AN INVESTIGATON OF GROUNDWATER POTENTIAL OF GADA TOWN, SOKOTO STATE USING VERTICAL ELECTRICAL SOUNDING

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DECLARATION

I here by declare that this thesis has been written by me and that the information contained here is a record of my own research work.

All sources of information obtained and other literary publications have been duly acknowledged by means of references.

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A.M. GADA DATE

DEDICATION

This Thesis is dedicated to my parents, my wife Hajara, my daughter Nabila and the ones to be.

CERTIFICATION

This thesis titled "An investigation of groundwater potential of Gada town, Sokoto State using uses vertical electrical sounding" by A.M. Gada meets the requirements of the regulations governing the award of Master of Science degree in geography (hydrology), of the Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The survey titled an investigation of groundwater potential of Gada town, Sokoto State using uses vertical electrical sounding was carried out with the aim of determining the ground water potential of the town and to determine as well suitable areas for siting of hand-dug wells. Wells are the only reliable source of water supply in the town and it's surrounding during the dry season when most of the wells dry up or have low yield. This necessitates the need to search for an alternative source of water supply and hence the need for appropriate geophysical survey to minimize the tendency of drilling abortive or low yield wells.

A geoelectrical survey using vertical electrical sounding VES was carried out at 28 VES stations, which were equally spaced at 100 meters intervals out of eight profiles established. The profiles run East-West and North-South depending on the direction of the available spaces, and were labeled A-H.

The survey covers Gada town, which is about 2Km^2 and the result, obtained from the interpretation of the VES data collected to the construction of geoelectrical and geologic sections. Bore holes loggs of the town were also used which aided the interpretation of the section.

A total of94 layers were encountered from the 28VES point survey in Gada town, and only 24 layers were found to be suitable for ground water prospecting. The layers were all located at the third and fourth states, and most of them were found on C and E profiles with 5 and 4 points respectively. C I, C2, C3, C4, C5, C6 for C profile and E3, E4, E6, E7, for E profile. A profile has two points at A2 and A4 on the 41h and yd strata, while only one point was located on B profile at B2 point on the 4th layers but highly promising.

All the remaining layer points are less significant as they fall within the non-suitable to moderate which are very unlikely to get water.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Scarcity of potable water has been a problem of great concern to humanity.. Hence the declaration of 1980- 1990 as the decade of water supply and storage by the '1976' U.N .conference of Human Settlements held in Canada. The Conference recommended the target of provision of potable water for all by 1990. Unfortunately the target has not been realized, especially in developing countries (Olarinde, 1998). The major sources of water supply to man are rainfall, rivers, lakes and the groundwater sources. Surface sources such as rivers and lakes because they can be seen and observed have always been easier to harness, extract and utilize. These Sources are also vulnerable to contamination and are subject to dwindling as a result of evaporation, careless extraction and misuse. Groundwater is another sources of water supply but requires a lot of efforts and investment to harness and extract. Yet, less than 3 percent of fresh water available at any given moment on our planet earth occurs in streams and lakes, while the remaining 97 percent is locked up in underground reservoir (Johnson, 1975). While groundwater may mean different thing to different people because of differences in perception and profession, it is used here to connote the water contained in the zone of saturation of the soil.

The geologic formation which contains and permits significant amount of water to move through it under ordinary field condition is termed aquifer. Aquifers can be confined or unconfined, depending on the presence or absence of water table within the favourable bedding disposition of the geologic formation. In contrast, some formation could be Aquiclude (contains water but cannot transmit it), Aquitard (transmit water at a very low rate) Aquifuge (neither contains nor transmit water), and leaky aquifers (loose or gain water from boundary formations).

Despite historical tendency favouring surface water development and exploration in urban and rural areas, a number of factors have been observed to favour exploitation of groundwater resources, particularly in dry regions such as parts of northern Nigeria. For example, groundwater:

i. minimizes reticulation cost of surface water, at least for supplies upto moderate discharge;
ii. has excellent microbiological and organic quality and often may require minimal treatment cost;
iii. capital costs for its development is relatively moderate and the land requirement minimal; and
iv. resources also lends itself to flexible development and capable of being phased with rising demands.

Unfortunately, available data on groundwater resources are few and greatly inadequate, especially in most developing countries like Nigeria. As such, successful development need be promoted by prospecting and exploration studies. Geophysical survey using different techniques are now available and being employed to investigate the hydrogeological condition of groundwater potential in dry environments such as in northern Nigeria. Presently, there are also the craze for construction of boreholes but with little sound technical information of where and how deep to drill. The fact that boreholes were drilled at locations predetermined by their owners, instead of on the basis of good hydrogeophysical investigation of the areas concerned has led to the high rate of unproductive and poor yielding boreholes (Offodile, 2002).

It is observed that by accurately establishing the most suitable well location through geophysical survey, the percentage of productive wells increased, while the huge expenses of dry or abortive boreholes are greatly reduced. (Odera et al., 1987)

1.2 THE RESEARCH PROBLEM

Northern Nigeria is characterized by a broad rainfall regime with total amount of rainfall ranging from 1500mm in the South to about 381mm in the extreme North (Sawa, 2002). In the extreme northern parts, distinct dry season often lasts more than 7 months in a year. When the rainy season comes it is in wet and dry spells with less predictable onset and cessation with variability's in intensities and spatial distribution. Besides, the high evapo-transpiration that prevails in the region results in large annual deficit water balance.

Most streams in the extreme north are not only ephemeral, but are also being competed for by livestock/ wildlife and human population. Hence the problem of water shortage. Even the "Fadamas" also close up. The alternative is groundwater resources.

The study area falls within this region in the Sokoto basin known as the Iullemeden Basin within the Rima group, which consist of Wurno, Dukamaje and Taloka formation. Dakamaje is shaley so it does not contain water, but Wurno and Taloka contain appreciable quantity of water (JICA,1990). Gada town falls within this geologic formation and water problem situation.

When dry season is severe, most handdug wells in the area dry-up. Only deep hand-dug wells provide water at intermittent intervals for the rest of the year and at reduced yield. The only reliable source of water supply in Gada town and its surrounding at this difficult time of the year is in the Fadama area where hand-dug shallow wells provide water at low yields. The groundwater in the Fadama locations is relatively easy to exploit and suitable for small scale development for domestic, livestock and irrigation, provided the rural population is small.

However, a major problem of groundwater supply in Fadama areas is its use for irrigation agriculture, with heavy manuaring/application of chemical fertilizers to grow vegetable and fodder. As such the water in some Fadama may not be potable.

The search for the proposed alternative source of water supply requires an appropriate geophysical survey method without which there is the tendency of drilling abortive or low yield wells. This has already been observed and there are many in Gada and the neighbouring villages, where many boreholes and hand-dug wells have dried up or have low yield.

Based on the nature of the bedrock of the area (weathered Rima Group Formation), and the stratigraphy, high water yielding aquifers are likely to be found on the upland and valley side areas (i.e. perched aquifer). Information regarding such requires proper and detailed geophysical surveys. This is the thrust of the study.

1.3 AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to characterize the groundwater potential of Gada town, Sokoto state, Nigeria. To achieve this aim, the following objectives were tackled:

i. to identify and describe the lithological details of the bedrock of Gada town using Vertical Electrical Sounding (VES) geophysical survey.

ii. to map its hydrogeological boundaries

iii. to classify the groundwater potential of the town.

1.4 SCOPE AND LIMITATION

The study is restricted to Gada town. It focuses on the development of groundwater potential as a source of water supply for the town. For now, the main sources of water supply for the community are from low yielding boreholes and hand-dug wells which provide potable water for the people and their livestock. However surface water can be found but only during rainy season in a dry river course that tends to surround the town in a north-east-south direction and which quickly dries up at the end of the rain. The water in the Fadama is mainly used for irrigation during dry season with the help of shallow hand - dug wells that sustains the farming activities.

These shallow hand-dug wells also serve as a major source of domestic water supply for people and their livestock when dry season is severe and most dug-wells upland dry up. Most of the boreholes dug in the town are abortive or have low yield or are not functioning.

1.5 JUSTIFICATION OF THE STUDY

Increase in the population of people and their livestock, coupled with increase in sanitation and personal hygiene, and demand for more water uses for the purposes of buildings, hospitals and the proposed sewarage system demand for usable water in Gada town. This therefore made it necessary to look for alternative source of water supply in the area to meet the rising demands. Besides, during the dry period water sellers ("Yan Taula"- Hausa) go about from one place to another in search of water mostly in the Fadama area. People use donkeys and trolleys which carry two to three drums (i.e 252 – 378 liters) per trip, while water sellers use tins (18 liters which they carry on their shoulders with the help of a stick on which they hang the tins one on each end of the stick. One Taula (2 tin cans) cost about ₦30 to ₦40 and a drum costs about ₦120 – ₦140 depending on the distance. Certainly there is urgent need to address the question of possible solution to the water problem in Gada Town.

CHAPTER TWO

LITERATURE REVIEW AND THE STUDY AREA

INTRODUCTION

In this chapter section 2.1 reviews the related literature, while section 2.2 discuss the geographical background of the study area and section 2.3 present the conceptual framework.

2.1 LITERATURE REVIEW

The study of groundwater began from the ancient times. The Greeks first observed that after rainfall, rain water disappear from the earth surface without a corresponding rise in the volume of water in oceans, seas and rivers.

In China, wells were already drilled at least 3,000 years ago with hand operated churn drills, to a depth of about l00m and lined with bamboo casings. Hand-dug wells have been sunk since time immemorial to a considerable depth atimes in several parts of the world (I.R.C., 1998). The technology of tapping groundwater at great depths through tube wells is a recent phenomenon.

Prospecting for water requires a basic knowledge of the various kinds of groundwater bearing formations that can be found in the earth crust. Without this knowledge, effective and efficient water exploration is impossible (1. R. C 1998).

The groundwater potential of an area may be determined through geophysical investigation. Geophysical technique is a collection of survey methods used to investigate the geology of an area by identifying and measuring certain physical properties of the bedrock materials.

Before the introduction of geophysical surveys, ancient people used the knowledge of their environment to locate possible areas for water wells. They mostly consider the nature of surface relieve looking for depressions in valleys or an area that favours the growth of threes and grasses as indication of water points, and so they dug there wells at those predetermine locations. This was the practice mostly by the people of arid environments more especially those in the desert. This "blind drilling" usually yields little results if at all it succeeds. However, since the mid 20^{th} century water investigation has gone geophysical.

Geophysical investigations, especially electrical resistivity measurements, are very useful in understanding the location and distribution and amount of groundwater available in an area.

Four basic methods of geophysical surveys available are seismic, electrical resistivity, gravimetric and magnetic. The first two depends on

i. the introduction of mechanical or electrical energy into the earth crust and

ii. transmission of the effect through the sub – surface material and its conditions.

The latter two methods involves the measurement of the variation in the intensity and direction of the natural forces of gravity and magnetism (Ogunjobi, 1995).

Thus geophysical methods often use one or combination of two for identifying and selection of favourable sites for groundwater investigation.

Geophysical techniques have been successfully used by UNICEF for water boreholes in Adamawa, Bauchi, Kwara and Niger states. The success rate was put at between 80 and 90% in contrast to between 20 and 30% success of a random drilling operation (Onugba, 1995). Furthermore, electrical resistivity surveys can be used for investigation of both large and small areas and are being used extensively in groundwater investigation because they are responsive to moisture condition. It is easier to identify water bearing formations for example during field investigation in an environment, for example dry gravel and sand have higher resistivity than saturated gravel and sand while clay and shale have very low resistivity.

A lot of geophysical investigations have been carried out in various places in northern Nigeria in the past. Osasomi's (1968) assessment of groundwater in the Kubanni valley, Zaria using VES found that the decomposed rock or horizons of gravel of the basin contains water at satisfactory yield and suggested locations of new wells/well points along the river bed as most desirable for a high yield. Also Omolokun (1970) worked in the same basin using resistivity and showed that groundwater with rich water aquifers existed and recommended the river course as the location of the best yield well sites.

Olowu(1967) carried out a study of surface water and its effect on groundwater in Zaria area, he found that all the streams in the area are seasonal except the Galma river. Akpoborie (1972) studied the hydrogeological structure which control underground water in the Samaru creek, he found that the flow of groundwater into the creek is controlled by structures like joints and fractures developed in the rocks. Eigbefo, (1978) used the existing hand-dug wells in Kubanni basin and deduced the water table depth in the area. He explained that the water table ranges from 3 - 10m and concluded that the thickness of the weathered basement aquifer varies from 1 - 30m in the area.

Jones and Du – Preez (1952) carried out electrical resistivity survey in the basement complex area of the Kubanni basin and reported the presence of well – developed steep – dipping joints which contain water in some granite outcrops in the basin, but did not give their locations.

Olufemi, (1985) reported that Messrs Preussag Limited conducted resistivity survey from 1981 - 1982 in Jama'a village of Kubanni basin for borehole sitting and they found the presence of faults within the bedrock which has caused a downthrown of certain parts of the bedrock. He commended the area as possessing high water yielding capability.

Also Shemang (1990) conducted electrical depth sounding at selected well sites within the Kubanni river basin and estimated the range to the basemen! to be about 3m to the west of A. B. U Zaria dam to about 44m around Ungwan Kubanni while the average depth to basement is about 12m. He interpreted the VES data suggesting that the overburden is mostly made up of clays, silts and sands, fresh laterite and weathered laterite.

Makinde, (1996) carried out field investigation of variant of the two electrode D.C. resistivity array within the Kubanni basin. His results showed that this method has the capability to correctly estimate layer thickness and the depth to basement.

Martin (1991), using Vertical Electrical Sounding (VES) at different Locations in Daura was able to map the hydrogeological section of the area. From the interpretation of VES sounding results showing the resistivity profile, he showed lithologic distribution in the bedrock. The results also showed variability in the position of aquifer interms of depth and size. Similarly, Sadiq (1990) carried out hydrogeological survey of aquifers using ABEM Terrameter, and identified variations in thickness of the overburden between one sounding points to another. Much of the success of Kwara state water cooperation was attributed to geophysical surveys carried out by UK Water Resource Consultant – "Hydrotechnical" using VES and Electromagnetic (EM) survey methods (Odera et al.,1987).

Recently, Dan-Azimi (2005) in an appraisal of groundwater prospecting within the two campuses of Bayero University, Kano using VES found that the Old site campus with greater thickness of overburden materials gave higher potential and hence recorded greater successes in groundwater prospecting than in the New site campus. Again, JICA (1990), undertook the study of groundwater development in Sokoto Sate. Electrical resistivity sounding was used to evaluate the groundwater potential of the area and found that a number of minor aquifers were found to lie between 30 and 200m deep and were often alternated with beds of clayey materials and finally commends that aquifers are fairly good. This indicates the intercalations of various layers on one formation (A sand or gravel in shale or clay formation). And also suggesting that many minor aquifers can be located at various depth within the cross-section.

SARDA (1988), also used electromagnetic (EM), and earth resistivity methods to investigate the Sokoto Fadama shallow groundwater and the conductivity profiles for vertical and horizontal dipoles indicate the presence of a material of high conductivity overlying one of lower conductivity (a clay or silt over sand and gravel presumably).

Groundwater situation in Gada town varies from one location to another as confirmed by hand-dug well measurements carried by the researcher. While a couple of wells sink (e.g Marafa's palace and at the market area) over twenty-five years ago are still having high yields throughout the year, others sunk at (e.g Tudun wada and football pitch) are low yielding and fluctuating. The location of this dug-wells fall on the same profiles each (i.e downslope and up slope repestively). There is need for other points to be identified for well sinking so as to augument and relieve the present water

Other relevant researches in relation to groundwater studies include the inferences concerning the nature and its probable fluctuations in the area. Since the seasonal fluctuation have been shown to occur in weather and climate of dry areas of Northern Nigeria (Hore, 1970) and since the soil and presumably sub-soil leading to weathered bedrock parts (Klikenberg, 1970) it is probable that with decreasing rainfall amount there is likely to be a general lowering of the groundwater situation in dryer northern parts (Sawa, 2002).

2.2 GEOGRAPHICAL BACKGROUND OF THE STUDY AREA

2.2.1 INTRODUCTION

Gada Local Government was created in 1989 by the Federal Military Government. It comprises of three districts, viz: Gada, Wauru and Kadadi districts, each headed by a district head called Uban Kasa Hausa. Gada town is the headquarters of Gada Local Government Area. Majority of the inhabitants of the town came from present day Niger Republic and others from other parts of Nigeria. Majority of the people of Gada town are Hausa speaking with a small fraction as Fulanis. The Bugajes and Adarawas also inhabit the town. The 1991 population census gave the population figure of 152,975 inhabitants for the local government, and Gada town alone has over 40,000 inhabitants (2.6%) with an annual growth rate of 2.5%.

2.2.2 LOCATION POSITION AND SIZE

Gada Local Government falls within the Sokoto - Rima basin in the north - western quadrant of Nigeria. The town itself is situated at the extreme northern point along Nigeria - Niger boarder. It shares boundary with Niger Republic in the north, Illela Local Government to the West, Sabon-Birni Local Government to the East and Gwadabawa and Goronyo Local Governments to the south. Much of the area is generally flattish with a gentle hills/knolls and depressions in some areas. Gada town is also found in a depression with series of hills surrounding it.

