GIS INTEGRATION OF ELECTRICAL RESISTIVITY, REMOTE SENSING AND HYDROGEOLOGICAL DATA TO DETERMINE GROUNDWATER POTENTIAL IN KIAMBU AREA, KENYA

BY

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2009

DECLARATION

I certify that the work carried in this report is wholly my effort and it has never been submitted nor published before except where references have been made to the various authorities therein.

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ABSTRACT

Groundwater is inextricably linked to surface water in the water cycle as it maintains wetlands and river flow during dry spells and is vital to the maintenance of their rich ecology and biodiversity. If we fail to protect our groundwater quality or quantity, our rivers and springs will also be impacted as these are natural groundwater discharge points.

In Kiambu area herein referred to as the "study area" there is a sharp rise in demand for groundwater due to increased establishment of floricultural, horticultural and coffee farms. This has resulted in drilling of additional borehole leading to over-abstraction of the aquifers as evidenced from lowering of water table. In addition, human encroachment to catchment areas (forested highlands of Tinganga and Ndumberi) most likely has affected the recharge mechanism thus inhibiting replenishment of the groundwater resources. These myriad problems called for integrated study to understand the groundwater potential. The results will form a basis for formulating policies and guidelines on protection and conservation of groundwater resources.

The geology of the study area mainly comprises a succession of lavas and pyroclastics of Cainozoic age overlying a foundation of folded Precambrian schists and gneisses of the Mozambique Belt.

An integrated approach of using Geographical Information System (GIS), Remote Sensing, Geophysical survey and the DRASTIC (Depth, Recharge, Aquifer, Soil, Topography, Impact of vadose zone and Conductivity) model procedures as tools were applied to determine distribution of ground water potential areas. Six steps were adopted in the production of the groundwater potential zone map: satellite and ancillary data acquisition, processing and analysis of satellite data, analysis of geophysical (vertical electrical sounding) data, preparing spatial baseline database in GIS, spatial data analysis and integration of results. Using Arc View 3.2 software, different thematic layers of lithology, land use cover, drainage patterns, slope, topography, transmissivity, resistivity measurements and rainfall were input parameters into the model.

From the results of the study four groundwater potential zones were delineated ranging from low to very high zones. The very high groundwater potential zone covers the southeast side and grades through high, medium, low potential in the northwestern side. The zones were as follows: (i) very high potential zone covers spatially about 13% of the total area and characterized discharge zones. It occurs as isolated perches within high potential zones (ii) high potential zones covers about 70% of the entire area i.e Kiambu Township (iii) medium zone covers about 15% and characterizes the catchment area (iv) low potential zone are less than 2% and occur as small isolated parts to the northwest of the study area.

Therefore, the method adopted for this study proved very successfully in meeting the objectives set and is an improvement to the methods previously used in delineating groundwater potential that focused on single parameter independently.

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CHAPTER 1: INTRODUCTION

1.1 General

The term groundwater refers to all water which is below the surface of the ground in the saturated zone and which is in direct contact with the ground or subsoil. The saturated zone is where all the cracks in the rock and all the spaces between the grains of rock or within the soil are filled with water. The upper limit of the saturated zone may be thought of as the water table (it is shown as a dashed line on Figure 1.1). The zone above the water table, where pore spaces contain both air and water, is known as the unsaturated zone.

