Ωmto 80m with valueof 313Ωm. The results showed rise and fall in resistivity values to the end of the traverse.The low resistivity points could be due to fracture development within the bedrock which contain zone which contain groundwater, whereas the high resistivities at 180 and 260m could be due to unfractured portion of the subsurface. Point S1A at 80m was selected for sounding.

The result for figure 4.54b revealed a decrease in resistivityfrom the start to 20m. The resistivity values increased and dropped further at 100m with a value of 212Ωm. Afterwards the line increased to the end at 160m.The low resistivity could be a fractured/weathered zone, whereas the high resistivities at zero, 120 and 160 m could be hard rock. Two low resistive points S1Band S1C at 40 and 100m wereselected for further investigation using VES.

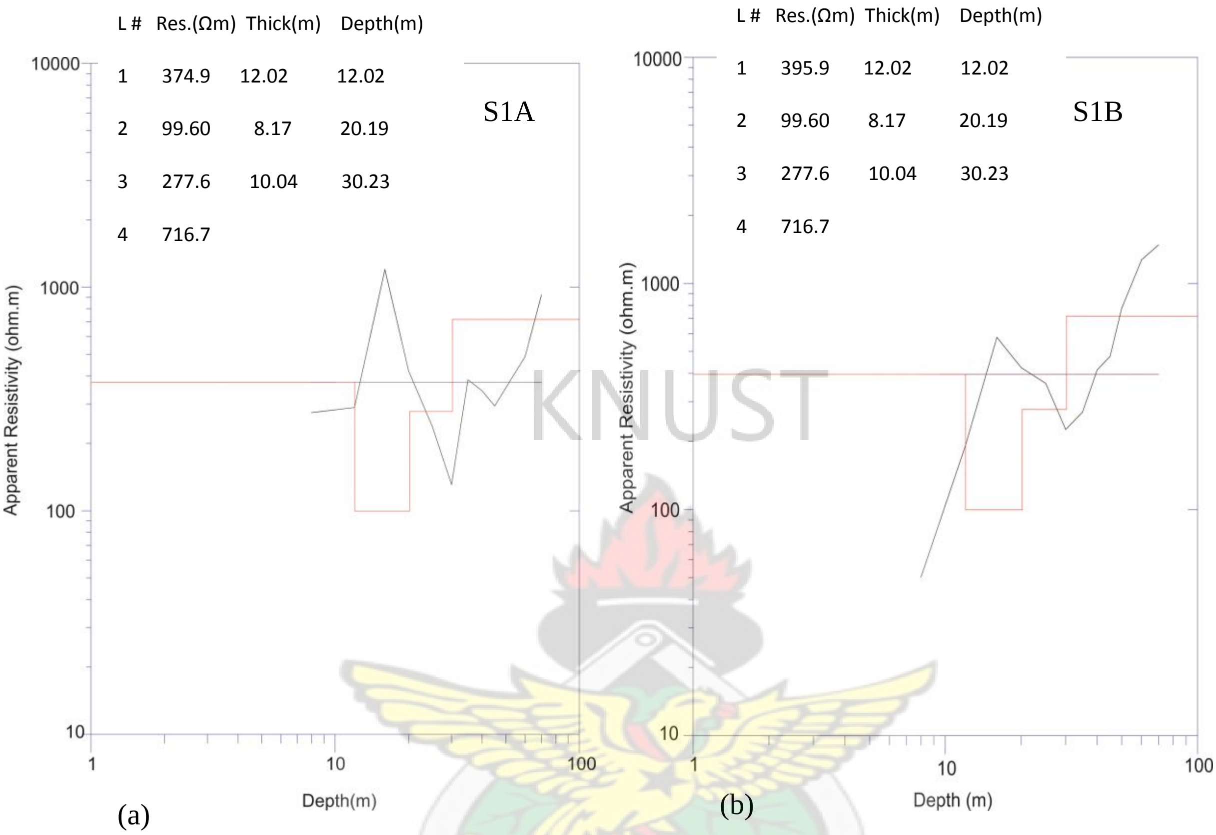


Fig.4.55 Vertical Electrical Soundings S1A and S1B- Odem

<u>Vertical Electrical Sounding:</u>

Figure 4.55a showed four layers with overburden resistivity value of 375Ωm down to a depth of 12m. The second layer could be a weathered zone with formation resistivity of 100Ωm from 12 to 20m. The third layer could be fractured bedrock with resistivity value of 278Ωm from 20 to 30m; whereas the fourth layer being hard bedrock with resistivityof 717Ωm from 30m downward.

The VES forfigure 4.55bshowed four layers with overburden resistivity of 396Ωm down to a depth of 12m. The second layer could be a weathered zone with resistivity of 100Ωm and 8m thick. The third layer could be fracturedbedrock with resistivity value of 228Ωm and thickness 10m. The fourth layer might be hard bedrock with resistivity of 717Ωm from 30m downward. Borehole was drilled at this point to 33 m. The static water level (SWL) was 3 m, whilst the yield was 18 lpm.

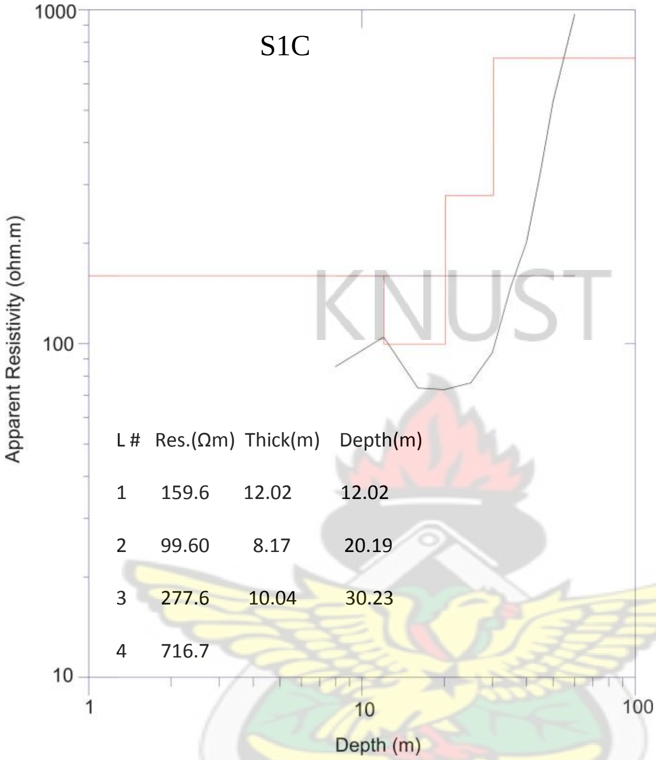


Fig.4.56 Vertical Electrical Sounding S1C- Odem

Figure 4.56 revealed four layers with overburden resistivity valueof 160Ωm from the top to a depth of 12m.The second layer could be a weathered zone with resistivity value of 100Ωm from 12 to 20m.The third layer is likely to be fracturedbedrock with value 278Ωm from 20 to 30m; whereas the fourth layer could be hard bedrock with resistivity of 717Ωm from 30m downward. The proposed drilling depth at this point is 30m. The formation was phyllite.