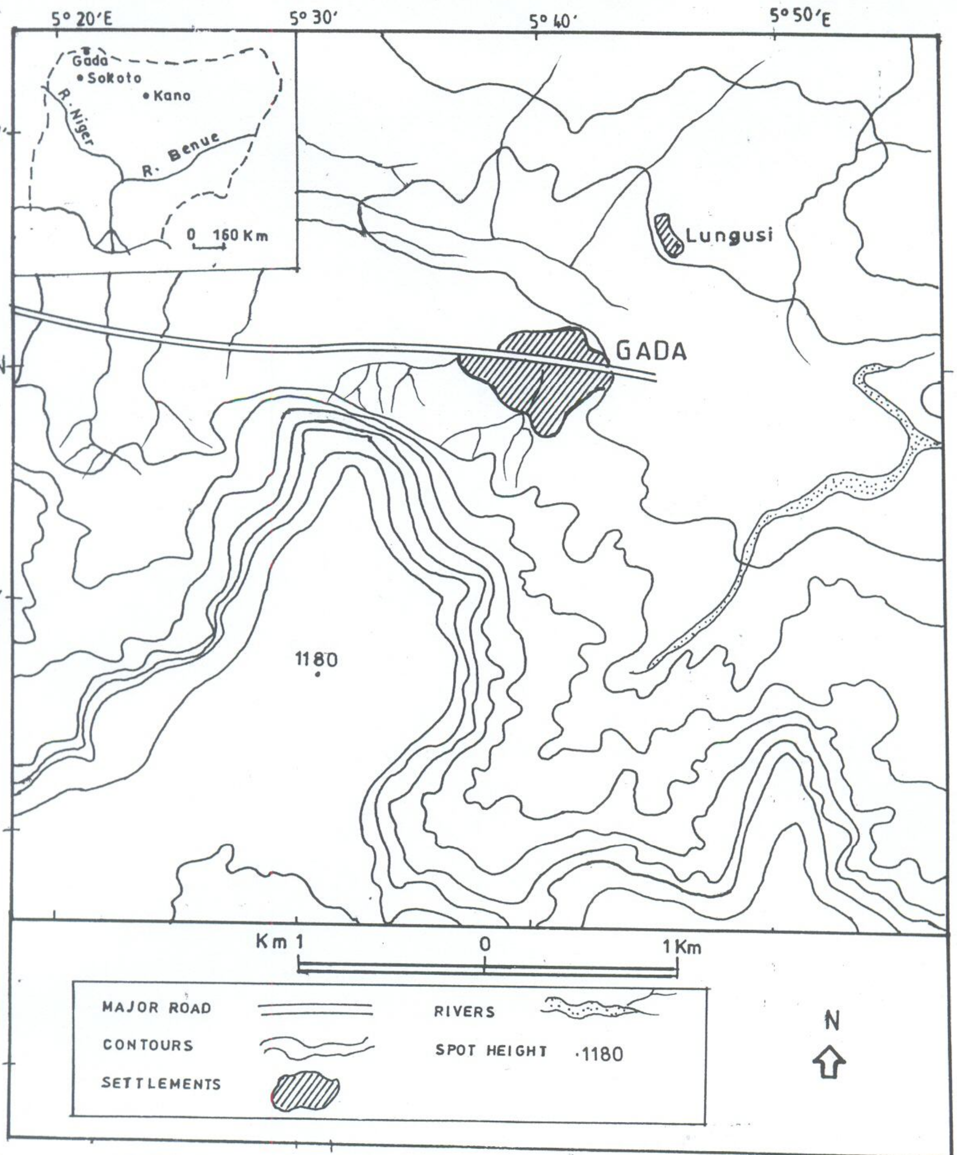


Fig.2.1: Location of Gada Town – the study area.

2.2.3 GEOLOGY

The general geology of the Sokoto basin is classified into three:

i. Pre-Cretaceous Basement rocks exposed in the south-eastern part of the area. These comprise of Older Granites, undifferentiated meta-sediments and metamorphic rocks

ii. Cretaceous Sedimentary formations. The distribution system is a belt zone in the middle part of the area from north-east to south-west. This system consist of the Gundumi, the Illo and the Rima group formations in ascending order.

iii. Tertiary Sedimentary formations and Younger Sediments in the north-western area of the State. This consists of the Sokoto group formations and the Gwandu formation in ascending order. Quaternary Sediments particularly covers the above three systems along the rivers (Udo, 1970).

The geology of Gada town (the study area) falls within the second category above. The relief is developed on the Rima Group formations which consist of Wurno, Dukamaje and Taloka formations. The area is generally flat with some depressions and hills overlain mostly with Aeolian Deposits from the Sahara. Gada town itself is in a depression as already noted above.

2.2.4 CLIMATE AND HYDROLOGY

The study area belongs to the typical tropical continental climate zone. The mean maximum temperature is about 45°C (highest in April to June) while the mean minimum temperature is about 16°C (lowest in December and January).

Long term annual precipitation in the area is very small, 400mm. It has a rainy and dry seasons alternating. About 90% of the effective precipitation is concentrated in 4months rainy season from June to September. The dominance of the northeasterly winds for more than seven months have great impact on the area making it dry for most of the year. (The northern section of the study area bordering the Niger Republic is already threatened by the encroachment of the Sahara Desert). The average relative humidity is 55% and wind velocity reach a speed of about 30km p/h between October and February but decreases to less than 15km/hr by April (Udo, 1970). Calculations of evapotranspiration using the Thornwaite method give figures of over l000mm at times.

The study area does not have any major river that passes through it. However, there exists a seasonal river and swamp/depression that surrounds the town. This swamp functions only during the rainy season where it drains and collects all the excess runoff water from the surrounding scarps and hills. The swamp serves as a major source of domestic water supply as well as for irrigation activity for the community during the dry season.

2.2.5 SOILS AND VEGETATION

Vegetation in the area is typical of Sudan Savannah, characterized by sparse shrubs interrupted by medium-sized isolated trees. There is more continuous cover of grasses during the rainy season, but during the dry season it is bare except for small scrubby plants. However, along the dry seasonal river valleys, short tree density increase. Trees like Baobab, locust bean, Tamarind and Gawo dominate the area while shrubs like Acacia, Sabara and Kalgo abound. Thorny and Xerophytic plants are more pronounced in the area, especially during the rainy season e.g Aduwa and Tsaida (Udo, 1970).

The study area also combines both the sahel and sudan savannah type of soil with sand and alluvial deposits dominating the area. On the upland, soil types such as sandy soil can be found, while along the Fadama areas soils like loamy and alluvial soils are found. Crops like millet, beans, guinea-corn and sorghum are cultivated upland during rainy season, while cash crops like onions, wheat, rice and suger-cane are cultivated in the Fadama during the dry-season.

WATER SUPPLY SITUATION.

In Sokoto state water for human utilization is, are usually limited to few towns or group of villages. Even rural populace were had to resorts to rain during the few (3-4 months) and ground water as the sources of water supply. Gada town is one of such rural areas. Boreholes with energy pumps and gravity type distribution systems are continuously being constructed, especially in the urban centres, while hand dug-wells and tube-wells with manual pumps are prevalent in the rural areas where they are used for dry season gardening and irrigation projects.

In the study area, the problem of shortage of potable water is a severe one. The few existing water supply sources have not been able to meet the demand of the rapidly growing population and animal life.

The present problem of water supply in the twon is that there where only two hand-dug wells which supplied limited volume of water during the dry season. Also tube wells with hand pumps dug have all become abortive and no longer yield water even during the rains. Even boreholes supplying an elevated tank with the capacity of about one millions gallons constructed by the Bi - Water Company have also dried up and faced with operational and maintenance problems. Thus, the town demands for more water for the ever growing population.

2.3 CONCEPTUAL FRAMEWORK

The environment could be said to be where we live and where we act, and it provides the resources that sustains us all. In man's quest for sustenance, he has had to interact with his environment in many ways one of which is the construction of wells and boreholes.

Each year more of the world's forests, grasslands, and wetlands disappear, and deserts grow in size as more people increase their use of the earth's resources.

Vital topsoil is washed or blown away from farmlands, lakes and reservoirs are being clogs with sediments, and water occurring underground is withdrawn faster than it is replenished. These are but few out of thousands environmental crises facing the world today.

Geographical knowledge provides a comprehensive understanding of the environment. It is one of the most important element in the training of a modern environmental specialist who, given the even more complicated conditions in the fields is capable of solving problems to the effective development of the environment. It also provides a key to the understanding and forecasting of the conditions by which environmental activities are conducted. The role of geographical studies to the present day - stage of the scientific and technical revolution becomes even more pronounced in connection with finding solutions to problems of environmental protection and the rational use of structures of the earth and natural resources. Since the negative impact resulting from man's transformation of the environment is continually increasing and has reached a global scale.

Since ancient times man has been dependent on the natural resources of the earth, and hydrological cycle has influenced his life and development to a great extent. The earliest stages of man's existence were influenced by the fluctuation of wet and dry periods. Variable hydrological conditions also dominantly affected the distribution of human population. The presence of permanent water supply made possible the production of surplus food and resulted in permanent settlement.

Hydrology is one aspect of geography that embraces the full history of water on the earth. Its sub – divisions include geomorphology, hydrometeorology, limnology, cryology and potamology. Geohydrology (incorporating geomorphology and hydrology), is a study related to sub – surface water which is the main concern of this study.

However, the phenomena of sub – surface water study are so interrelated. Solutions to their problem can only be attained by a completely interdisciplinary approach by scientists from various fields. This is due to the fact that hydrology is very broad science and therefore borrows heavily from other branches of science and integrates them for its own interpretation and use. Supporting sciences such as physics, chemistry, mathematics, geology, agriculture, fluid mechanics, statistics, computer science are but few to mention out of which may be used in hydrologic investigations.

The term groundwater in geographical context is understood to mean the water found within the saturated voids or pore - spaces in the soil. Its study is described as Geohydrology or hydrogeology, stressing the importance of geomorphology and geology. It is all about the study of groundwater and its relationship with the structure of the earth and host rock, and rainfall in an area.

Groundwater being very important resource is also known to occur more widely than surface water, the ration of surface to groundwater was put at 1:33 (March, 1996, and Walton,1970).

This investigation is therefore to assess the geographical structural implications of the town with a view to geohydrologically assessing the groundwater potential of the area. The vertical electrical sounding was adopted and carried out to locate the possible or potential aquifers within the surveyed area.

CHAPTER THREE

METHODOLOGY OF DATA COLLECTION

INTRODUCTION

In this chapter, the kinds of instruments used, methods and techniques employed for the geophysical survey, the procedure of the laboratory analysis, and the mapping of the geophysical survey data are described.

Prior to the fieldwork, a reconnaissance survey was undertaken to get familiar with the terrain and map out probable plan of work. The field work was undertaken from the month of May to July, 2004 with the help of field assistants and laboratory technicians from the Geophysics Department of A.B.U, Zaria.

3.1.1 MATERIALS AND INSTRUMENTS

The terrameter (SAS) 300 was chosen for the field work because it is the one available functional equipment that the researcher could get. It was procured on rent at the cost of ₦10, 000.00 per day. The restriction to the limited time and cost actually affected the data size collected.

The equipment ABEM Terrameter SAS 300, 4 copper electrodes, 2 reels of wire and connecting wires, twine ropes, crocodile clips, hammers, measuring tapes and the compass were assembled for the field survey.

The terrameter SAS 300 is the basic unit in resistivity survey. The Signal Averaging System (SAS) is the method whereby consecutive readings are taken and the results are automatically averaged continuously in digital form as the resistivity of the ground. The instrument has three main units; the transmitter, the receiver and the microprocessor. While the electrically isolated transmitter sends out well defined regulated current signals and the receiver discriminates noise and measures voltage correlated with the transmitted current signals. The microprocessor monitors, controls operations and calculates results to ensure optimal accuracy and sensitivity. Thus, there is less chance of operators error. Beside, the instrument generates the data fast. The power is supplied by a portable generator and a rechargeable battery pack.

3.1.2 FIELD EXPERIMENTAL DESIGN

As already describe in chapter one, the study area is badly gullied (plate 1 A & B, page 23). The settlement is hemmed to the south by steeply rising scarplet, remnant of receeding plan which is been gullied. To the north lies the flat marshy land used for gardening and dry season farming. Also within the settlement the housing layout is best described as clustered with just a couple of wide footpaths. Hence the conventional gridding system recommended for field design for geophysical study was not feasible. Rather, the survey was run on transects along the wide tracks of land between buildings identified during the reconnaissance.

However, it has been shown that different electrode arrangement (arrays) can be used, and the most common ones being the Wenner, Schlumberger and Dipole – Dipole. The electrode array most commonly used for vertical electrical sounding is the Schlumberger array. It is the type adopted for this research.

(A)

(B)

Plate 1 (A &B): Ariel view of Gada town

Some of the advantages of the Schlumberger array are that fewer moves of electrode are needed than compared with the Wenner array where all the four electrodes must be moved between readings. Another advantage is that lateral variation caused greater errors when the potential electrodes are moved than where the current electrodes are moved. Furthermore, duplication of reading with the same values of ½ distance of current electrode A – B (AB/2) but different value of ½ distance of potential electrode M – N (MN/2) allows an approximate corrections to be made for the effect of lateral variations (Ogunjobi, 1995).

Thus, the first reading was taken with AB/2 equal to 1m; MN/2 being 0.3m. Several readings were taken, with progressively larger values of AB/2 while MN/2 was kept constant up to 3.5m. Then MN/2 increased while AB/2 remained constant for two readings. Several more readings were taken with increased values of AB/2 and a constant value of MN/2 and so on.

Sampling Procedure: Because of the non-homogeneity and rough nature of the topography of the town which is badly gullied throughout, purposeful random sounding was done to cover the whole town. Harvey (1969) observed that the relative precision of any sampling procedures depends upon the shape of the phenomena in question.

Considering the nature of the topography of the town, the transects identified during the reconnaissance were taken each at a time in while gridding of the whole town was between 2 and 3 km^2. This made us to use purposeful random sounding taking existing live/defunct bore holes/hand dug – wells into consideration as a guide.

A total of 28 survey points were identified and the sounding was conducted at each point successively, giving a 100m interval from one sounding point to another where necessary. Although this method is difficult compared to gridding a particular area, it proved to be very effective as it yields a good deal of information (Harvey 1969: 366). Hagget, Cliff and Fercy (1977) believe that the efficiency of this sampling procedure is related to the gaps in-between survey points, that the wider the survey point the less reliable is the result obtained and vice versa.

The maximum electrode spacing reached was 100m as the depth of interest for the study area, although the depth of the overburden in the study area was estimated and reported by previous workers to be between 200 and 300m (Oteze, 1971).

While the VES points are few (28), the records of wells and boreholes (abortive/yielding) were sort for and acquired from the Ministry of Water Resources Development, Sokoto State to corroborate the readings along the transect lines. This was deemed necessary because:

i. it will augment the VES points, and
ii. the depth of the VES points can be interpolated from the defunct/yielding wells.

Plate 2: Note line of Electrodes and the Terrameter being operated by the technician from Geophysics Dept. A.B.U, Zaria and Researcher

Plate 3: Extension of the line of profile – B

Plate 4: Defunct/Dried borehole along profile F1

All together, six boreholes records were made. Together with the VES points, they provide opportunities for better interpretation of the cross sections derived at each VES point.

3.2 GEOPHYSICAL SURVEY TECHNIQUES

Geophysical survey involves the use of specialized and precision instrument/equipment for collection of data about the character and condition of the earth's surface materials. In prospecting for groundwater, the data to be collected relate to the thickness of the overburden (weathered materials) and depth and size of the groundwater acquifers. Among the many techniques used for groundwater prospecting are the gravimetric, seismic, magnetic and electrical resistivity surveys. All are geophysical surveys.

However, the electrical resistivity technique has been shown to be rapid and economical to use. In resistivity surveys there are differences in the results one gets depending on the technique and the kind of arrangement of the electrode (array) adopted for the field survey. There are three kinds of electrode arrays, viz: the Wenner, Schlumberger, and Dipole – Dipole. The Schlumberger array in preference to the Dipole – Dipole and Wenner arrays was chosen because it has become widely used in many parts of the world and even here in Nigeria, such as in Kano (Dan Azumi, 2004), in Zaria (Hassan, 1987, Dogara, 1998, Yusuf, 2000) and in Sokoto Fadama studies (SARDA, 1988, JICA, 1990). Besides, it has been recommended for its high efficiency, lower economic costs and portability in the field. Furthermore, interpretation of the resistivity is readily understood and lends itself to graphical representation (Onugba, 1995). In this study the Schlumberger array was adopted in preference to the former two. This is because of the advantages it has over the other two as stated earlier (3.1.2).

The basis of the electrical resistivity method is that when electrical current is applied into the ground through electrodes, variations in conductivity alters the current flow patten within the earth and this in turn affects the distribution of the resulting electric potential in the earth. The degree to which the potential at the surface is affected by the current flow depends on the size, location, shape and conductivity of the material within the ground. The electric current was passed in to the ground using two electrodes that are driven in to the ground and connected to the parameter with the use of crocodile clips and wires.