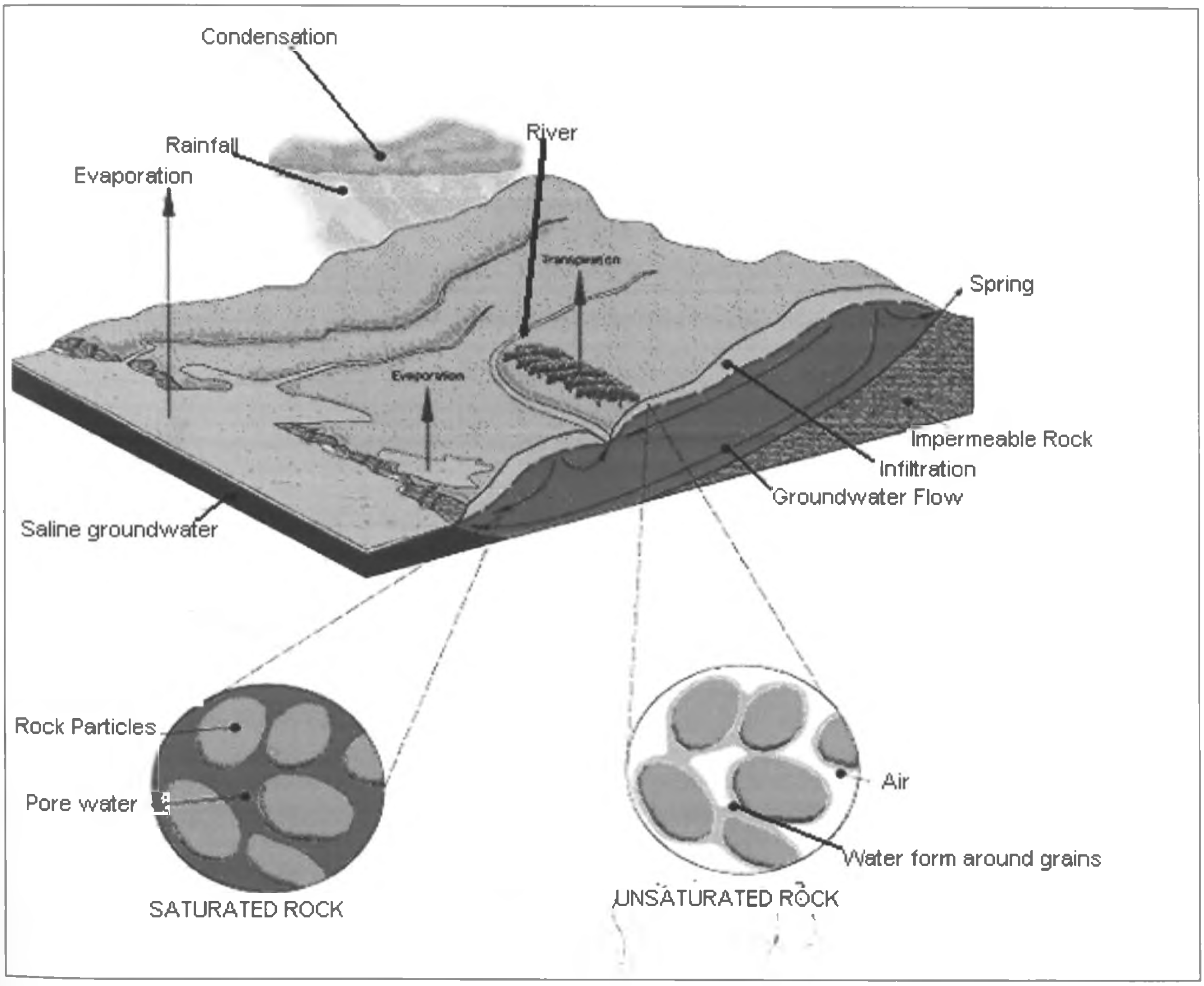


Figure: 1.1 A Groundwater System: The Saturated and Unsaturated Zones

1.2 Statement of the Problem

The study area has a large number of water yielding boreholes which have been drilled over the years due to the continued demand for water in the area. This has led to an over-abstraction of the aquifers resulting to lowering of the water table. This is evident from the lowering of the water rest levels of the boreholes recently drilled in the area (Kenya Ministry of Water and Irrigation). This phenomenon has affected the yielding capacity of highly productive boreholes to the extent that the upper aquifers penetrated by the recent deep boreholes had to be sealed, old shallow boreholes deepened or having their pumps lowered to deeper levels in the borehole in order to allow for larger drawdown and yield (Kenya Ministry of Water and Irrigation).

The water supply from Kiambu Municipal Council to the inhabitants of (2006) study area is both insufficient and unreliable. It is being restricted only to domestic use. This has resulted into an acute water shortage with groundwater as the only alternative.

Increased establishment of floricultural, horticultural and coffee farms in Kiambu district and its environs have increased water demands tremendously leading to over-abstraction of existing groundwater resource. The reduction of available water resources will eventually set forth an ecological imbalance in the environment with certain ecosystems competing unfavorably.

The rising population particularly in catchment areas has directly resulted into human encroachment to land in the forested highlands of Limuru and Kikuyu which are outside and to the west of the project area. The subsequent deforestation has directly affected replenishment of the groundwater resources. Rainfall has significantly been affected in terms of intensity, pattern and distribution in those areas and subsequently groundwater recharge by increasing the runoff in the area. There is therefore dire need to determine the distribution of various aquifers, the information which is currently missing. Such knowledge will be of prime importance in formulating policies and guidelines on protection and conservation of the catchment areas.