4.17 PIPIISO

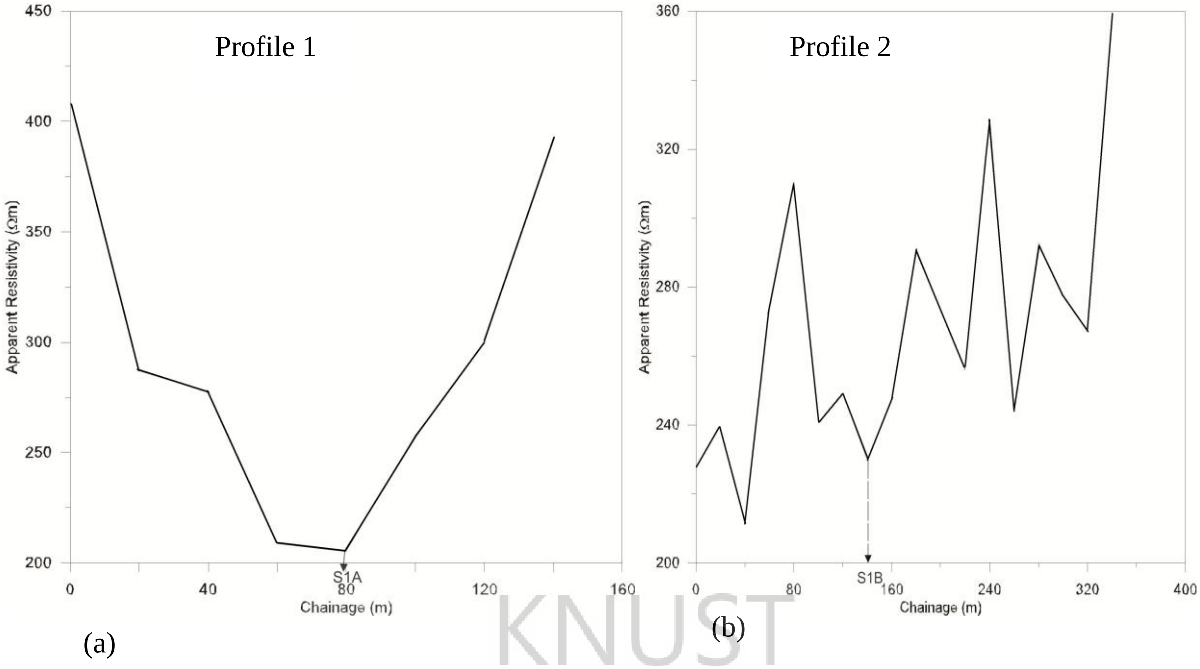
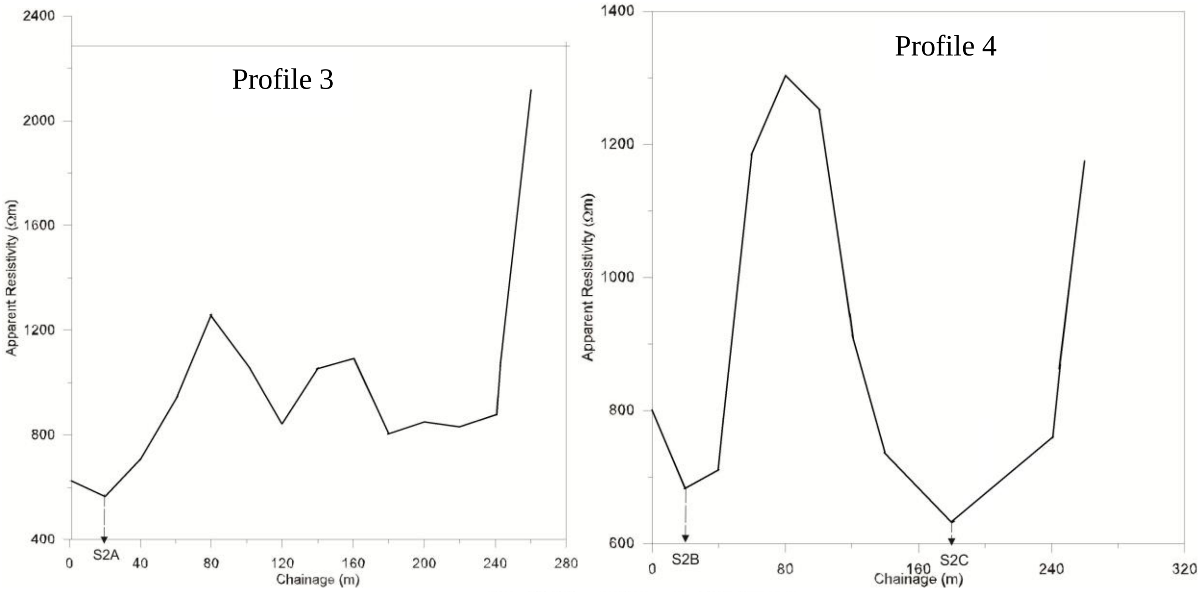


Fig.4.57 Resistivity Profile 1and 2 at 40m depth- Pipiiso

Resistivity Profiling:

Figure 4.57a showed a decrease in terrain resistivity from zerowith a value of 410 Ωm to 80m with a value of 205Ωm. The curve increased to the end of the profile at140m.The low resistivity could be due to fractures with the potential to store groundwater whereas the high resistivity at zero and 160m might be attributed to rock hardness of the subsurface. Point 80m along this traverse was selected for sounding.