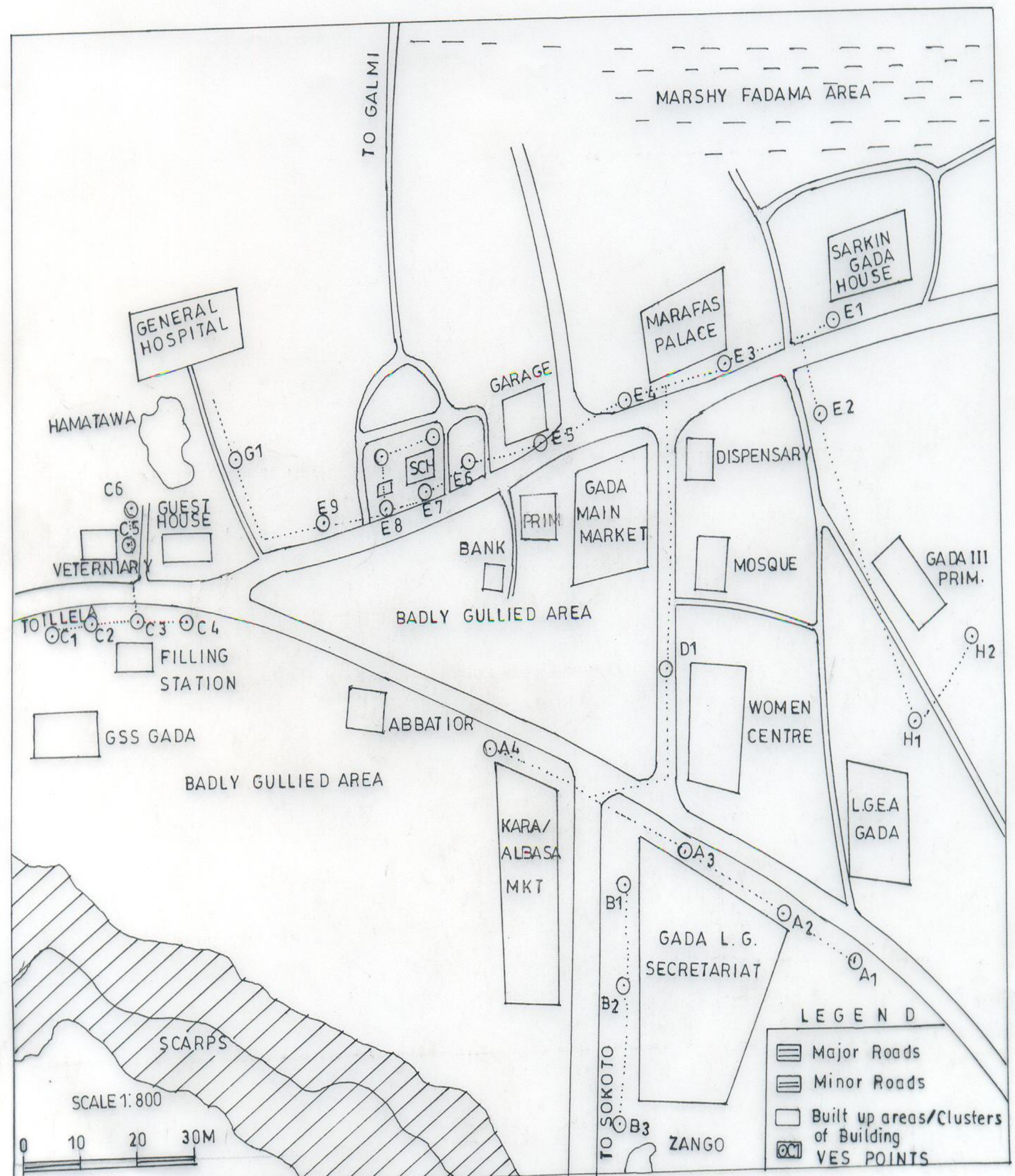


FIG. 3·1: GADA TOWN IN VES TRANSECTS AND SURVEY POINTS.

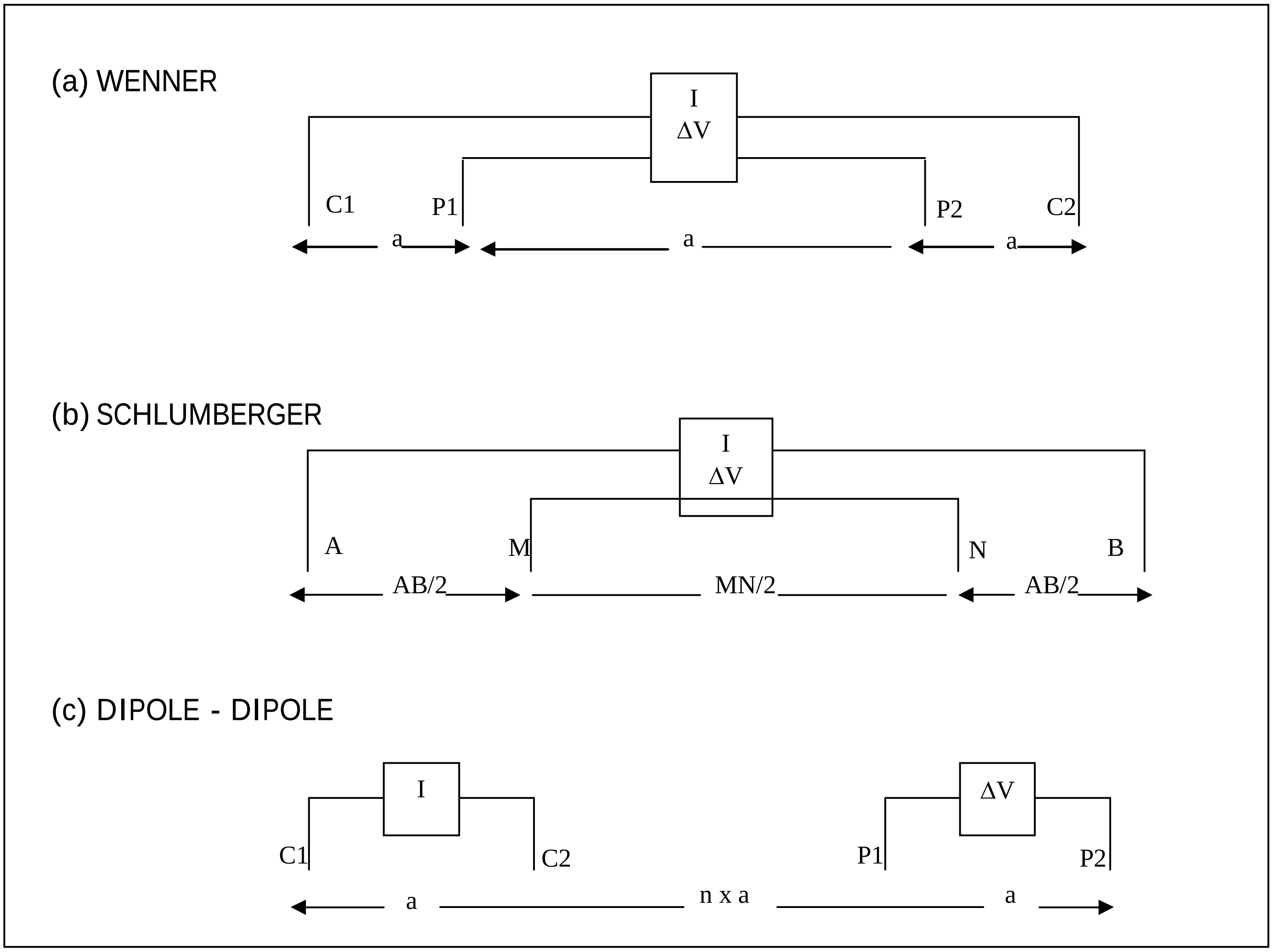


FIGURE 3.2 COMMON ELECTRODE ARRAYS

The ratio of the voltage output (i.e the potential difference) to the current input gives the resistance R of the ground. i.e,

R = V/I

Where,

R is the resistivity (ohm – m (Ω))

V is the voltage in volts (V)

I is the current in ampere (A)

Vertical Electrical Sounding (VES)

The resistivities of rocks and soil vary and depend on whether the earth material is wet or dry. The water content is also a function of the porosity and degree of saturation of the formation. Although it is not possible to identify a rock or soil on the basis of its resistivity alone, it may be possible to make certain deductions about the nature of the geology of an area on the basis of resistivity survey interpretations. For example, resistivity surveys have the advantage of indicating whether the bedrock formation is likely to be an aquifer or not. Usually, formation with high to very high resistivity is very unlikely to be an aquifer and therefore cannot contain water.

3.2.1 Field Procedure

As described earlier, the electrodes array was laid along each transect and readings were taken at two hundred meters (i.e 100m back and 100m forward). Series of readings were taken with different electrode spacing and with the centre point of array being kept constant. The procedure involves expanding the current electrodes AB, while keeping the potential electrodes MN relatively fixed (Battacharya, 1968), and the readings of the potentials taken as described earlier (3.2). Details of the field geotechnical survey and the plan of operation are illustrated in figure 3.1.

The apparent resistivity measured with the smallest spacing was virtually the resistivity of the surface layer. As the spacing is increased, progressively deeper layers influenced the apparent resistivity. The current passing through the earth between two potential electrodes and the resultant potential differences were computed to give resistivity of a layer at a surface in digital form by the Terrameter SAS 300.

3.3 LABORATORY ANALYSIS AND MAPPING

The Vertical Electrical Sounding (VES) data collected was studied and converted into Apparent Resistivity values by multiplying them with the corresponding geometric factor. The geometric factor was calculated using the formula:

$$K = \Pi\left[\frac{(AB/2)^2 - (MN/2)^2}{MN}\right]................(eq1)$$

$$Pa = \lambda\left[\frac{(AB/2)^2 - (MN/2)^2}{MN}\right]V/I.............(eq\ 2)$$

Where K =geometric factor

P_a = apparent resistivity

AB = current electrodes

MN = potentials electrodes

The computed apparent resistivity values with their corresponding electrode spacings were used for interpretation. The apparent resistivity values were plotted on a graph against the current electrode spacing (AB/2) using the log – log sheet, with AB/2 on the abscissa and corresponding apparent resistivity on the ordinate.

The curves are illustrated in graphical form and shown in figures 4.1 to 4.28.

3.3.1 Contouring of VES values

After series of VES surveys had been carried out the resulting apparent resistivities were then used to produce the lithological curves by joining points of equal values together. This can help to delimit possible areas where water bearing layers are located.

Unfortunately, obtaining the groundwater contour map for the whole area was not possible because the actual distance between varying profiles was not known as a result of the purposeful random sampling employed in place of the gridding pattern that makes this possible.

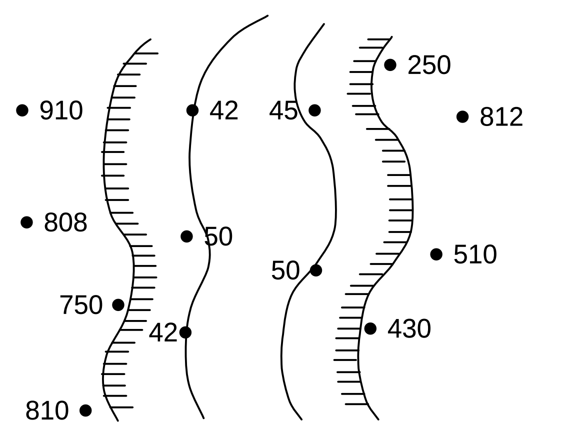


Fig. 3.3: Contour of VES Values

Any well located in the unshaded area would not be expected to yield water because the resistivities here are either too low or too high (50 or 910). The shaded areas with resistivities of between 100 and 1000 are possible areas for well location. It is also possible to draw maps and sections of equal resistivities at different depths from the curves obtained. These will allow us to see a clear section of the structural geology of the area.

3.3.2 Lithological Interpretation

To obtain the different lithological variations between VES points and among different geotechnical survey transects, the VES survey data at each point were plotted on the log – log graphical (3 x 2 circles) as already described in section 3.3.1. From the computer print out of the curves using software "ZODDY – ATO" (i.e. figures 4.1 to 4.28) the depth of each layer found in each VES point can be calculated and the lithological sections obtained.

Initially attempts were made to use BBC micro – computer software "ZODDY – SURFER" for the lithological interpretations using the field survey data. Unfortunately, the computer crashed and all the details were lost. And because of the time and financial constraints, it was not possible to continue with it.

However, it is the conventional practice in VES interpretation to make the assumption that layers of bedrocks are homogenous and isotropic. Any deviation from these ideal situations introduced errors in interpretation. (Aminudden, 1990, Dogara,1998). The problem of ambiguity of equivalence and suppression can be minimized with the interpreter's field experiences and knowledge of geology of the study area. The resistivity of the bedrock layers vary considerably from one geological formation to another and also within any one particular layer. Variation can be very large for near the surface formed by unconsolidated sediments (Vingol, 1972). There may be specific relationship between lithology and resistivity, but the accepted generalized and order of increasing resistivity is from one deposits, to another, say clay, sand and gravel, limestone and lastly crystalline rocks.

In sedimentary bedrocks, resistivity profile is used for differentiating between coarse-grained materials like gravel or sand (permeable layer is indicated by higher resisitivity) and fine – grained material like silt or clay (aquiclude indicated by very low resistivity). While in the basement bedrocks, the profiles differentiate decomposed rocks (probable water bearing zone indicated from comparatively low resistivity) to fresh bedrock (aquiclude indicated by very high resistivity).

Telford, Geldert, Sherifu, and Keys (1976) also define resistivity ranges of sediments generally as:

Rock type	**Resistivity (Ω-m)**
Consolidated shales	20 to 2000
Argillites	10 to 800
Conglomerates	200 to 10, 000
Sandstones	1 to 6.4×10^8
Limestone	50 to 10^7
Dolomites	350 to 5000

Unconsolidated wet clay	20
Marls	3 to 70
Clays	1 to 100
Alluvium and sands	10 to 800
Oil sands	4 to 800

However, Sokoto Agricultural and Rural Development Authority (SARDA) (1988) gave electrical resistivity of sediments in Sokoto Fadama Areas as:

Wet clay	1 to 30Ω-m
Dry clay	7 to 500Ω-m
Silty clay	20 to 50Ω-m
Silt	30 to 100Ω-m
Sandy silt	20 to 200Ω-m
Alluvial sand and gravel	100 to 900Ω-m

The above ranges cannot be fully accepted as it is restricted to Fadama soils along the river valleys, neglecting other sediments in the upland areas.

Thus, the following correlations have been observed between resistivity and lithology in the Sokoto sedimentary basin.

Lithology	**Resistivity**
Clay, silt, Alt. Sand and clay or silt	10 to 50
Sandy clay, Alt. Sand and clay or Silt	50 to 150
Sand or sandstone	150 to 1000

Coarse sand or sandstone, gravlley- more than 1000

Sand, limestone

JICA,1990.

Based on samples in the present studies and field measurements, the resistivity ranges produced by JICA, (1990) for differentiating sediments in Sokoto basin was adopted and simplified as follows:

Table 3.1: Modified Resistivity Range and Layer Numenclature

Resistivity range	**Layer**	**Lithology**
1000 and above	A	coarse sand, gravel
51 to 1000	B	sand, sandstone
50 to 151	C	sandy-clay, silt
Lass than 50	D	clay, silt.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

INTRODUCTION

In this chapter, section 4.1 presents the data collected during the field work, while section 4.2 summarizes and interpretes the data. Section 4.3 presents a discussions of the reults.

4.1 DATA PRESENTATION

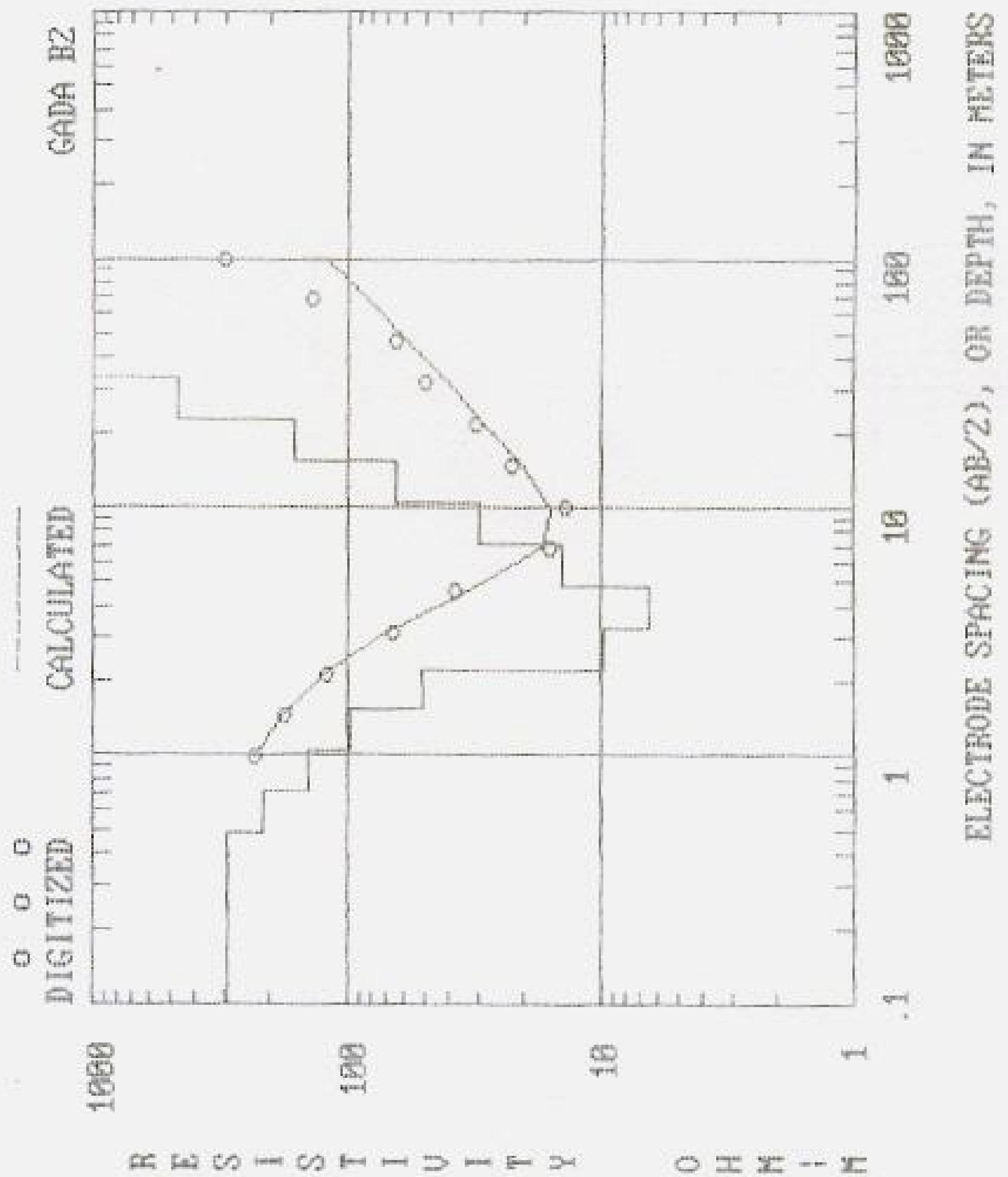
A total of 28 VES points were surveyed in Gada town using letters and figures to represent each VES point as shown in figure 3.1. The resistivity values and calculated apparent resistivity values of the VES points as discussed in 3.3.2 are presented in tables 4.1 – 4.7. Likewise the field survey data were plotted on log – log graphs to obtain the curves for identifying various layers of the stratigraphy using the BBC MICRO computer programme ZODDY-ATO as discussed earlier in section 3.3.2.