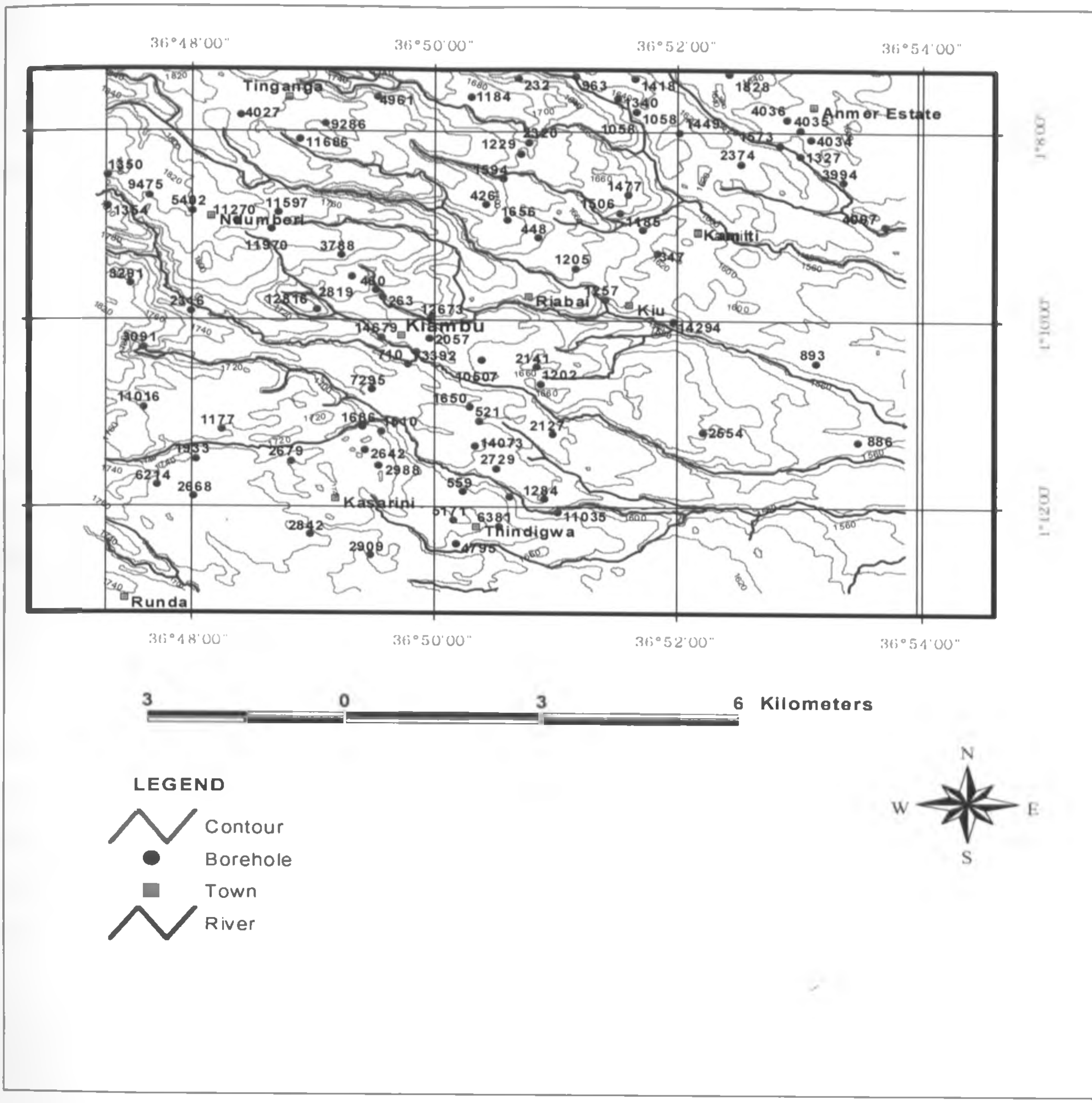


Figure 1.2: Boreholes in the Study Area

1.3 Location, Climate and Physiography

The study area covers Kiambu Township and its environs of Kiambu District, Central Province. It lies on the eastern side of the Eastern Rift Valley and covers part of 1:50,000 Topographic Sheets No.148/2 for Kiambu bounded approximately by latitudes 1^0 07'30" S and 1^0 15' 50" S and longitudes 36^0 45' E and 36^0 55' E. (Figure 1.3). It covers an approximate area of 80 km^2 on an altitude of 1800 m.

The climate of the study area is of tropical type with bimodal rainfall distribution pattern. The two rainy seasons last from March to May for long rains and mid-October to mid-December for short rains. The mean annual rainfall is 1200 mm with mean temperatures of about 25^0 C. There is a hot spell during the months of January to February and a cold spell in the month of July when temperatures are sometimes below 18^0c.