Along figure 4.57b, an erratic resistivity pattern was observed. The low resistivities could be bedrock fractures zoneswhereas the high resistivities at 80, 240 and 340m might also be due to vertical intrusions such as dikes. Even though the point 140 m was selected, it was not considered for drilling becausewas close to S1A.



(a) (b)

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Fig. 4.58 Resistivity Profiles 3 and 4 at 40m depth- Pipiiso

<u>Resistivity Profiling:</u>

The result for figure 4.58a was also quite erratic. The low resistivity anomalies could be weathered zones, whereas the high resistivities at 80 and 260m could be due to boulders. A low resistive point S2A at 20mwith resistivity value 563 Ωm was picked for further investigation.

Figure 4.58b showed a slightdecrease from the start and shot up to 80m.Subsequently, it declined to 180m with value 631Ωm and rose againto 260m.The low resistivity could be due toweathered zone with high potential to contain groundwater, whereas the high resistivityvalues at points 80 and 260m could be due to rock hardness. Two lowanomaly resistivity points S2B and S2C at 20 and 180m respectively were selected for further probing.

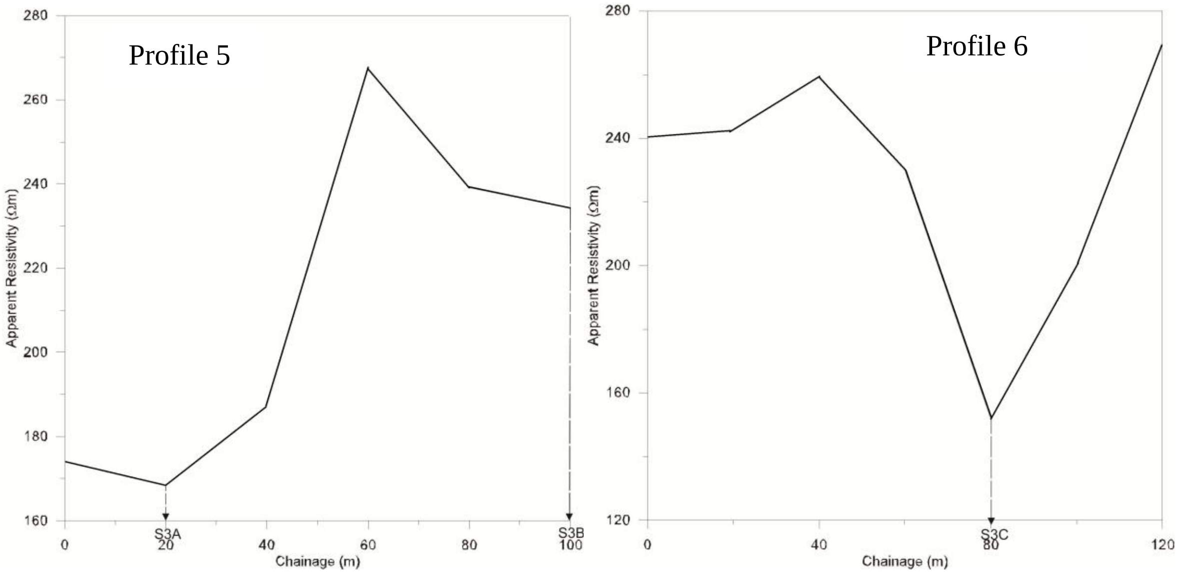

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Fig.4.59 Resistivity Profiles 5 and 6 at 40m depth- Pipiiso

<u>Resistivity Profiling:</u>

Result for figure 4.59a indicated a slight decrease in resistivity from the startbefore it rose significantly to 60m. Subsequently, it declined to the end of the profile at 100m.The low resistivity could beweathering whereas the high resistivity at 60m could be due to consolidation of the subsurface. Points S3Aand S3B at 20 and 100mwhich recorded 169 and 234 Ωm respectively were selected for sounding.

Fig.4.59bexhibited an increase in resistivity from the startto 40m and then dropped to 80m with value 152Ωm. Subsequently, it rose again to the end of the profile at 120m.The low resistivity could be a weathered zone whereas the high resistivities at 40m and 120m could be due to consolidation of the subsurface. A low resistive point S3C at 80m was marked for detailed investigation.