The average depth (thickness) penetrated by the VES was 17.46 metres with the highest thickness being 34.28 metres while the lowest was 0.6 meter. However, the highest and lowest resistivities were 8569.46 and 4.66 ohm – metres respectively with an average of 4287.06 ohm – metres. From field experience, this is very high. However, it should be noted that the vertical electrical soundings were not done in grided format. As such, between transects and among VES points distances were not coordinated. Thus, it is not practicable to draw Iso-resistivity curves that can give areas of equal groundwater potential. However, based on examination of lithological characteristics and similarities or contrasts, groundwater potential were inferred.

The data are presented as figures and tables from pages 40 to 70. (Fig 4.1 to 4.10 and Table 4.1 to 4.11 respectively).

GADA B2 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.49	297.88	4.86	6.43
0.71	214.02	7.13	14.19
1.05	141.55	10.47	30.37
1.54	97.37	15.37	65.32
2.26	50.20	22.56	161.13
3.31	9.77	33.11	472.11
		99999.00	1654.92



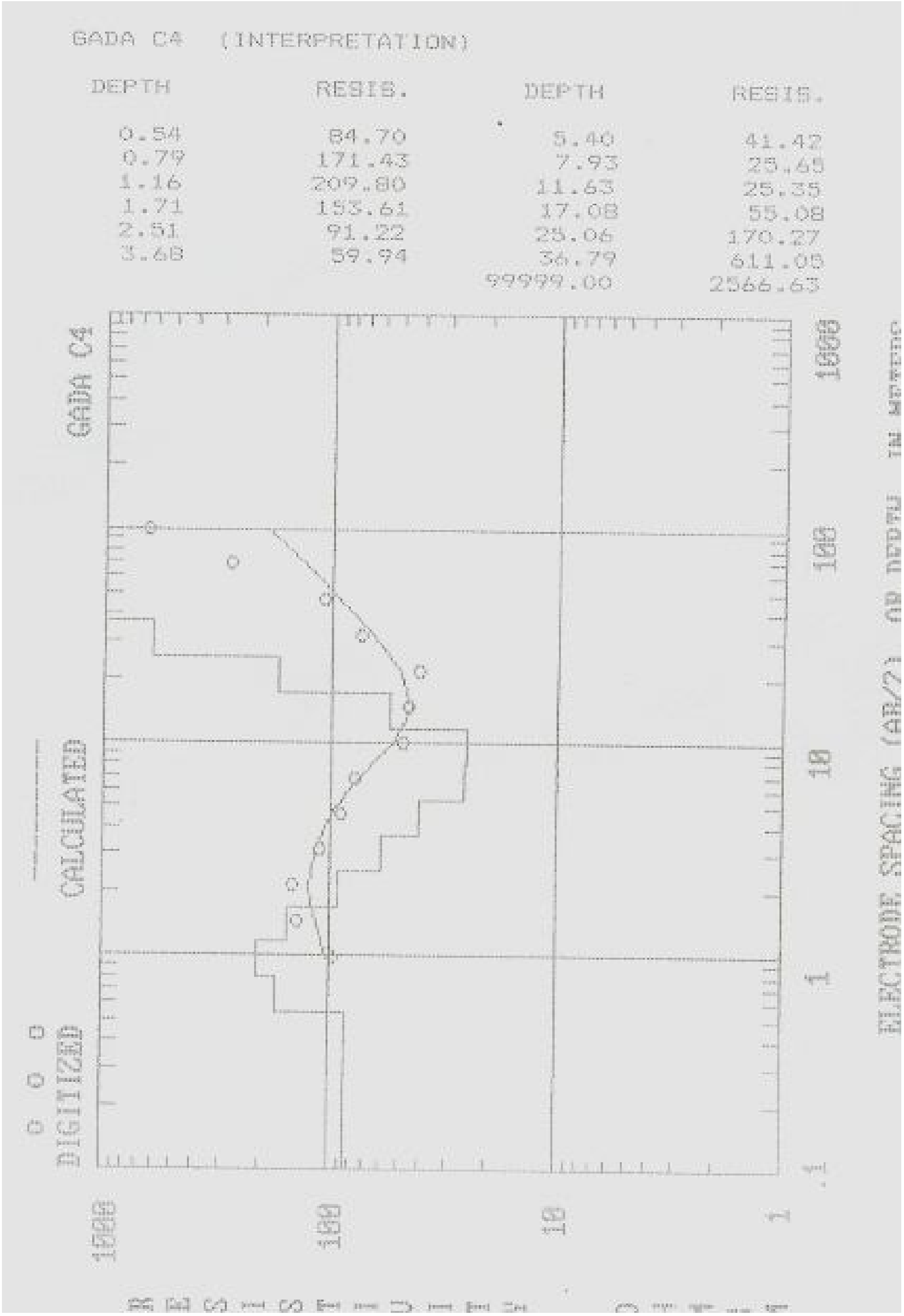


Figure 4.2: Digitised calculated curve at C_4 VES point

GADA E3 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.44	54.74	4.37	5.51
0.64	83.90	6.42	8.83
0.94	124.37	9.42	27.55
1.38	140.86	13.83	85.78
2.03	81.41	20.30	249.58
2.98	19.39	29.80	750.16
		99999.00	2594.43

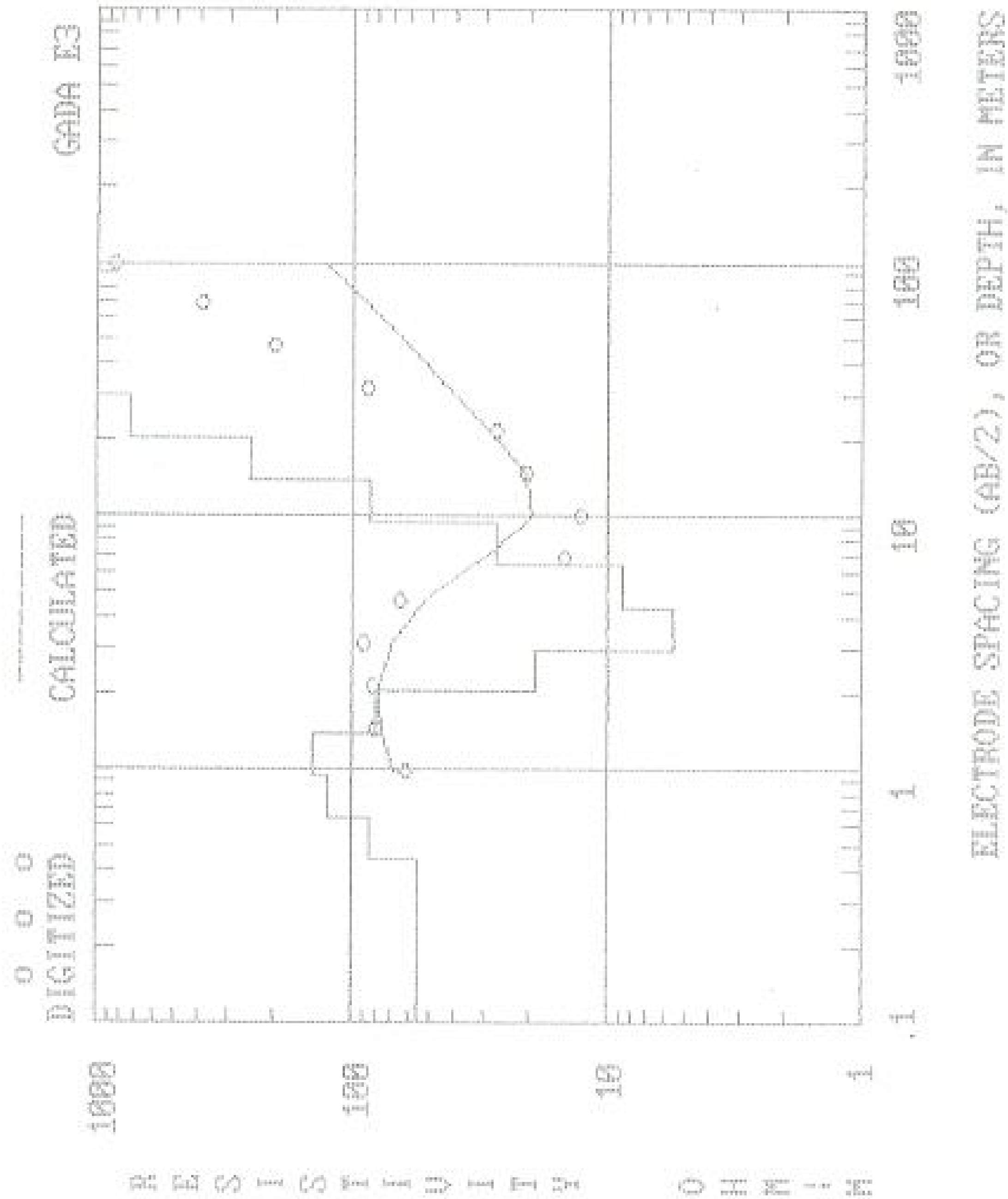


Table 4.1: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	A1		A2		A3		A4	
			RES	APP RES	RES	APP RES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	105.1	500.78	71.3	339.73	140.4	668.98	8.47	40.36
1.5	0.3	11.3097	43.3	489.71	31.5	356.26	42.4	479.53	3.81	43.09
2.2	0.3	24.8709	17.55	436.48	12.73	316.61	23.1	574.52	1.695	42.16
3.2	0.3	53.1453	6.75	358.73	4.68	248.72	6.47	343.85	620 x10	32.95
5.0	0.3	130.4285	800xl0^{-3}	104.34	1.530	199.56	652 x10^{-3}	85.04	100.0 x 10^{-3}	13.04
7.0	0.3	256.0922	45.0x10^{-3}	11.52	665 x10^{-3}	170.30	167. 5x10^{-3}	42.90	85.0x10^{-3}	21.77
10.0	0.3	523.1275	40.0x10^{-3}	20.96	380 x10^{-3}	198.79	11.8 xl0^{-3}	6.17	10.6 x10^{-3}	5.55
7.0	1.0	75.3982	1.554	117.17	1.130x10^{-3}	85.20	944 x10^{-3}	71.18	955 x10^{-3}	72.01
10.0	1.0	155.5085	240xl0-j	37.32	320Xl0^{-3}	49.76	52.0 x10^{-3}	8.09	655 x10^{-3}	101.85
15.0	1.0	351.8584	26.2xl0^{-3}	9.22	185.0xl0^{-3}	65.09	*0.50* x10^{-3}	*0.18*	535 x10^{-3}	188.24
22.0	1.0	758.6946	2.75xl0^{-3}	2.09	170.0xl0^{-3}	128.98	5.66 x10^{-3}	4.29	502 x10^{-3}	380.86
32.0	1.0	1606.9246	1. 87x10^{-3}	3.0	250 x10^{-3}	401.73	50.5 x10^{-3}	81.50	490 x10^{-3}	787.39
22.0	3.5	211.7209	19.25xl0^{-3}	4.08	68.0 xl0^{-3}	14.40	29.8 x l0^{-3}	6.31	445 x10^{-3}	94.22
32.0	3.5	454.0723	4.00x10^{-3}	1.82	58.5 x10^{-3}	26.56	10.00 x l0^{-3}	4.54	470 x10^{-3}	213.41
46.0	3.5	*944.1608*	57.8xl0^{-3}	54.57	52.0 x10^{-3}	49.10	6.50 x l0^{-3}	6.14	507 x10^{-3}	478.69
68.0	3.5	2069.7486	48.0x10^{-3}	99.35	48.5 xl0^{-3}	100.38	15.50 x l0^{-3}	32.08	206 x10^{-3}	426.37
100.0	3.5	4482.4917	29.7x10^{-3}	133.13	61.0 xl0^{-3}	273.43	19.00 x l0^{-3}	85.17	194.0xl0^{-3}	869.60

Table 4.2: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	Bl		B2		B3		Cl	
			RES	APP RES	RES	APPRES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	48.2	229.66	49.4	235.38	16.62	79.19	72.2	344.02
1.5	0.3	11.3097	21.2	239.77	15.44	174.62	6.64	75.10	36.4	411.67
2.2	0.3	24.8709	8.74	217.37	4.92	122.36	2.50	62.18	17.59	437.48
3.2	0.3	53.1453	3.48	184.95	1.295	68.23	1.037	55.11	8.01	425.70
5.0	0.3	130.4285	910 xl0^{-3}	118.69	246x10^{-3}	32.09	165.0xl0^{-3}	21.52	2.32	302.60
7.0	0.3	256.0922	287 x l0^{-3}	73.50	31.5x10^{-3}	8.07	39.0x10^{-3}	9.99	700x10^{-3}	179.26
10.0	0.3	523.1275	87.5 x l0^{-3}	45.77	13.98	7.31	14.50xl0^{-3}	7.59	220x10^{-3}	115.09
7.0	1.0	75.3982	732 x10^{-3}	55.19	301x10^{-3}	22.69	352x10^{-3}	26.54	3:53	266.16
10.0	1.0	155.5085	50.0x10^{-3}	7.78	105.5x10^{-3}	16.33	158.0xl0^{-3}	24.57	807x10^{-3}	12.55
15.0	1.0	351.8584	5.25x10^{-3}	1.85	66.5x10^{-3}	23.40	98.0x10^{-3}	34.48	113.0x10^{-3}	39.80
22.0	1.0	758.6946	7.04x10^{-3}	5.34	57.0x10^{-3}	43.25	83.0x10^{-3}	62.97	9.00x1O,j	6.83
32.0	1.0	1606.9246	7.57x10^{-3}	12.16	54.5x10^{-3}	87.58	85.0x10^{-3}	136.59	288x10^{-3}	462.79
22.0	3.5	211.7209	7.03x10^{-3}	6.03	92.5x10^{-3}	19.58	93.0x10^{-3}	19.69	52.2x10^{-3}	11.05
32.0	3.5	454.0723	36.5x10^{-3}	16.57	71.0x10^{-3}	32.24	16.00 x l0^{-3}	7.27	24.0x10^{-3}	10.90
46.0	3.5	944.1608	7.50x10^{-3}	7.08	68.5x10^{-3}	64.68	7.25x10^{-3}	6.85	5.93x10^{-3}	5.60
68.0	3.5	2069.7486	1.50x10^{-3}	3.10	66.0x10^{-3}	136.60	2.62x10^{-3}	5.42	-16.0310^{-3}	45.17
100.0	3.5	4482.4917	4.00xl0^{-3}	17.93	68.5x10^{-3}	307.05	1. 12x10^{-3}	5.02	-85.5x10^{-3}	383.25