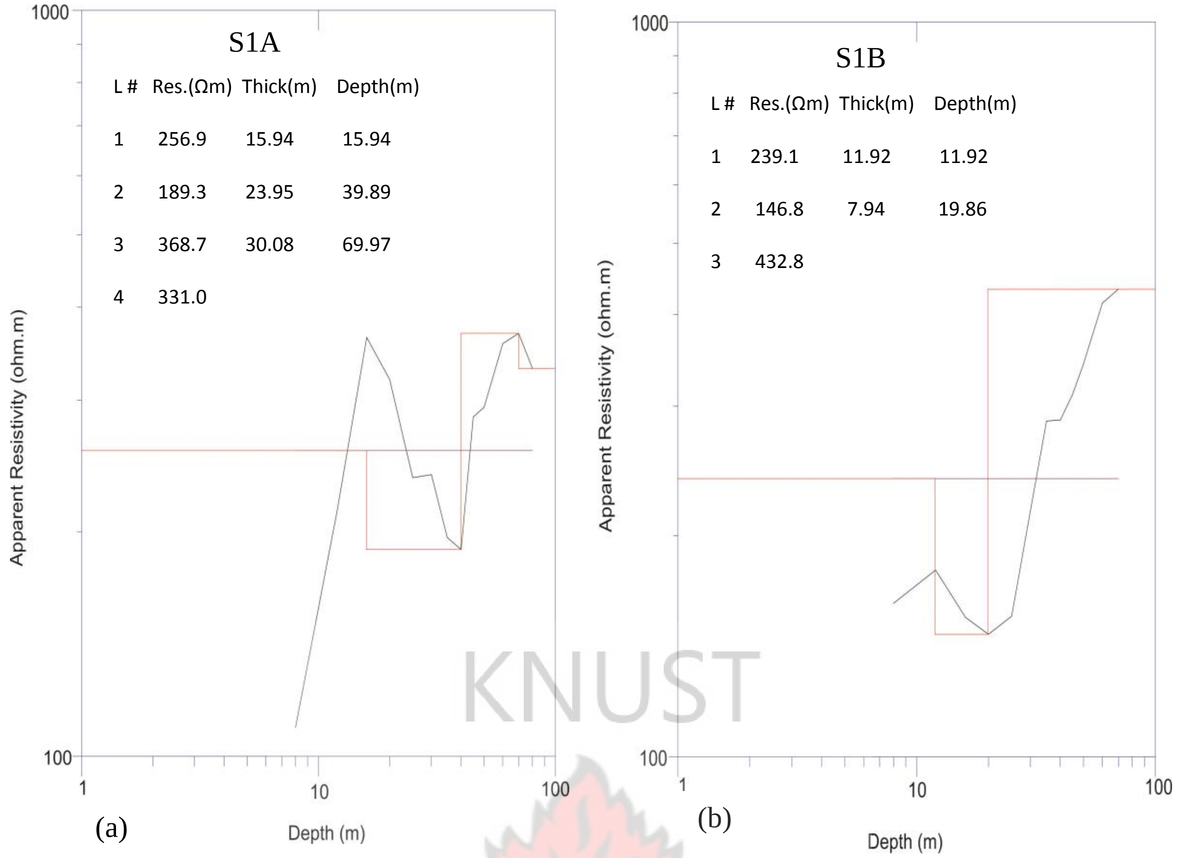

Fig.4.60 Vertical Electrical Soundings S1A and S1B- Pipiiso

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Vertical Electrical Sounding:

Figure 4.60a had four layers with overburden resistivity value of 257Ωm down to a depth of 16m. The second layer could be a fracture rock with the potential to store groundwater and has resistivity of 189Ωm from 16 to 40m. The third layer could be fractured bedrock with resistivity value of 278Ωm and 30 m thick. The fourth layer could be hard bedrock with resistivity of 331Ωm from 70m downward. The aquifer is expected at 40m.

The analysisfor figure 4.60bshowed three layers with overburden resistivity of 239Ωm from the top to 12m. This is followed by aweathered zone with resistivity of 147Ωm from 12 to 20m. Third layer could be fractured bedrock with resistivity of 433Ωm from 20m downward. Drilling at this point is recommended to a depth of 30m.

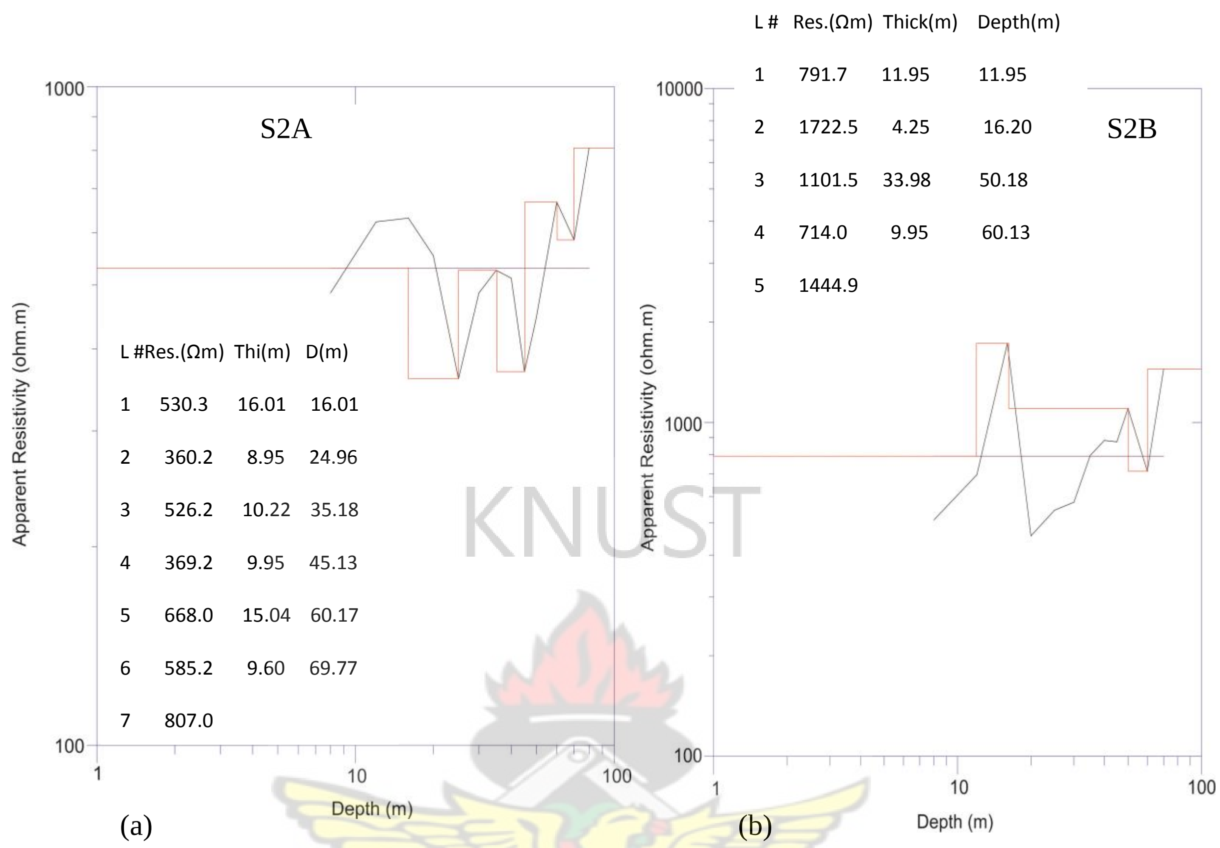

Fig.4.61 Vertical Electrical Soundings S2A and S2B- Pipiiso

Figure 4.61a had seven layers with overburden resistivity of 530Ωm down to a depth of 16m. The second layer could be a weathered zone with resistivityof 360Ωm from 16 to 25m. The third to fifth layers could be slightly-fractured bedrock with an intermediate less resistive fourth layer which might be weathered or fractured due to temperature and pressure changes. The sixthand seventh layers could be hard bedrock withresistivity values of 585Ωm from 60to 70m and 807 Ωm from 70m downwards. The anticipated drilling depth at this point is 46 m.

Analysis forfigure 4.61b showed a five layer model with overburden resistivity of 792Ωm down to a depth of 12m.This was followed by the second and third layers, with resistivityvalues of 1723Ωm from 12 to 16m and 1102Ωm from 16 to 50m correspondingly.The high resistivity of the second layer could be interpreted as an intrusive rock. The decrease in resistivity in the fourth layer could be due to fracturing between the fresh and hard bedrock. Its resistivity was 714Ωm from 50 to 60m. The fifth layer was hard bedrock with resistivity of 1445Ωm from 60m downward. The depth of borehole drilled at this point was 48 m. The static water level (SWL) and yield were 6m and 17 lpm respectively.

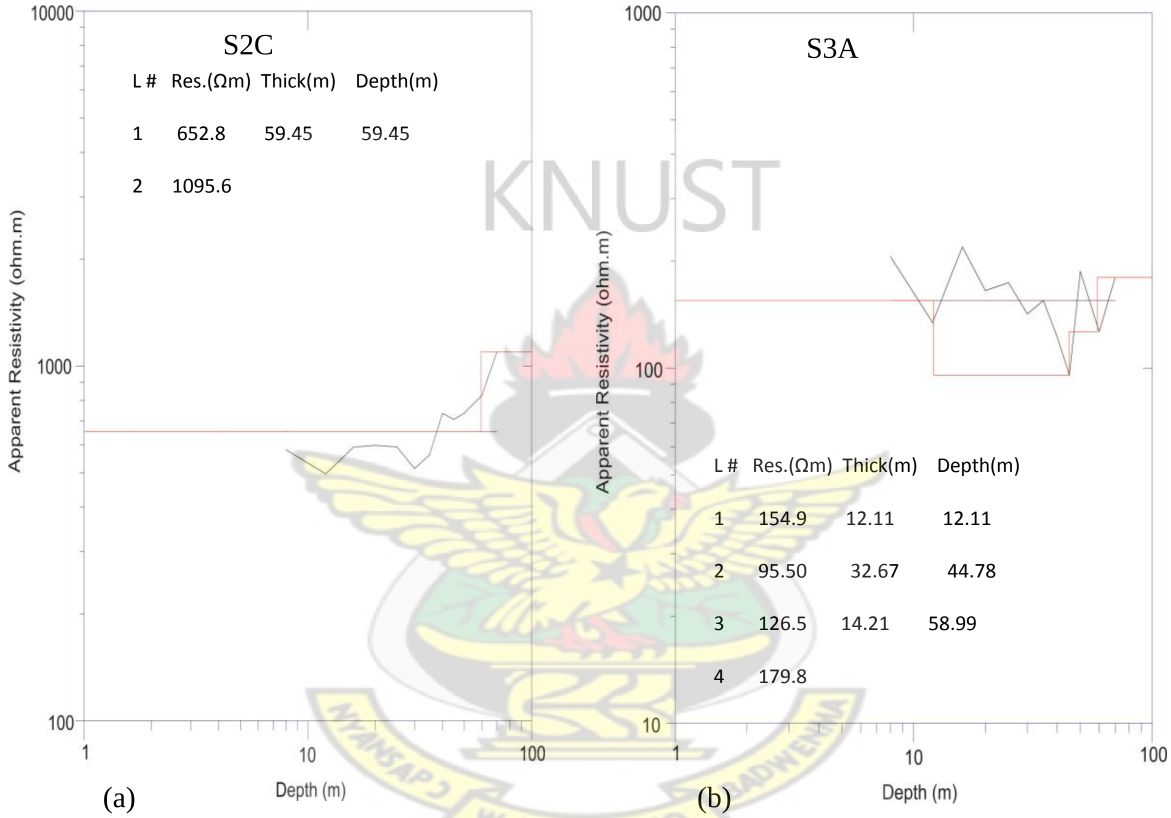

Fig.4.62 Vertical Electrical Soundings S2C and S3A- Pipiiso

Analysis for figure 4.62a indicated a two-layer structure with very thick overburden of resistivity 653Ωm from the top to 59m. This is underlain by bedrock with resistivity 1096Ωm from 59m downward. Drilling at this point was not recommended because there was no clear indication of a fractured/weathered zone.

Figure 4.62b had four layers with overburden resistivity of 155Ωm down to a depth of 12m. The second layer could be a fractured zone with resistivity of 96Ωm from 12 to 45m.The third layer could be slightly-fracturedbedrock with resistivity of 127Ωm from 45 to 59m. The fourth layer could be semi-fresh hard bedrock with resistivity of 180Ωm from 59m downward. The proposed drilling depth was 45m.