Table 4.3: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	C2		C3		C4		CS	
			RES	APP RES	RES	APP RES	RES	APP RES	RES	APP RE
1.0	0.3	4.7698	54.1	257.78	27.5	131.03	20.4	97.20	17.90	85.29
1.5	0.3	11.3097	26.3	297.45	16.29	184.24	12.07	136.51	8.98	101.5
2.2	0.3	24.8709	10.77	267.86	9.34	232.29	5.71	142.01	4.46	110.9
3.2	0.3	53.1453	3.61	191.85	4.23	224.80	2.11	112.14	2.33	123.8
5.0	0.3	130.4285	360xl0^{-3}	46.95	1.982	258.51	297xl0^{-3}	38.74	1.212	158.0
7.0	0.3	256.0922	132.5xl0^{-3}	33.93	1.275	326.52	228xl0^{-3}	58.39	842xl0^{-3}	215.6
10.0	0.3	523.1275	24.3xl0^{-3}	12.71	937xl0^{-3}	490.17	70.7xl0^{-3}	36.99	675xl0^{-3}	353.1
7.0	1.0	75.3982	1.566	243.53	2.91	219.41	1.285	96.89	1.367	103.0
10.0	1.0	155.5085	397xl0^{-3}	61.74	1.497	232.80	373xl0^{-3}	58.00	985x 10^{-3}	153.1
15.0	1.0	351.8584	129.0x10^{-3}	45.39	902x10^{-3}	317.38	22.0xl0^{-3}	7.74	875xl0^{-3}	307.8
22.0	1.0	758.6946	36.0xl0^{-3}	27.31	717xl0^{-3}	543.98	9.5xl0^{-3}	7.21	852x10^{-3}	64.41
32.0	1.0	1606.9246	9.00xl0^{-3}	14.46	620xl0^{-3}	996.29	21Oxl0^{-3}	337.45	797xl0^{-3}	1280.
22.0	3.5	211.7209	475xl0^{-3}	100.57	715xl0^{-3}	151.38	354xl0^{-3}	74.95	692xl0^{-3}	146.5
32.0	3.5	454.0723	330xl0^{-3}	149.84	515x10^{-3}	233.85	169xl0^{-3}	76.74	382xl0^{-3}	173.4
46.0	3.5	944.1608	312xl0^{-3}	294.58	495xl0^{-3}	467.36	113xl0^{-3}	106.69	290xl0^{-3}	273.8
68.0	3.5	2069.7486	302xl0^{-3}	625.06	495xl0^{-3}	1024.53	134xl0^{-3}	277.35	297xl0^{-3}	614.7
100.0	3.5	4482.4917	305xl0^{-3}	1367.16	520xl0^{-3}	2330.90	144xl0^{-3}	645.48	345xl0^{-3}	1546.4

Table 4.4: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	C6		D		El		E2	
			RES	APPRES	RES	APP RES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	54.7	260.63	41.2	196.43	3.57	17.01	17.11	81.53
1.5	0.3	11.3097	27.0	305.36	14.80	167.38	1.735	19.62	5.40	61.07
2.2	0.3	24.8709	14.29	355.41	7.51	186.78	745xl0^{-3}	18.53	1.605	39.92
3.2	0.3	53.1453	7.83	416.13	3.39	180.16	345xl0^{-3}	18.34	550x10^{-3}	29.23
5.0	0.3	130.4285	3.19	416.07	5 l0x 10^{-3}	66.52	100.0xl0^{-3}	13.04	240xl0^{-3}	31.30
7.0	0.3	256.0922	1.446	370.31	270xl0^{-3}	69.14	55.0x10^{-3}	14.09	175.0 x 10^{-3}	44.82
10.0	0.3	523.1275	533x10^{-3}	278.83	200xl0^{-3}	104.63	40.0x10^{-3}	20.93	140.0x10^{-3}	73.24
7.0	1.0	75.3982	5.68	428.26	250x10^{-3}	18.85	55.6x10^{-3}	4.19	245x10^{-3}	18.47
10.0	1.0	155.5085	1.575	244.93	73.5x10^{-3}	11.43	19.3x10^{-3}	3.00	200 x10^{-3}	31.10
15.0	1.0	351.8584	594xl0^{-3}	209.00	1.50x10^{-3}	0.53	15.00x10^{-3}	5.28	190.0x10^{-3}	66.85
22.0	1.0	758.6946	365xl0^{-3}	276.92	5.50x10^{-3}	4.17	23.00xl0^{-3}	17.45	185.0x10^{-3}	140.36
32.0	1.0	1606.9246	329xl0^{-3}	528.68	19.6x10^{-3}	31.51	21.00xl0^{-3}	33.75	190.0x10^{-3}	305.32
22.0	3.5	211.7209	324xl0^{-3}	68.60	25.5x10^{-3}	5.40	41.00xl0^{-3}	8.68	16.50x10^{-3}	3.49
32.0	3.5	454.0723	226x10^{-3}	102.62	70.5x10^{-3}	32.01	41.00x10^{-3}	18.62	3.25xl0^{-3}	1.48
46.0	3.5	944.1608	186x10^{-3}	175.61	72.0x10^{-3}	67.98	13.00xl0^{-3}	12.27	1.25xl0^{-3}	1.18
68.0	3.5	2069.7486	151xl0^{-3}	312.53	76.0x10^{-3}	157.30	23.00x10^{-3}	47.62	0.12xl0^{-3}	0.25
100.0	3.5	4482.4917	136x10^{-3}	609.62	77..5x10^{-3}	347.39	17.00xl0^{-3}	76.20	7.33xl0^{-3}	32.86

Table 4.5: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	E3		E4		E5		E6	
			RES	APP RES	RES	APP RES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	11.25	53.60	6.37	30.35	19.60	93.39	12.46	59.37
1.5	0.3	11.3097	6.15	69.55	3.24	36.64	11.20	126.67	4.91	55.53
2.2	0.3	24.8709	6.26	155.69	4.97	123.61	5.07	126.10	1.685	41.91
3.2	0.3	53.1453	2.45	130.20	1.077	57.25	2.65	140.84	607xl0^{-3}	32.26
5.0	0.3	130.4285	3.57xl0^{-3}	0.47	697xl0^{-3}	90.91	1.757	229.16	237xl0^{-3}	30.91
7.0	0.3	256.0922	0.540xl0^{-3}	0.14	607xl0^{-3}	155.45	865xl0^{-3}	221.52	135.0x10^{-3}	34.57
10.0	0.3	523.1275	21.7xl0^{-3}	11.35	610xl0^{-3}	319.11	992xl0^{-3}	518.94	25.0xl0^{-3}	13.08
7.0	1.0	75.3982	257xl0^{-3}	19.38	55.0xl0^{-3}	4.15	392xl0^{-3}	29.56	697xl0^{-3}	52.55
10.0	1.0	155.5085	12.00xl0^{-3}	1.87	83.5xl0^{-3}	12.98	160.0xl0^{-3}	24.88	355xl0^{-3}	55.21
15.0	1.0	351.8584	52.0xl0^{-3}	18.30	3.25xl0^{-3}	1.14	65.0xl0^{-3}	22.87	195.0x10^{-3}	68.61
22.0	1.0	758.6946	3.00xl0^{-3}	2.28	8.50xl0^{-3}	6.45	82.5xl0^{-3}	62.59	160.0xl0^{-3}	121.39
32.0	1.0	1606.9246	51.0xl0^{-3}j	81.95	19.25xl0^{-3}	30.93	77.5xl0^{-3}	124.54	425xl0^{-3}	682.94
22.0	3.5	211.7209	230xl0^{-3}	48.70	302xl0^{-3}	63.94	25.0xl0^{-3}	5.29	315xl0^{-3}	66.69
32.0	3.5	454.0723	204xl0^{-3}	92.63	284xl0^{-3}	128.96	3.50xl0^{-3}	1.59	162.5xl0^{-3}	73.79
46.0	3.5	944.1608	212xl0^{-3}	200.16	283xl0^{-3}	267.36	2.25xl0^{-3}	2.12	400x10^{-3}	377.66
68.0	3.5	2069.7486	185.5xl0^{-3}	383.94	273xl0^{-3}	565.04	5.68xl0^{-3}	11.76	4.00xl0^{-3}	8.28
100.0	3.5	4482.4917	190.5xl0^{-3}	853.91	269x10^{-3}	1205.79	2.25xl0^{-3}	10.09	18.25xl0^{-3}	81.81

Table 4.6: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	E7		E8		E9		Fl	
			RES	APP RES	RES	APP RES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	57.9	275.88	14.21	67.71	16.35	77.90	54.1	257.78
1.5	0.3	11.3097	19.53	220.88	6.92	78.26	8.62	97.49	10.68	120.79
2.2	0.3	24.8709	3.82	95.01	3.28	81.58	4.77	118.63	2.28	56.71
3.2	0.3	53.1453	$952xl0^{-3}$	50.59	1.197	63.61	2.75	146.15	$890xl0^{-3}$	47.30
5.0	0.3	130.4285	$302xl0^{-3}$	39.40	$175.0xl0^{-3}$	22.82	1.632	212.86	$240xl0^{-3}$	31.30
7.0	0.3	256.0922	$232xl0^{-3}$	59.41	$120.6xl0^{-3}$	30.88	1.285	329.08	$55.0x10^{-3}$	14.09
10.0	0.3	523.1275	$215x10^{-3}$	112.47	$1.\ 2x\ 10^{-3}$	0.63	1.077	563.41	$21.2x10^{-3}$	11. 09
7.0	1.0	75.3982	$332x10^{-3}$	25.03	$435xl0^{-3}$	32.80	1.182	89.12	$82.5x10^{-3}$	6.22
10.0	1.0	155.5085	$187.5x10^{-3}$"	29.16	$39.0x10^{-3}$	6.06	$595x10^{-3}$	92.53	$24.0x10^{-3}$	3.73
15.0	1.0	351.8584	$37.5x10^{-3}$	13.19	$9.75x10^{-3}$	3.43	$325xl0^{-3}$	114.35	$4.00x10^{-3}$	1.41
22.0	1.0	758.6946	$5.0xl0^{-3}$	3.79	$0.87x10^{-3}$	0.66	$230xl0^{-3}$	174.50	$3.75x10^{-3}$	2.85
32.0	1.0	1606.9246	$3.035xl0^{-3}$	4.88	$632xl0^{-3}$	1015.58	$187.5x10^{-3}$	301.30	$0.75x10^{-3}$	1.21
22.0	3.5	211.7209	$79.5xl0^{-3}$	16.83	$1.004xl0^{-3}$	0.21	$550xl0^{-3}$	116.45	$165.5xl0^{-3}$	35.04
32.0	3.5	454.0723	$57.5xl0^{-3}$	26.11	$448xl0^{-3}$	203.42	$457xl0^{-3}$	207.51	$155.0x10^{-3}$	70.38
46.0	3.5	944.1608	$31.5xl0^{-3}$	29.74	$4.34x10^{-3}$	4.10	$447xl0^{-3}$	422.04	$147.0xl0^{-3}$	138.79
68.0	3.5	2069.7486	$27.0xl0^{-3}$	55.88	$1.\ 830xl0^{-3}$	3.79	$452xl0^{-3}$	935.56	$143.5x10^{-3}$	297.01
100.0	3.5	4482.4917	$2.31xl0^{-3}$	10.35	$5.66x10^{-3}$	25.37	$465xl0^{-3}$	2084.36	$139.5x10^{-3}$	625.31

Table 4.7: Resistivities and Calculated Apparent Resistivity Values of the VES Points

AB/2	MN/2	K	F2		G		HI		H2	
			RES	APP RES	RES	APP RES	RES	APP RES	RES	APP RES
1.0	0.3	4.7698	16.15	76.95	39.3	187.26	30.19	143.87	56.5	269.21
1.5	0.3	11.3097	8.30	93.87	18.59	210.25	10.15	114.79	22.7	256.73
2.2	0.3	24.8709	4.23	105.20	7.27	180.81	2.14	53.22	4.47	111.17
3.2	0.3	53.1453	1.497	79.56	2.78	147.74	541.2xl0^{-3}	28.77	1.422	75.57
5.0	0.3	130.4285	152.5xl0^{-3}	19.89	637xl0^{-3}	83.08	139.7xl0^{-3}	18.23	37.5xl0^{-3}	4.89
7.0	0.3	256.0922	61.0x10^{-3}	15.62	425 x10^{-3}	115.75	49.2xl0^{-3}	12.62	36xl0^{-3}	9.22
10.0	0.3	523.1275	25.5xl0^{-3}	13.34	350 xl0^{-3}	183.09	25.5xl0^{-3}	13.34	12.1xl0^{-3}	6.34
7.0	1.0	75.3982	522x10^{-3}	39.36	1.130	85.20	167.3xl0^{-3}	12.62	134xl0^{-3}	10.10
10.0	1.0	155.5085	30.0xl0^{-3}	4.67	640xl0^{-3}	99.53	85.7xl0^{-3}	13.34	2xl0^{-3}	0.31
15.0	1.0	351.8584	6.16xl0^{-3}	2.17	492x10^{-3}	173.11	40.8xl0^{-3}	14.37	1.5xl0^{-3}	0.53
22.0	1.0	758.6946	7.87xl0^{-3}	5.97	370x10^{-3}	280.72	23.6xl0^{-3}	15.97	7.86xl0^{-3}	5.97
32.0	1.0	1606.9246	12.62xl0^{-3}	20.27	427xl0^{-3}	686.16	10.7xl0^{-3}	17.27	7.64xl0^{-3}	12.27
22.0	3.5	211.7209	22.0xl0^{-3}	4.66	737x10^{-3}	156.04	75.4xl0^{-3}	15.97	2.5xl0^{-3}	0.53
32.0	3.5	454.0723	3.37xl0^{-3}	1.53	842x10^{-3}	382.33	37.8xl0^{-3}	17.17	32.3xl0^{-3}	14.67
46.0	3.5	944.1608	3.00xl0^{-3}	2.83	762xl0^{-3}	719.45	23.0xl0^{-3}	21.72	2.0xl0^{-3}	1.89
68.0	3.5	2069.7486	5.75xl0^{-3}	11. 90	880 xl0^{-3}	1821.38	13.00x10^{-3}	26.91	15.37xl0^{-3}	31.81
100.0	3.5	4482.4917	16.52xl0^{-3}	74.05	867 xl0^{-3}	3886.32	21.00xl0^{-3}	94.13	11.12xl0^{-3}	49.85

4.2 DATA INTERPRETATION

The summary of the resistivity and thickness of the layers of each VES points shown on table 4.2 -4.8 are presented in table 4.9.

The laboratory analysis described in section 3.3 and the plotted apparent resistivity values plus the derived values of the thickness of the respective layers were carefully examined and patterns identified. However, because of the problem encountered in the process of data mapping using the computer programme, Zoddy, “Surfer”, and the crashing of the system because of heavy usage, manual plotting was used to draw the sections for lithological interpretations. This was found to be equally reliable as shown in the presentation of the section in figures 4.5 – 4.10.

4.2.1. Classification of Layers

The resistivity value and thickness of the layers are very important factors in determining the groundwater potential. In basement complex bedrocks and under normal circumstances, the thicker the overburden the more probable it will contain water and vise versa (Dan - Azumi, 2005). Similarly, in sedimentary bedrocks, the same pattern was displayed with very little variations here and there due to various layer intercalations in the stratified beds.

As explained in Section 3.3.2, in sedimentary bedrock, the resistivity of the overburden classification requires field experience and knowledge of the particular geological formation of the area. It became necessary to consider the experiences of previous workers like JICA (1990), based on my own field situation and surface

TABLE 4.8: SUMMARY OF THE RESISTIVITY AND THICKNESS OF THE LAYERS OF EACH VES POINT

VES points.	FIRST LAYER		SECOND LAYER		THIRD LAYER		FOURTH LAYER		FIFTH LAYER	
	Thickness (m)	Res. Ohm-m	Thickness (m)	Res. Ohm-m	Thickness (m)	Res. Ohm-m	Thickness (m)	Res. Ohm-m	Thickness (m)	Res. Ohm-m
A1	2.51	448.61	34.28	17.88	–	95.83				
A2	2.51	320.10	34.28	70.75	–	593.84				
A3	1.71	493.74	3.69	66.99	33.1	13.88	–	212.38		
A4	0.94	50.09	3.43	31.57	10.4	426.36	–	2485.09		
B1	3.31	212.17	–	13.21						
B2	1.54	187.71	13.83	29.38	19.28	316.62	–	1654.92		
B3	1.24	65.41	–	17.56						
C1	4.86	395.78	28.25	27.14	–	442.69				
C2	2.03	285.68	4.39	23.00	15.37	204.67	–	2300.4		
C3	2.03	322.04	–	4876.33						
C4	3.68	128.45	13.4	36.87	23.39	390.66	–	2566.63		
C5	2.68	109.61	15.59	414.46	–	1949.22				
C6	4.68	443.56	10.51	111.65	22.6	347.19	–	1540.40		
D1	1.71	165.49	15.37	34.95	21.42	177.04	–	1354.06		
E1	22.56	16.52	–	252.43						

E2	0.64	71.87	–	18.41						
E3	2.03	97.06	7.39	15.32	22.41	361.8441.63	–	2594.43		
E4	1.05	35.5	3.81	86.12	6.66	41.63	15.9	237.45	–	2309.66
E5	1.05	109.47	3.81	218.40	6.66	95.91	–	24.51		
E6	0.71	62.85	6.42	44.74	26.69	272.52	–	65.27		
E7	1.05	273.18	32.06	32.01	–	219.74				
E8	2.26	79.86	–	4.66						
E9	1.05	91.24	2.26	276.33	8.21	93.39	14.35	496.33	–	7197.95
F1	0.71	283.20	9.76	27.53	12.8	293.46	–	2479.03		
F2	1.54	116.74	31.57	12.31	–	98.44				
G1	1.38	218.68	5.04	85.05	8.79	428.88	–	8569.46		
H1	1.05	139.79	32.06	18.17	–	205.51				
H2	1.71	216.36	23.35	13.65	–	122.98				

Table 4.9: Summary of Layer Resistivity at VES Points

Class		Layer Resistivity at VES points	Suitability
A	A^{ii}	C3.	Highly Suitable
	A^{iii}	C5.	
	A^{iv}	A4, B2, C2, C4, C6, D1, E3 F1, G1.	
	A^{v}	E4, E9	
B	B^{i}	A1, A2, A3, B1, B2, C1, C2, C3, C6, D1, E7, F1, G1, H2.	Suitable
	B^{ii}	C5, E1, E5, E9.	
	B^{iii}	A2, A4, B2, C1, C2, C4, C6, D1, E3, E6, E7, F1, G1, H1.	
	B^{iv}	E3, E4, E9.	
C	C^{i}	A4, B3, C4, C5, E2, E3, E5, E6, E8, E9, F2, H1.	Moderately Suitable
	C^{ii}	A2, A3, C6, E4, G1.	
	C^{iii}	A1, E5, E9, F2, H2.	
	C^{iv}	E6.	
D	D^{i}	E1, E4.	Not Suitable
	D^{ii}	A1, A4, B1, B2, B3, C1, C2, C4, D1, E2, E3, E6, E7, E8, F1, F2, H1,H2.	
	D^{iii}	A3, E4,	
	D^{iv}	E5.	

and surface materials. Hence the adoption of a modified JICA'S classifications in table 3.1.