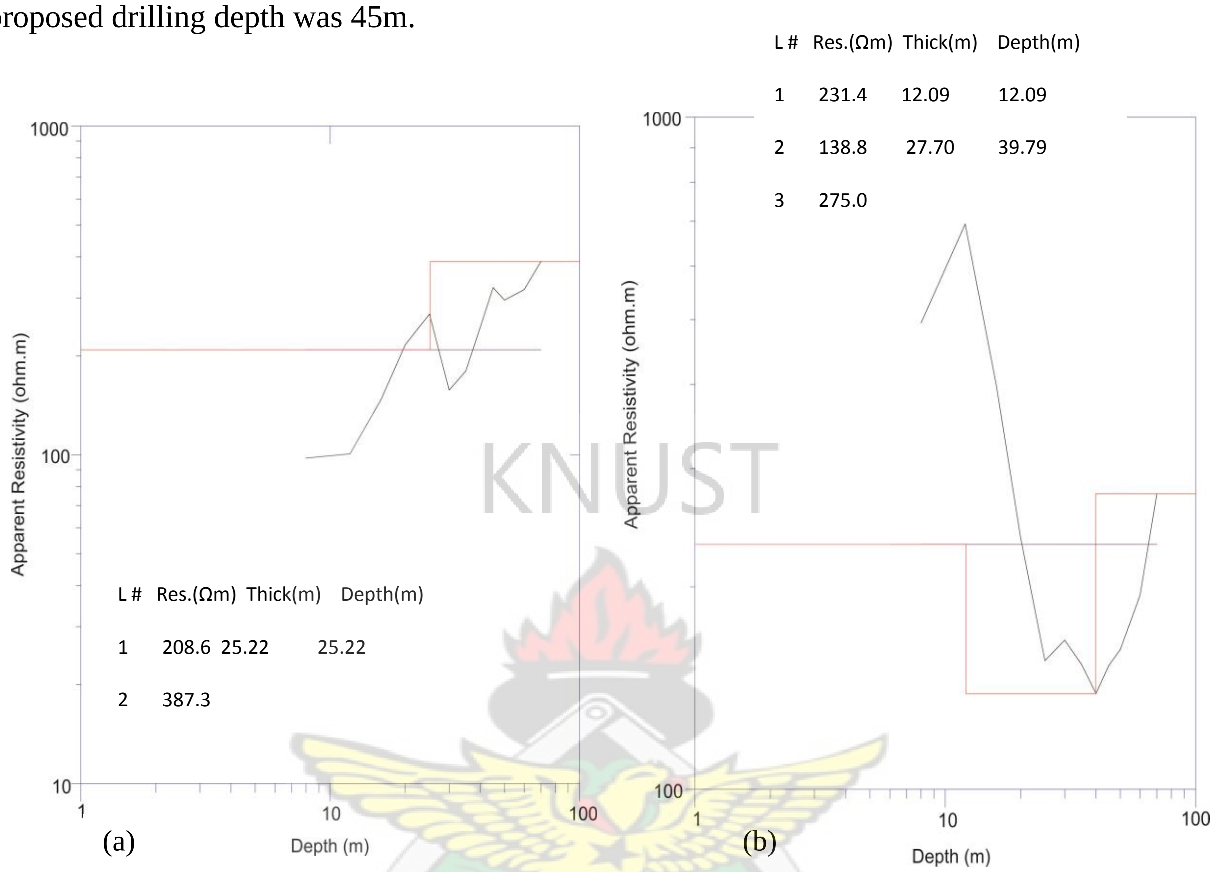

Fig.4.63 Vertical Electrical Soundings S3B and S3C- Pipiiso

The study showed two layers for figure 4.63a with overburden resistivity valueof 209Ωm down to 25m. The top soil down to about 8m was likely to be clay because it had resistivity of 97 Ωm. This was followed by bedrock with resistivity 387Ωm from 25m downward. Drilling at this point was recommended to a maximum depth of 35m.

Depth probing at figure 4.63b indicated three layers with overburden resistivity of 231Ωm from the top to 12m. This was underlain possibly by fractured/weathered zone with resistivity of 139Ωm from 12 to 40m. Third layer could be hard bedrock with resistivity of 275Ωm from 40m downward.One borehole was drilled at this point to a depth of 36 m. The static water level (SWL) and yield were 5 m and 40 lpm respectively.The rock penetrated was phyllite.

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4.18 SILENCE STATE

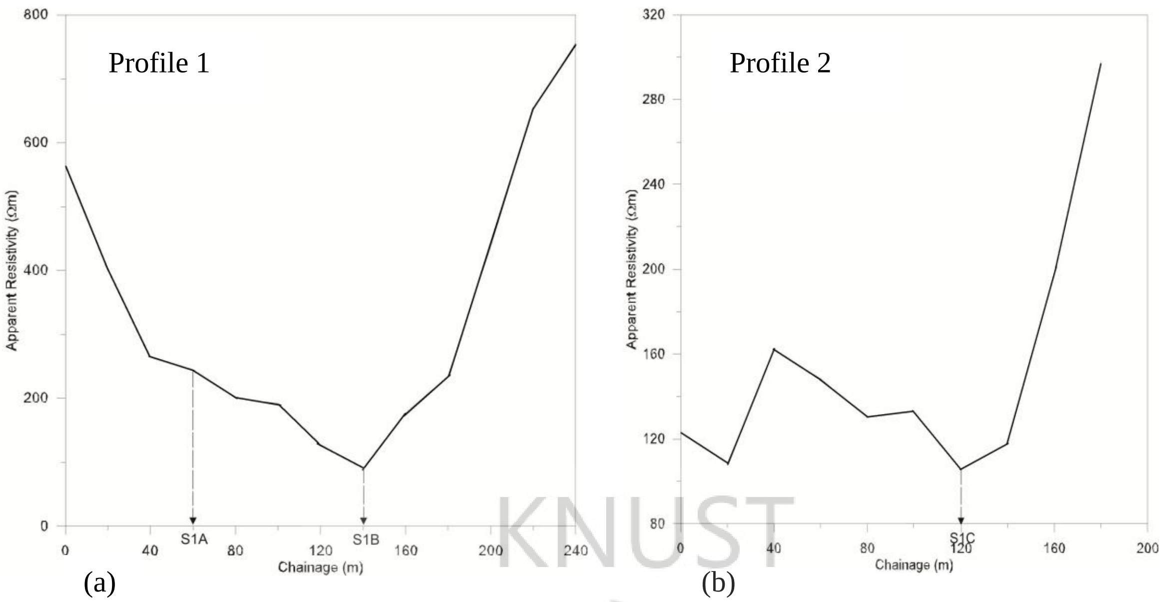

Fig.4.64 Resistivity Profile 1 and 2 at 40m depth- Silence State

<u>Resistivity Profiling:</u>

Figure 4.64a indicated a decrease from the beginningwith a value of 560 Ωm to 140 m with resistivity of 259Ωm. The resistivity then increased till the end of the traverse. The low resistivity could be a fracture zone, which contained mineralization or groundwater whereas the high resistivity at zero and 240m could be due to consolidation of the subsurface. Two low resistivity anomaly points S1Aand S1B at 60 m and 140m with values 244 and 90Ωm were selectedfor sounding.

Result for figure 4.64b showed a slight decrease in resistivity from the startto 20m. It rose to 40m and then dropped again at 120m with resistivity of 106Ωm. Finally, the curve rose to the end of the profile at 180m.The low resistivity could be a fractured zone, which could contain minerals or groundwater whereas the high resistivity at 40 and 180m could possibly be due to compaction of the subsurface. Point S1C at 120m was picked for further work but the 20m point was not selected because it was close to profile 1.