Thus, in order to show the spatial variation in the overburden layers, the resistivities of the VES points were divided into four classes after considering the ranges given by various researchers e.g. SARDA (1988) and JICA (1990)

In this study, the resistivity values above 1000 were considered as class A (i.e. highly suitable for ground water storage). Resistivity values ranging from 150 to 1000, consisting of all VES points in class B may be regarded as suitable class. The ranges between 50 – 150 is class C made up of moderately suitable class. Resistivity values below 50, grouped as class D, were considered not suitable. Table 4.9 illustrates the classification distribution of VES points based on layer Resistivities while the frequency of occurrence of each VES points, based on the suitability classification above, is presented in table 4.10.

Table 4.10: Frequency of the VES points based on the resistivity of the overburden layers

First layer			
Class	Frequency	Percentage (%)	Remark
A	0	0	Highly suitable
B	14	50	Suitable
C	12	42.9	Moderately suitable
D	2	7.1	Not suitable
Total	28	100%	
Second layer			
Class	Frequency	Percentage (%)	Remark
A	1	3.6	Highly suitable
B	4	14.3	Suitable
C	5	17.8	Moderately suitable
D	18	64.3	Not suitable
Total	28	100%	

The resistivity results were compared with boreholes log of existing or driedup wells. The layers of subsurface structures of the borehole logs confirmed the layers revealed by the resistivity interpretations. The agreement could be attributed to intercalation of sand, clay and shale with varying degree of compaction and saturation as evidenced in the borehole log (figure 4.6). Olatinwo

(1981) reported a similar experience of occurrence of high resistivity layers in sedimentary structures by Krule and Mladenoic (1969) and in his research for groundwater exploration in Makurdi environs. It is described as a masking problem and attributed it to the occurrence of high resistivity layer between conducting layers. The depth of existing boreholes in Gada town is generally about 200m.

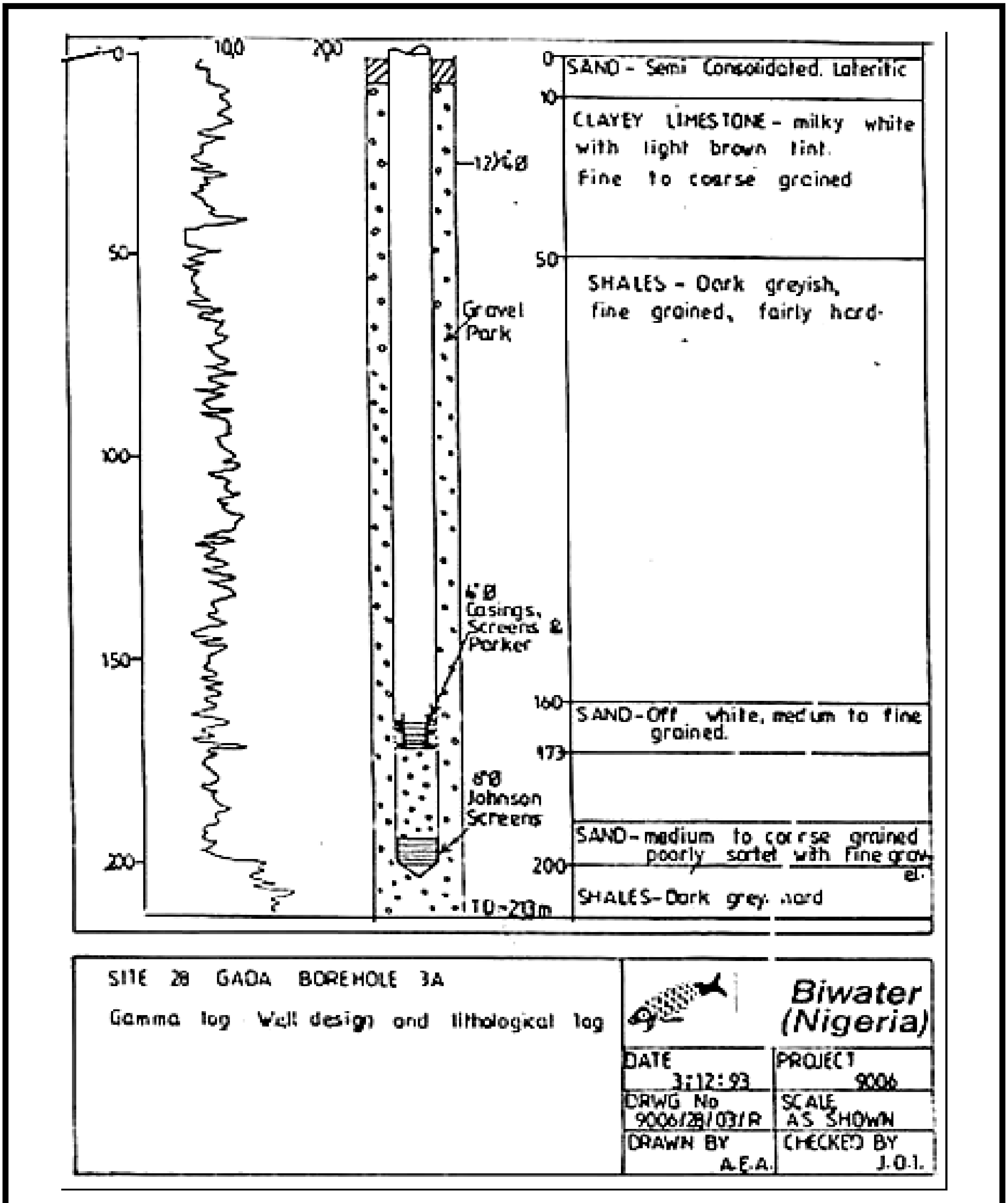


Figure 4.4 Borehole Gamma and lithological log of Gada town.

Table 4.11: Lithological logs of some existing boreholes in Gada Town.

A: Gada Hospital

Depth (m)	Lithology
0 – 8	Laterite
8 – 18	Clay + laterite
18 – 66	Clay
66 – 112	Silt + clay sands
112 – 165	Silty clay
165 – 189	Fine sand + clay

B: Gada MRDC (Market area)

Depth (m)	Lithology
0 – 2	Laterite
2 – 9	Silty – clay
9 – 24	Clay
24 – 173	Silty – clay
173 – 182	Fine sand + clay

C: Gada Veterinary

Depth (m)	Lithology
0 – 2	Laterite
2 – 9	Fine sand
9 – 167	Clay
167 – 182	Fine sand + clay

D: Gada Sarki's Palace

Depth (m)	Lithology
0 – 1	Laterite
1 – 20	Clay
20 – 85	Silt – clay
85 -164	Clay
164 – 170	Silty - clay
170 – 185	Fine sand + clay

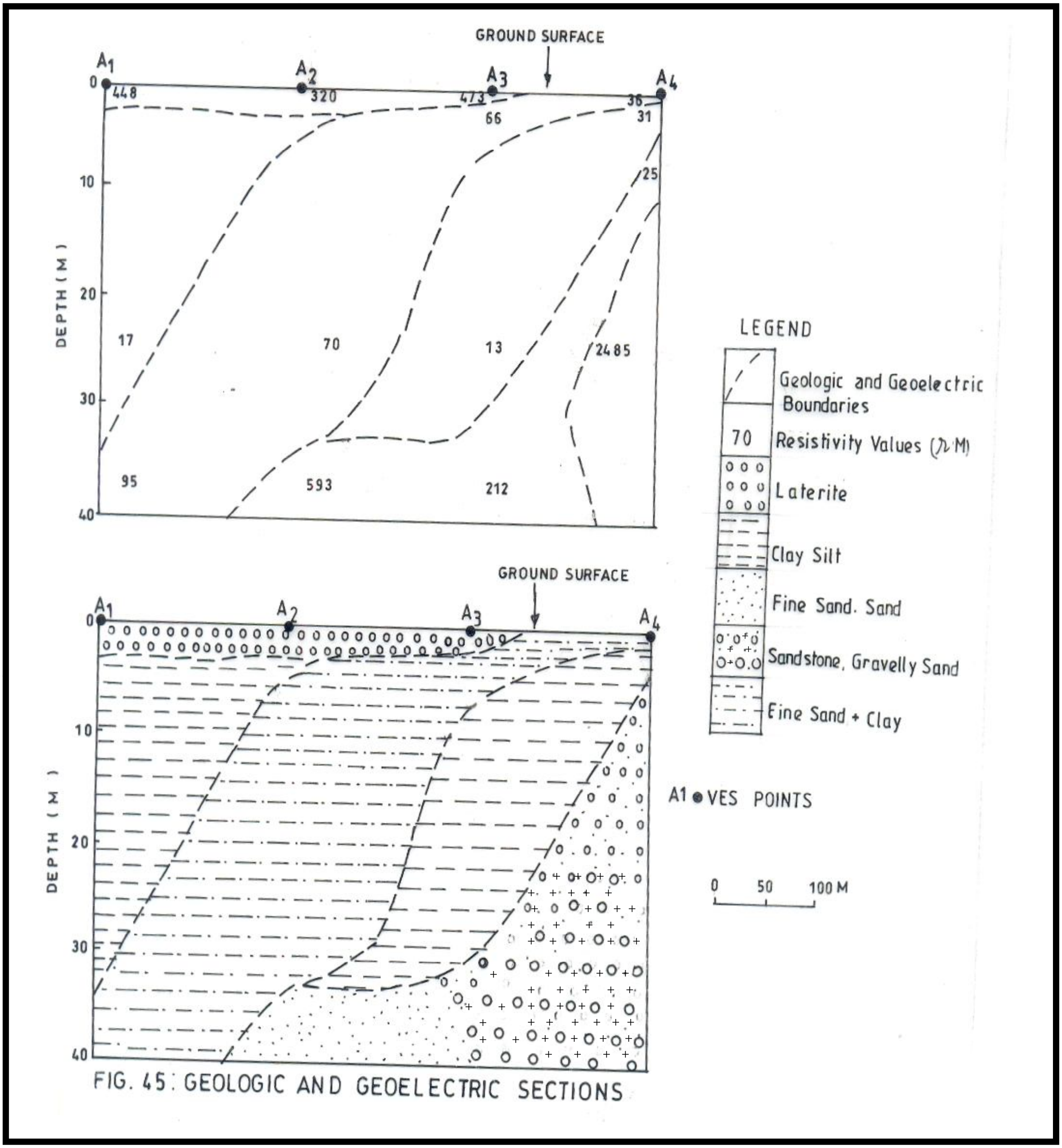


Fig. 4.5. Cross -sections of the VES points for A profile.

The maximum depth of the electric current at VES A1 and A2 was 34.28m and each of them penetrated three layers. However, maximum depth at VES A3 and A4 with 4-layers each were less, only 33.1m and 10.4m respectively. An old borehole Gada vertinary, was identified close by. From the veterinary borehole log data the depth of VES points A1, A2, and A3 are comparable to the second and third layers which are located between clay, silty-clay and silt + clay bands, while the depth of A4 (10.4m) stopped at the top of laterite with little clay proportion, or fine sand zone as in the Gada veterinary borehole location (Table 4.12c).

Along the "A" profile, the resistivity of the upper layer ranged from 50 – 493 ohm-m with an average of 271.5 ohm-m. The estimated thickness of this layer varied from 0.94 – 2.51m between A4 and A1 (Table 4.9).

The second layer has a resistivity in the range of 17.88 – 70.75 ohm-m. The layer has the lowest resistivity value ranges and hence, the likely most conductive layer under the profile. The thickness of the layer varies from 3.43 – 34.28m. The third layer has relatively high resistivity at some points (A2 and A4) and moderate to very low resistivity at the other two points (A1 and A3). The resistivity ranges from 13.88 – 593.83 ohm-m. The thickness of this layer measured from 10.4 at VES A4 and 33.1m and A3 respectively. However, at A1 and A2 the thickness tends to infinity as shown by the depth of the electric current penetration.

The fourth layers on these profiles are the deepest layers penetrated and have high to very high resistivity. They were encountered at VES points A3 and A4. The resistivities were 212.38 and 2485.09 ohm-m respectively, and the thickness of the layers also tended towards infinity. Fig. 4.5. shows the cross section derived from the profile. The section suggests that the top layer most probably consists of two different soil types. The high resistivity zone (A1, A2 and A3) is considered to be lateritic to fine sand zone, while the medium resistivity zone (A4) is considered to be clay which alternated with sand.

Figure 4.5 also suggest that the second layer most probably consists of two rock types. The zone of medium resistivity (A2 and A3) consists of either sandy clay or a combination of clay and silt materials.

The third layer is composed of three types of soil materials. (Figure 4.5). The high resistivity points (A2 and A4) consist mainly of sand and sandstones, while the medium resistivity point (A1) indicate the presence of clay or silt material in sand. The low resistivity point (A3) indicated that clay is dominant at this point.

The fourth layer which is found only at VES points A3 and A4 indicated high to very high resistivities which consist of sandy material at point A3 and coarse sand to gravelly sand at point A4.

Figure 4.6 shows the composite cross section for B-profile. The section shows that the area around VES points B1 and B3 has two layers, while VES point B2 four layers (Table 4.8 and figure 4.6).

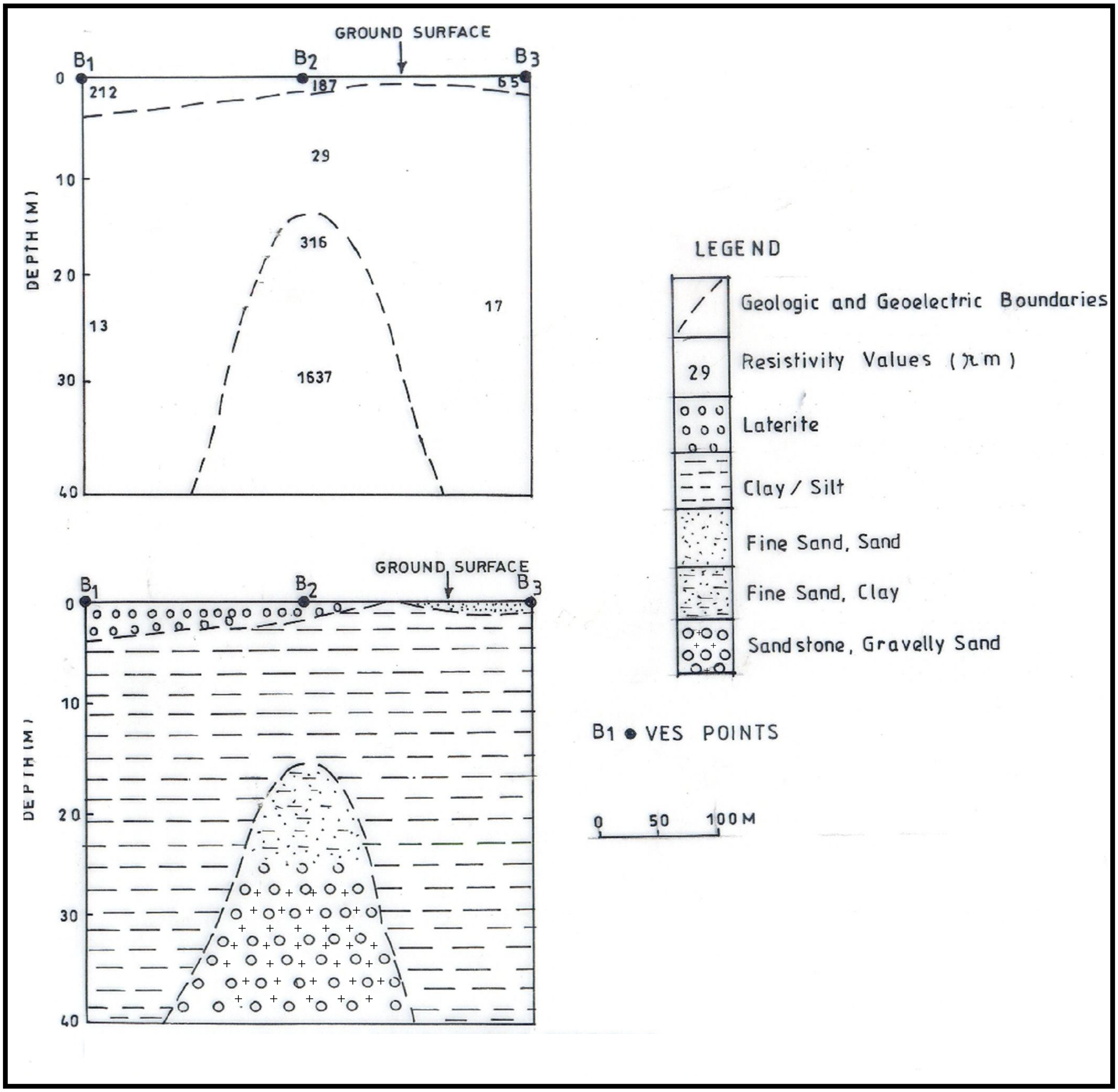


Fig. 4.6: Geological and Geolectric section for B – Profile

The first layer shows high resistivity at VES points B1 (212.17ohm-m) while B2 (187.72 ohm-m) shows that the soil was probably of compacted sandy material or laterite. At VES Point B3, medium resistivity was encountered indicating that the soil material there was probably clay-sand or clay-silt. The thickness of the layer at three points were 3.31m, 1.54m and 1.24m for B1, B2 and B3 respectively.

The second layer shows very low resistivities at all the VES points, indicating the dominance of clay or silt material in the area. The thickness of this layers ranges from 13.83 to 29.8m. The differences may be explained in terms of field observations of the extent of weathering and erosion in the area, especially between Zango and the Secretariat i.e between B-profile and C-profile points.

At VES point B2, four layers were encountered. The resistivities for these layers were high to very high, indicating the presence of sandy material in the third layer and compacted coarse sand and sandstone in the fourth layer. The thickness of the third layer is 19.28m and from 19.28m to infinity for the fourth layer.

Fig 4.7. shows the cross sections for VES C1 – C6 near GSS, parallel to the main road leading to the main town. Six VES points were sounded, with four points going along the road (C1 – C4) and the remaining two points (C5 and C6) going northwards to Hamatawa village (Figure 3.1).

The first zone is probably a zone of laterite or sandy materials because it has resistivity values between 285.68 – 443.56 ohm-m (between C1, C2, C3 and C6). The first layer suggests two soil types with high resistivities at VES points C1, C2 and C3, indicating the presence of sandy material. The zone of medium resistivity with resistivity range of 128.45 and 109.61 ohm-m at VES points C4 and C5 is most likely a layer of silty-clay or sandy-silt.

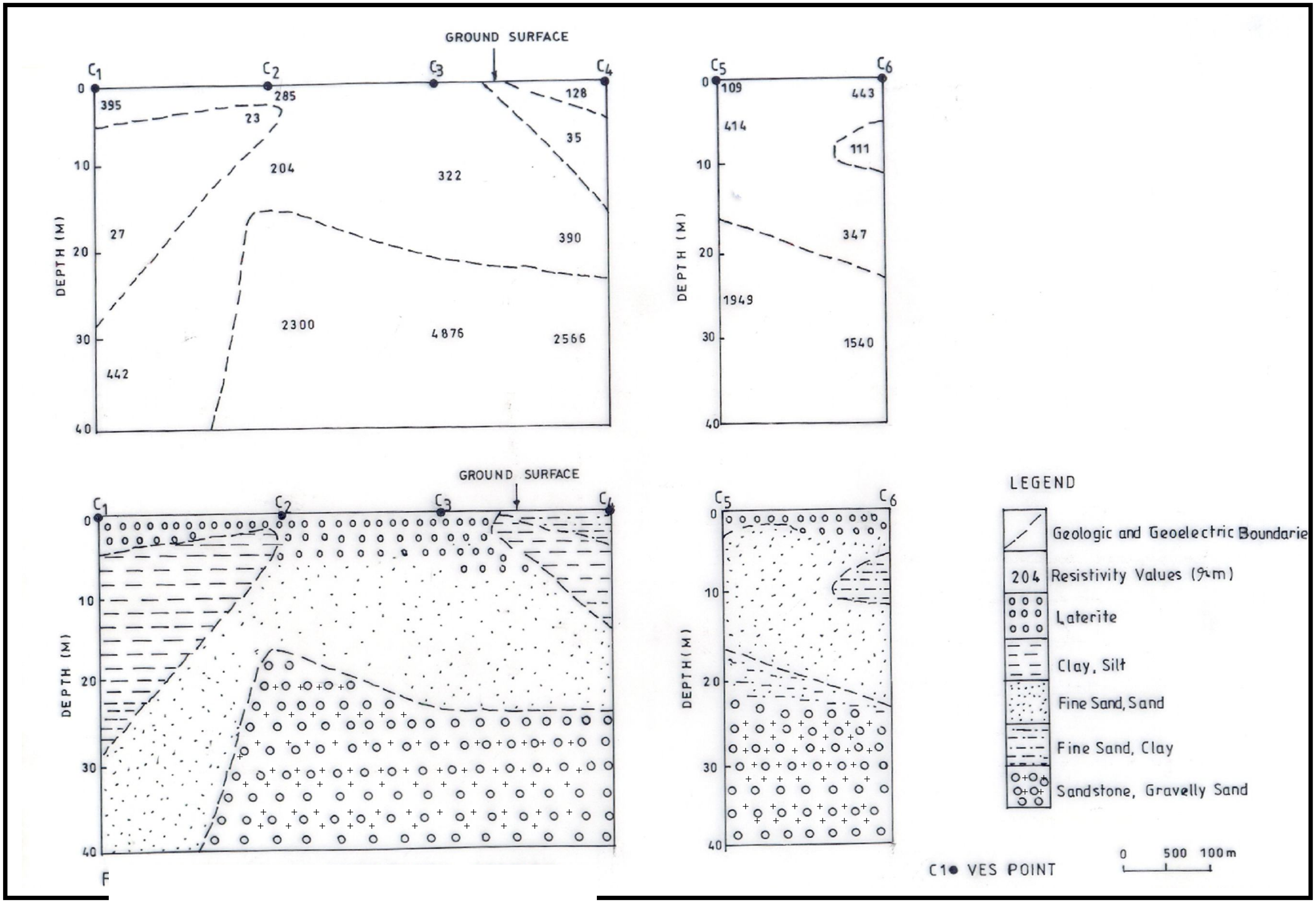


Fig. 4.7: Geologic and Geolectric Sections for C profiles

The second layer is generally a low to medium and high resistive layer with the exception of VES point C3, where very high resistivity was obtained, probably because it is the only point with two layers in the profile and because it falls within a village where the extent of erosion exceed that of the surrounding areas in the profile. The layer at this point indicates the presence of gravelly sand or limestone alternating with sand; while the other three VES points (C1, C2 and C4) indicate the dominance of clay/silt materials. VES points C5 and C6 show a high-to-moderate resistivity, indicating the presence of sand/sandstone on VES point C5, and alternation of sand and clay or silt in VES point C6. The third layer is generally a high to very high resistivity layer while VES points C1, C2, C4 and C6 show resistivity ranges between 204.67 – 442.49 ohm-m, which is considered high, and indicating that sandy materials and sandstones predominate the points, while point C5 shows the dominance of coarse sandstone with a resistivity value of 1949.22 ohm-m.

The fourth layer which only shows up on 3 – VES points (C2, C4 and C6) indicates very high resistivity values of 2300.4, 2566.63 and 1540.40 ohm-m respectively. These confirm the presence of sandy limestone or gravelly sand.

Figure 4.8 shows VES point D as a lone point sounded at Tudun Wada along the road to Marafa’s palace from the Secretariat. One sounding was done due to inaccessibility of the terrain as a result of settlement and other man-made features which will not allow the soundings to be taken along the line.

Four layers were encountered at this VES point D with the first layer showing a relatively high resistivity of 165.49 ohm-m, and a thickness of 1.71m. This indicates that

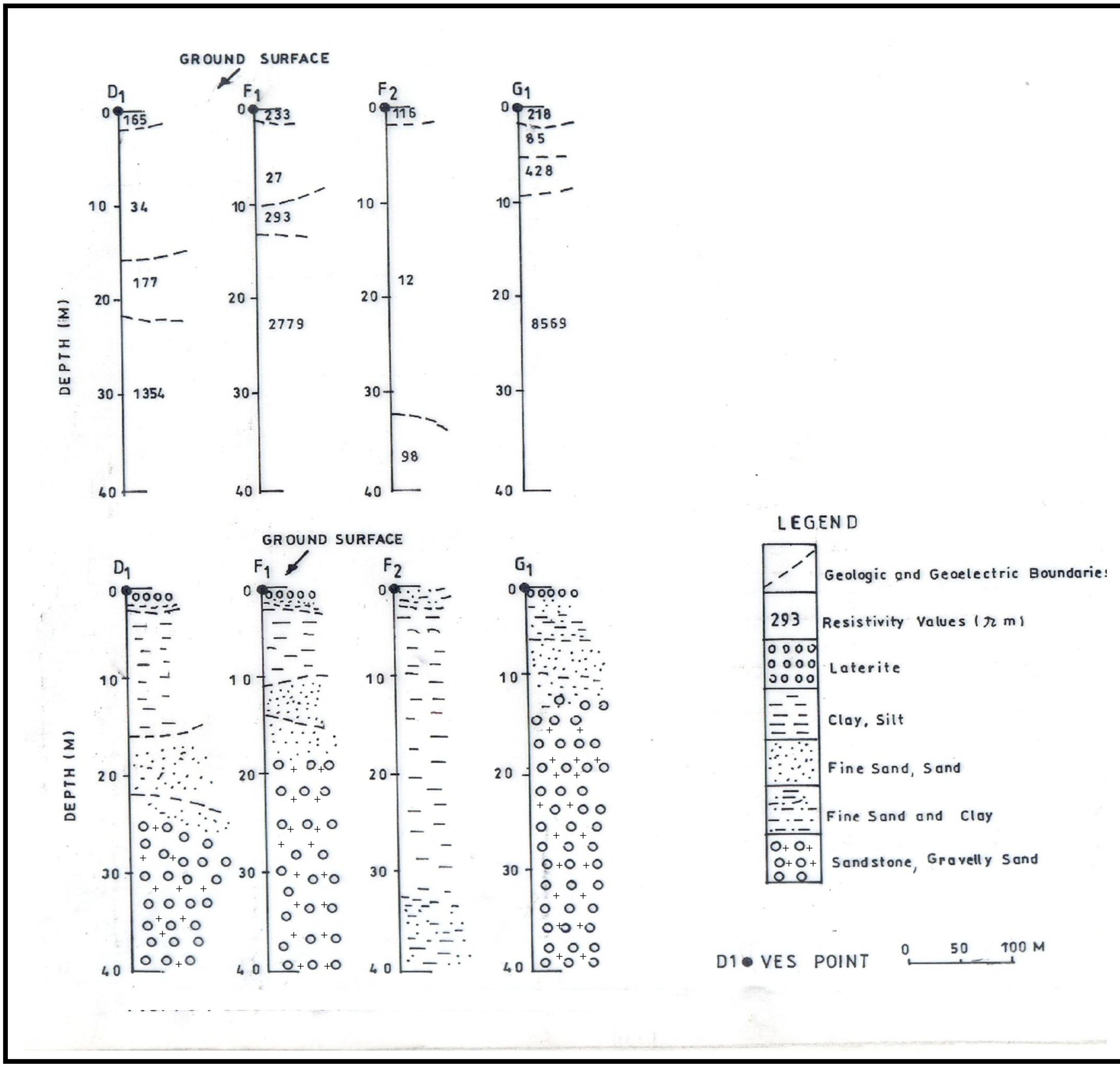


Fig. 4.8: Geologic and Geolectric Sections for D, G and F Profiles

the top layer is mainly laterite or sandy material. The second layer shows low resistivity of 34.95 ohm-m, thus, indicating the dominance of clay material in this layer. The third and fourth layers show high to very high resistivities of 177.04 and 1354.06 ohm-m, indicating the presence of sand or sandstone to coarse sand respectively.

Fig 4.9. Shows the cross section obtained from profile E. this profile runs from east-west VES points E1- E9, with only VES point E2 running southwards (figure 3.1). The cross-sections indicate that the region between VES points E1, E2, and E8 posseses 2-layers, VES point E7 shows 3-layers while VES points E3, E5 and E6 show 4-layers, and VES points E4 and E9 show 5-layers. This clearly confirms the ruggedness of the topography of the town from one location to another.

The resistivity of the first layer is generally moderate to low resistivity. However, high resistivity was obtained at VES point E7 (273.18 ohm-m) with a thickness of 1.05m, indicating the presence of lateritic material at the top soil. VES points E2, E3, E5, E6, E8 and E9 also show a relatively moderate resistivity values. This indicates the presence of sandy clay or sandy silt materials, while VES points E1 and E4 show very low resistivities, thus, confirming the dominance of clay material in the area.

The second layer exhibits three types of rock materials across the profile. VES points E2, E3, E6, E7 and E8 show very low – low resistivities, indicating the dominance of silty – clay or silt or clay materials. The depths range from 0.64 to 2.03m. This was further confirmed by well and borehole logs along Marafa's palace where VES points E2 and E3 are located. VES points E1, E4, E5 and E9 indicate a moderate to high resistivities. The presence of fine sand and sandstone is probably expected at VES points E1, E5 and E9, while silty-clay or fine sand with clay is expected at VES point E4.

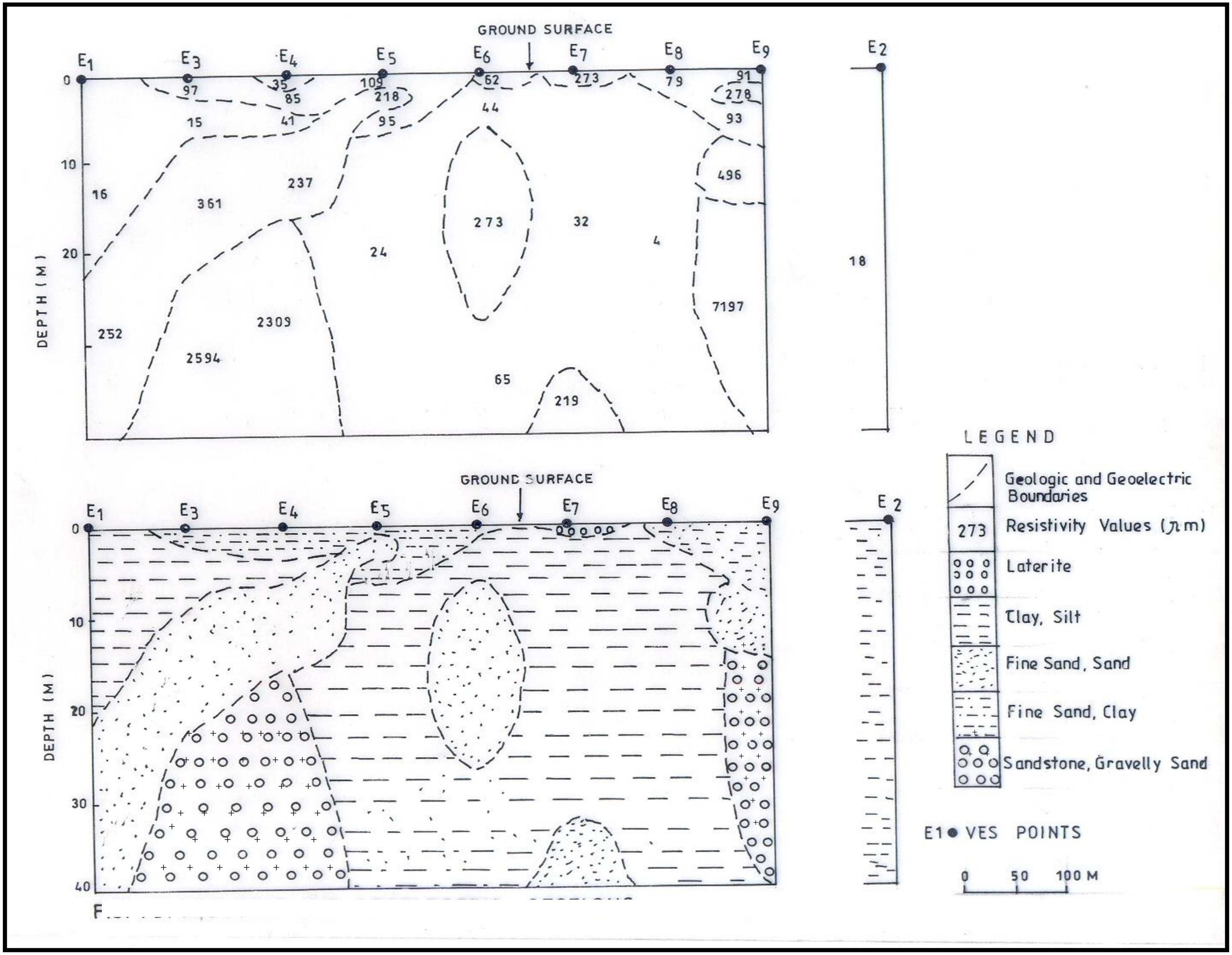


Fig. 4.9: Geologic and Geolectric Sections for E Profiles

The third layer showed high resistivities at VES points E3, E6 and E7, suggesting the presence of fine sand – sandy material or sandstone. The resistivity ranges between 219.74 and 273.52 ohm-m. VES point E4 show low resistivity indicating a silt or clay material, while VES points E5 and E9 shows a moderate resistivity, indicating the presence of sand with clay bands or silty-clay.