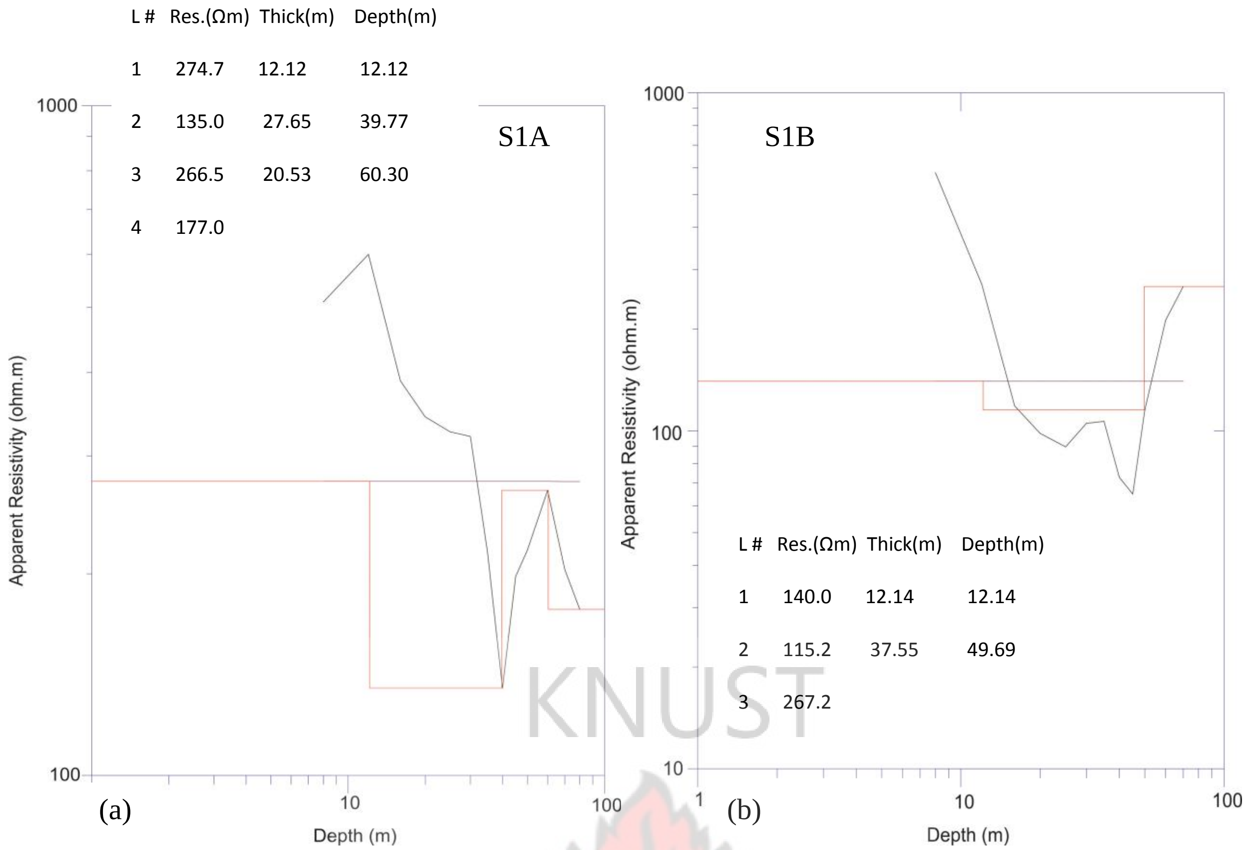

Fig.4.65 Vertical Electrical Soundings S1A and S1B- Silence State

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<u>Vertical Electrical Sounding:</u>

Figure 4.65a revealed four layers with overburden resistivity of 275Ωm, which was 12m thick. The second layer could be a fractured/weathered zone with mineralization potential or groundwater and had resistivity of 135Ωm and thickness of 28m. The third layer could be slightly-fracturedbedrock with value of 227Ωm and thickness of 20m. The fourth layer could be an intermediate layer between the fresh bedrockand the hard bedrock with resistivity of 177Ωm from 60m downward.Borehole was drilled at this point to a depth of46 m. The static water level (SWL) and yield were 9 m and 20 lpm respectively. The formation penetrated during drilling was phyllite.

VES analysisforfigure 4.65b showed three layers with overburden resistivity of 140Ωm from the top to 12m. This was underlain by thicka fractured/weathered zone withresistivity of 115Ωm from 12 to 50m. The third layer could be bedrock with resistivity of 267Ωm from 50m downward. Groundwater at thispoint could be drilled to a maximum depth of 50 m.

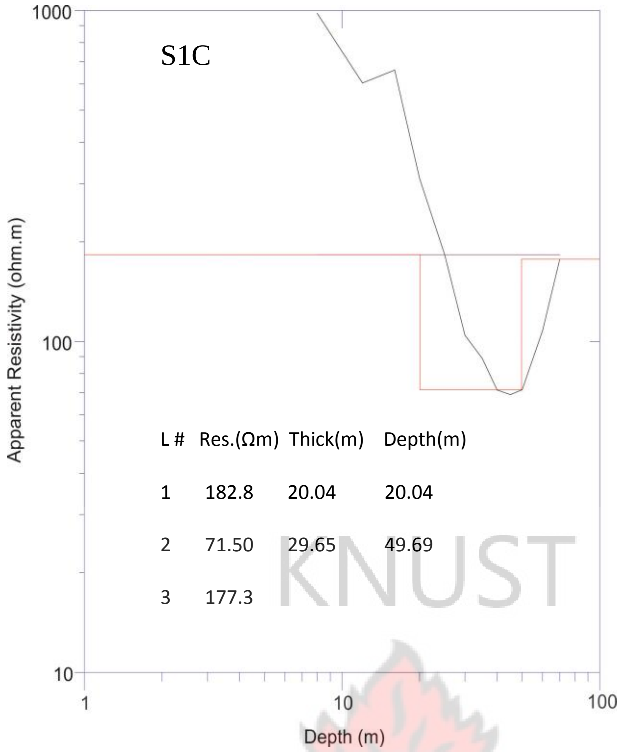

Fig.4.66 Vertical Electrical Sounding S1C- Silence State

VES analysis forfigure 4.66 showed three layers with upper layer resistivityof 183Ωm from the top to 20m. This might be followed by a fractured/weathered formationwith resistivity of 72Ωm from 20 to 50m. Third layer could be bedrock with resistivity of 177Ωm from 50m downward. The aquifer could beintercepted at 50m; the bedrock and aquifer material could probably be phyllite.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The Vertical Electrical Sounding (VES) results showed low to moderately high apparent resistivity values in the formations. The interpretation of the sounding results revealed that most of the communities were underlain by an overburden thickness ranging from 12to 16m. Moderately weathered material ranging from less than one meter to several meters in thickness separate the overburden from the underlying fracturedbedrock and the hard bedrock. Thebedrock may be associated with fractures in some of the communities and these resulted in relatively lower resistivities.

Minimum borehole yieldof17 lpmwas recorded at Akokora Yaw Amoah, Etoakrom and Pipiiso; whiles maximum yield of 150 lpm was obtained at Hwiremoase. The meanborehole yield was 38 lpm. Average borehole depth and static water level were 48 and 8 m respectively (see appendix 1).

The success rate was 64 % as 13 out of the 36 drilled holes were dry. Potable drinking water which conformed to World Health Organization (WHO) guideline values were provided for beneficiary communities (see appendix 3).

5.2 Recommendations

The researcher observes that profiling at a constant depth of 40m is a limitation on the study because prospective water-bearing zones could occur beyond this depth; hence further studies could be done to explore more boreholes in the district.

Theelectromagnetic method using Geonics EM34-3 conductivity meter could also be used to locateresistivity anomaly zones that have the potential to store groundwater.

Resistivity method used for the project was efficient and reliable as the success rate was 64%.

Finally, further work to determine groundwater infiltration and consequent pollution from various minerals such as Iron, Magnesium and human activities should be done to ensure safety of consumers.

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APPENDICES

APPENDIX 1: Borehole depth, Airlift yield and Geological formation of successful boreholes

Community	Borehole Depth (m)	Airlift yield (lpm)	Geological formation
Adom Koforidua- S1C	40	60	Granite
Ahinsan Newton- S1A	40	40	Granite
Ahinsan Pri. Camp- S1C	60	50	Phyllite
Akokora Y. Amoah- S1A	46	17	Phyllite
Akrokerri P. J.H.S- S1B	53	20	Granite
Akwansirem- S1A	44	40	Phyllite
Akwansirem- S2A	48	80	Phyllite
Akwansirem- S3B	50	30	Phyllite
Anwona- S1C	47	18	Phyllite
Anwona- S2B	52	51	Phyllite
Anwona- S3B	32	30	Phyllite
Anwona- S4B	64	20	Phyllite
Ayokoa S. Church- S1C	48	30	Quartzite
Etoakrom- S1B	48	17	Phyllite
Fumso Ketewa- S1B	47	20	Quartzite
Hwiremoase- S1B	56	150	Phyllite
Hwiremoase- S2B	68	30	Phyllite
Kojo Nkwanta- S1C	56	18	Phyllite
Odem- S1A	33	18	Phyllite
Pipiiso- S2B	48	17	Phyllite
Pipiiso- S3C	36	40	Phyllite
Pipiiso- S4A	48	50	Phyllite
Silence State- S1A	46	20	Phyllite

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APPENDIX 2: **GPS coordinates of project communities**

NAME OF COMMUNITY	GPS COORDINATES
1. Adom Koforidua	6.1^0N 1.3^0W
2. Ahinsan Newtown	6.2^0N 1.3^0W
3. Ahinsan Prison Camp	6.1^0N 1.3^0W
4. Akokora Yaw Amoah	6.1^0N 1.3^0W
5. Akrokerri JHS	6.2^0N 1.4^0W
6. Akwansirem	6.1^0N 1.3^0W
7. Anitoa	6.1^0N 1.2^0W
8. Anwona	6.1^0N 1.3^0W
9. Ayokoa Saviour Church	6.1^0N 1.3^0W
10. Domeabra II	6.2^0N 1.4^0W
11. Etoakrom	6.1^0N 1.2^0W
12. Fumso Ketewa School	6.1^0N 1.2^0W
13. Hwiremoase	6.1^0N 1.3^0W
14. Kojo Nkwanta	6.1^0N 1.3^0W
15. Odem	6.1^0N 1.2^0W
16. Pipiiso	6.1^0N 1.2^0W
17. Silence State	6.2^0N 1.3^0W

APPENDIX 3: Analysis of some water samples

Analysis of water sample-Ahinsan Newton (S1A)

ITEM	PARAMETER (in mg/l unless otherwise stated)	WHO GUIDELINE VALUES (GV)	TEST RESULTS
1	Colour App/True (Hazen Units)	15.0	3 / 0
2	Odour	Unobjectionable	Unobjectionable
3	Taste	Unobjectionable	Unobjectionable
4	Turbidity (NTU)	5.0	0.61
5	Conductivity (µS/cm)	1000	103.1
6	Total Dissolved Solids (TDS)	1000	51.0
7	pH	6.5-8.5	7.02
8	Total Alkalinity (as mg/l $CaCO_3$)	-	84.0
9	Total Hardness (as mg/l $CaCO_3$)	500.0	46.0
10	Sodium	200	0.02
11	Calcium	200	8.8
12	Magnesium	150	5.83
13	Iron (Total)	0.3	0.0
14	Manganese	0.1	0.002
15	Potassium	30	1.6
16	Phosphate	400	0.04
17	Chlorine	250	6.0
18	Fluorine	1.5	0.45
19	Sulphate	400	0.0
20	Arsenic	1.5	0.0
21	Nitrate	50.0 max	0.01
22	Ammonia	1.5	0.0

REMARKS: Source is chemically and bacteriologically safe for human consumption

Analysis of water sample-Anwona (S1C)

ITEM	PARAMETER (in mg/ l unless otherwise stated)	WHO GUIDELINE VALUES (GV)	TEST RESULTS
1	Colour App/True (Hazen Units)	15.0	9 / 0
2	Odour	Unobjectionable	Unobjectionable
3	Taste	Unobjectionable	Unobjectionable
4	Turbidity (NTU)	5.0	1.41
5	Conductivity (µS/cm)	1000	303.0
6	Total Dissolved Solids (TDS)	1000	151.0
7	pH	6.5-8.5	6.83
8	Total Alkalinity (as mg/l $CaCO_3$)	-	134.0
9	Total Hardness (as mg/l $CaCO_3$)	500.0	62.0
10	Sodium	200	1.0
11	Calcium	200	23.2
12	Magnesium	150	0.97
13	Iron (Total)	0.3	0.0
14	Manganese	0.1	0.004
15	Potassium	30	2.86
16	Phosphate	400	0.02
17	Chlorine	250	28.0
18	Fluorine	1.5	0.50
19	Sulphate	400	0.0
20	Arsenic	1.5	0.0
21	Nitrate	50.0 max	0.32
22	Ammonia	1.5	0.0

REMARKS: Source is chemically and bacteriologically safe for human consumption