The fourth layer shows a high resistivity at VES points E4 and E9. This indicates the presence of fine sand deposits or sandstone. VES points E5 and E6 shows a low to moderate resistivity, giving the soil material in the area as silty clay and sandy clay materials, respectively. Only VES point E3 shows a very high resistivity of 2594.43 ohm-m, indicating that the area is gravelly – sand or sandstone.

The last layer on the profile is the fifth layer which is found on VES points E4 and E9. Both points show very high resistivity values of 2309.66 and 7197.95 ohm-m respectively, indicating that the area is dominated by coarse sand to gravelly sand or sandy limestone.

Fig 4.8. shows the F profile cross-sections, where two points were sounded, each on a separate stand point. The 1st one was laid northwards to the rest house frontage (F1), and the 2nd was run east-west direction beside rest house and stop at Mailafiya's house (F2).

The resistivity of the first layer show a moderate to high restivity of 283.20 and 116.74 ohm-m for F1 and F2 respectively, with thickness of 0.71 and 1.54m. This indicates the presence of silty-sand at VES point F2 and sandy material at F1 VES point. The second layer shows very low resistivities at both VES points (F1 and F2), thus indicating the dominance of clay material in this zone. The third layer also shows a similar lithology with the first layer, confirming that only a thin layer band of clay separates it with the first layer. This proved the intercalation pattern of the stratified layers in the region as discuss earlier. The resistivities of this layer are 293.46 and 98.44 ohm-m for F1 and F2 VES points respectively.

The fourth layer found at VES point F1 is completely missing in point F2. This is probably because of the extent of erosion along this point which goes down towards the fadama area (figure 3.1). The resistivity at VES point F1 shows a very high resistivity of 2479.95 ohm-m, indicating the presence of a coarse sand and sandstone.

Figure 4.8 shows another lone VES, point G1, which was run around the general Hospital of the town, stoppingat about 150m away from the main entrance to the Hospital (figure 3.1). The sounding indicates a 4-layers cross-section. The first layer shows a high resistivity value of 218.68 ohm-m, indicating that the top soils is lateritic in nature or is of sandy material. The second layer is moderate with resistivity of 85.05 ohm-m and a thickness of 5.04m, showing the alternation of clay or silt on sand material. The third and fourth layers give high to very high resistivities of 428.88 and 8569.46 ohm-m respectively. This clearly indicates the coarse and gravelly nature of the sand material of these layers.

The last profile is H – profile which is shown on Fig 4.10. There are two VES points on this profile, H1 and H2 and both show a 3 – layer strata to the depth penetrated by the electric current.

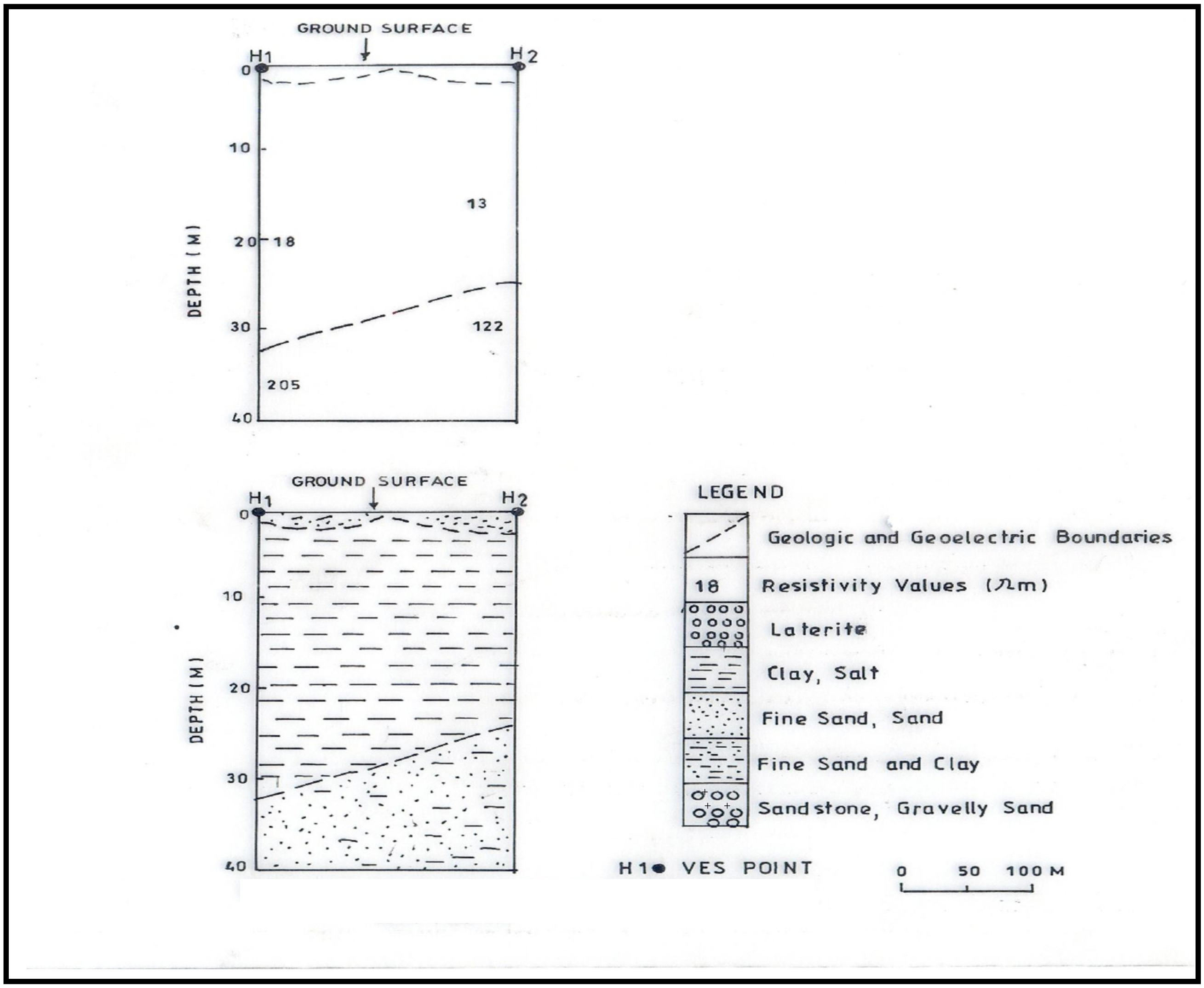


Fig. 4.10: Geologic and Geolectric Sections for H Profile

The first layer show a moderate to high resistivities of 139.79 and 216.36 ohm-m for VES points H1 and H2 respectively, indicating a sandy-clay or silty-sand material for VES point H1, and the dominance of sand at VES point H2. The second layer at both VES points indicates a very low resistivity, which show that clay or silty materials predominates the layer, with thicknesses of 32.06 and 23.35m for H1 and H2 respectively. The third layer also shows similar lithology with the first layer, though it shows a little reversing trend in soil material composition at VES points. Thus, the dominant of sandy-coarse sand material here is at point H1, while clay-sand or silt-sand occupied the H2 point.

4.3 DISCUSSION OF RESULTS

A careful investigation of the 28 VES points surveyed and their geologic lithologic characteristics showed that 94 layers were penetrated. The layers so penetrated vary in depth and thickness of each layer. The classification of the layers (Table 4.10) revealed that only twenty three in classes A&B have potential for yielding groundwater, probably all seasons. As many as ten belonged to class A (highly suitable) for groundwater prospecting and extending as deep as to the fourth layer (i.e between 15 and 26m) except for VES point C5 which lies within the third layer only.

Of all the eight (A-H) transects the C commanded the highest VES points with high probable groundwater potential in the town. Three of the VES points on C transect fell on sites having their aquifer in the fourth layer (at VES C1,C4 and C6) and one VES point located on VES C5 but with its aquifer in the third layer. Thus, the area stretching from Government Secondary School to the front of the petrol filling station moving northwards to Hamatawa village is highly suitable for groundwater prospecting (figure 4.7). The borehole log at the veterinary clinic confirmed the lithologic similarities with that at VES point C5 (i.e the presence of fine sand as from 2m-9m underlying the lateritic top soil. Another transect with VES points with high groundwater potential is E. In fact, it is the longest transect with 9 VES points, and (4 VES points E3,4,6 and 7). VES points E3 and E4 stood out as the best. The two were located along the corridor between the main market and the town motor park and on the hillslope side at Tudun Makada. Here again there was an all season hand-dug well with records of the material into which the well was sunk.The records indicated a 2m lateritic top soil layer underlain by a 9m silt-clay and fine sand found up to a depth of 24m. When compared with the surveyed VES points, the resistivity records revealed that at E3 near Marafa;s (i.e chiefs palace) and close to the hand dug well the vertical electrical sounding penetrated down to the fourth layer. The stratigraphic characteristics also included top lateritic material (m) and the underlying layer varied very little from that of the hand-dug log and very deep (about 16m). It need be stated that because of the time constraint and the cost involved, the VES throughout the 28 points surveyed could not penetrate beyond 40m.

However, on transects A,D,F,G and H there were fewer VES points, though the points have high potential. The reason for the few points is because of compound enclosures and inability to undertake a grided VES survey. Besides, some of the transects had to be taken along the roads (which have lateritic compactions).

CHAPTER FIVE

SUMMARY AND CONCLUSION

INTRODUCTION:

This chapter, summarizes the major findings of the study, presents the conclusion of the of the study, and presents suggestions for further researches.

5.1 MAJOR FINDINGS

After careful inspection of the resistivity and lithologic characteristics of all the VES points surveyed, patterns of similar classes were identified and mapped along profile lines. The aim is to show and locate areas of high ground water potential.

Also potential VES point's classifications were used to detect patterns. The two classes, A (highly suitable) and B (suitable) were selected as those with favourable VES points for groundwater prospecting. The reason being that the classes C & D are less suitable and most of the points stopped at layer two. For example in classes Ci and Dii with twenty-one VES point (although repeated in several places) never exceed layer two which by all standards in the area are shallow (15.59m) on the average.

But the most important points are the 24 VES points found on class A and B, respectively on the C and E profiles, with the thickness range from 15 to 24m on the C profile and 15 to 26m on the E profiles. These are favourable points for groundwater prospecting especially the hand-dug wells which doesn't exceed the prescribed meters in the area as generally observed.

Table 5.1: Groundwater potential VES points in Gada-town.

Class		A	B
Layers	4	A_4 B_2 C_2 C_4 C_6 D_1 E_3 F_1 G_1	E_3 E_4
	3	C_5	A_2 A_4 B_2 C_1 C_2 C_4 C_6 D_1 E_6 E_7 H_1

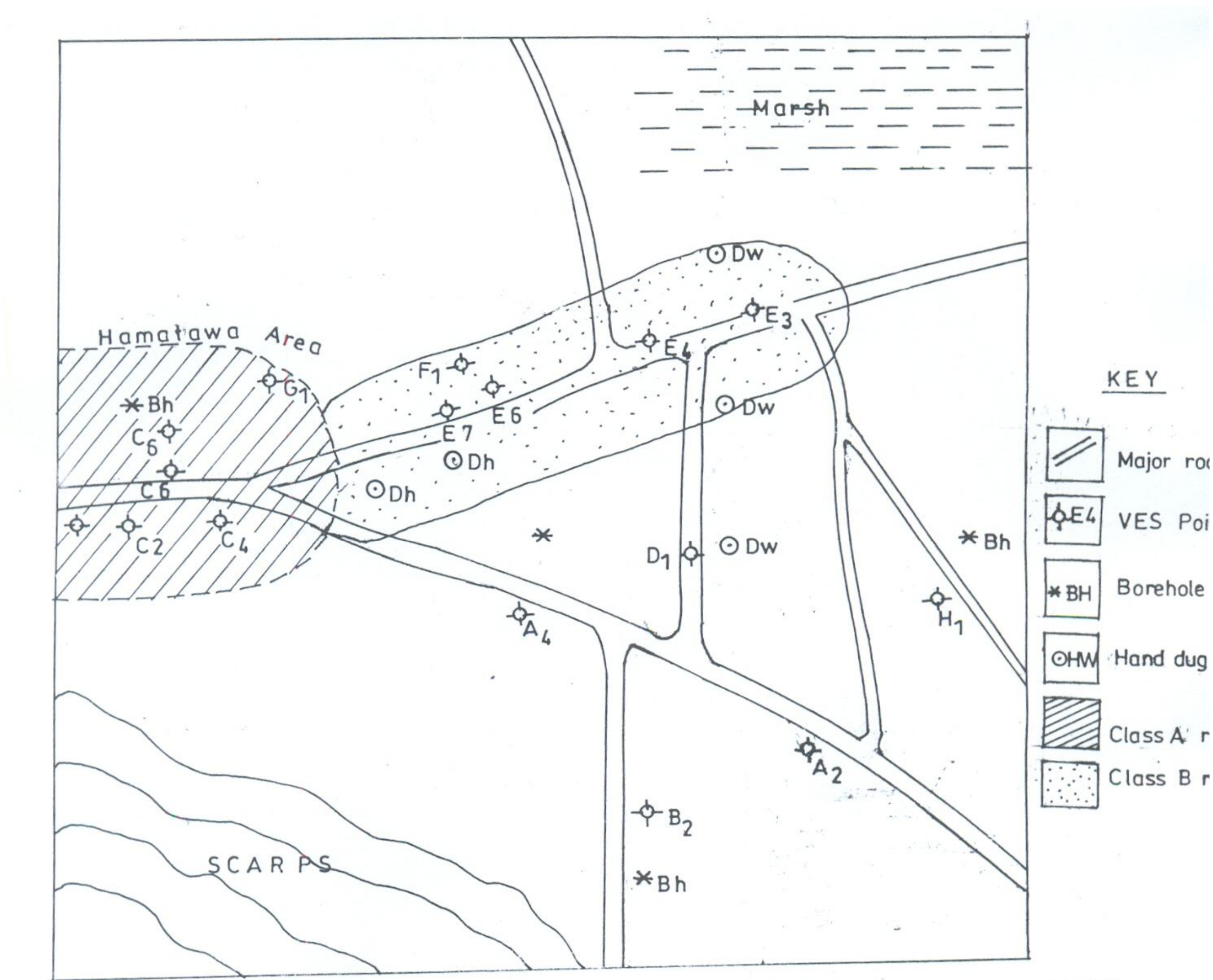


FIG. 5.1 : PROBABLE HIGH YIELDING GROUNDWATER LOCATIONS BASED ON VES POINTS INTERPRETATIONS.

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5.2 SUMMARY:

The research was conducted within Gada town in Sokoto State with the principal aim of characterizing the ground water potential in the area, using one of the groundwater investigation methods of vertical electrical sounding (VES). A purposeful random transect survey was used to cover the town instead of the conventional grid squares. The reason for using the random transect method was because of the unsuitable terrain and the compact compound layout of the town which made some of the areas inaccessible. Hence, eight transects were established and a total of 28 VES points were surveyed.

From the eight transects surveyed, three, A, C and E provided 23 VES points (representing 82% of the total 28 points surveyed). Ten of these belonged to class A and all of them have aquifer located between 15 and 26 metres (in the fourth layer except for VES C5 which is located in the third layer).

5.3 CONCLUSION

From this study, different parameters, particularly resistivity of third and fourth layers and their lithological characteristics were determined and analyzed. Using these parameters, it was observed that there are variations in the levels of groundwater potential from one area to another in the town, with the low areas around Gada GSS to general Hospital and from Marafa's palace up to the main Garage as having higher prospects than the remaining areas. Of significant importance is the area around the L.G secretariat down to L.E.A. and towards Zango village which shows high potential groundwater prospecting.

Since it was not possible to use the conventional grid system for the geotechnical survey, mapping of the hydro geological boundaries of the area was not undertaken. However the use of existing borehole records in the town also help in interpreting the hitrology of the sections derived at from resistivity surveys which in turn helped in accessing the suitability of the ground water potential points. Two major areas were identified and delineated for successful groundwater prospecting viz (1) the Hamatawa and (2) the corridor between the market area and motor pack stretching from Marafas palace to the hill slopes at Tudun Makada.

5.4 SUGGSTIONS FOR FURTHER STUDIES

No geophysical method of investigation can give a complete information of an area, and the Schlumberger configuration used in this work cannot be exception, especially as its use in the present study has shown.

However, it is important to point out that in the present study, it was possible to extend the distance more than 26 metres at depths greater than 4 layers were not observable. Indeed it is an important short-coming of the study and will be the focus of correction if the study were to be undertaking again. Certainly further studies that should be done must be advised to go deeper than fourth layer. Even so, the 23 VES points identified as highly suitable and suitable for ground water prospecting belonging to classes A and B if dug will increase sources of water supply and go along way to ease water shortage problems in the environment.

If similar research is to be carried out in future, the following suggestions should be taken to improve the results.

I. Other geophysical methods of investigation such as the seismic and magnetic methods could be employed for further studies, and at a depth of not less than 400meters.

II. Before locating any borehole in future, intensive geographical investigation is neseccary for appropriate siting in order to avoid an abortive or low yield borehole drilling.

III. For future borehole drilling, the depth should not be less than 180 meters for borehole and 30 meters for hand -dug wells in the town.

IV. More research should be carried out for the determination of the resistivity values of the underlying layers for proper evaluation.

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