The drainage pattern is more or less dendritic with many small tributaries joining the main rivers. The rivers flow from west to East controlled by the topography of the project which slopes towards eastern side. The western part altitude is about 1800 m and the Eastern side is about 1400 m. The project area is drained by Riara, Kiu and Gathara-ini Rivers.

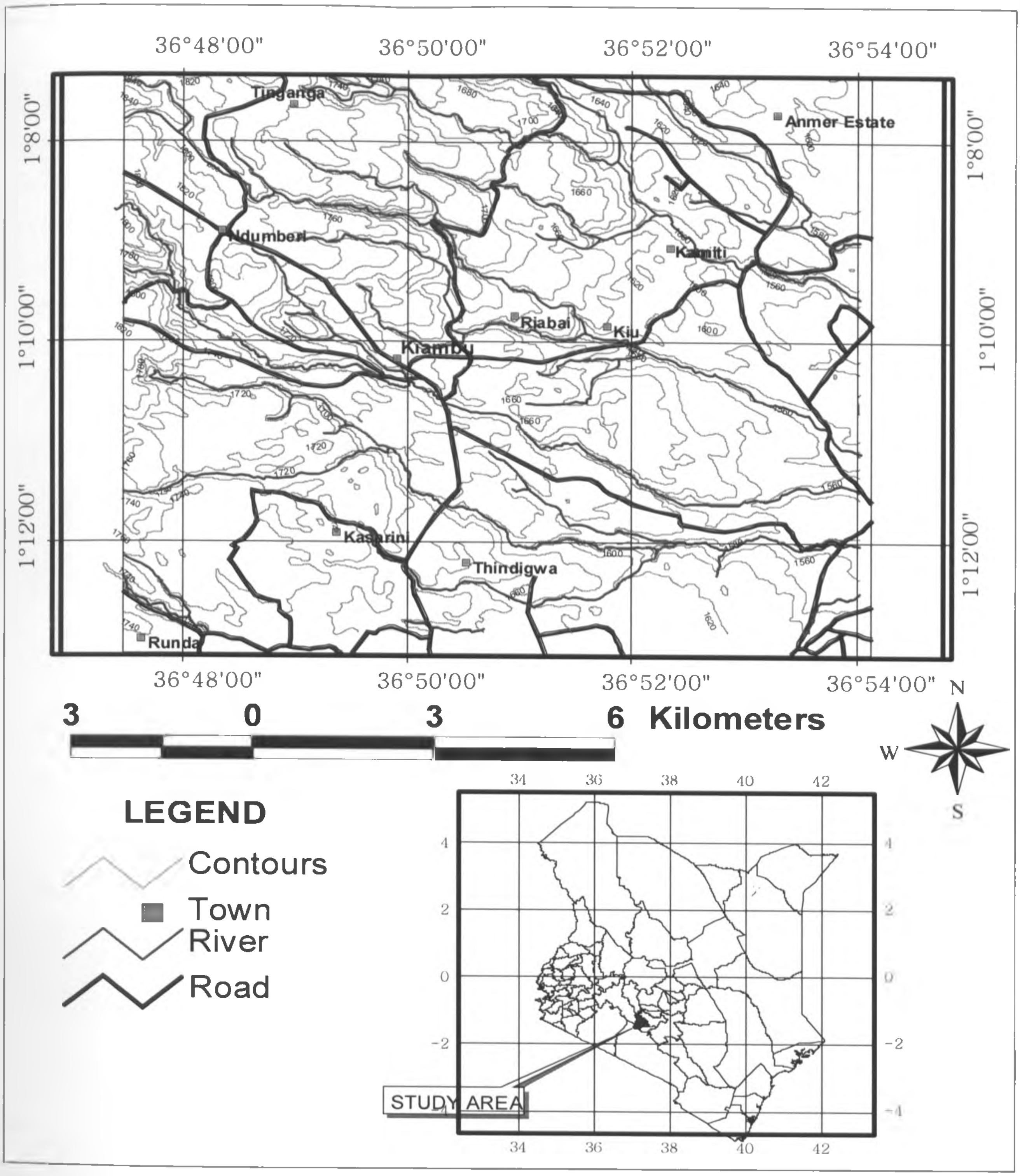


FIGURE 1. 3 Location Map of the Study Area

1.2 Geology of the Project Area

The geology of the study areas was described by Gevaerts (1964) and Saggerson (1991) (Fig. 1.4).The rocks mainly comprise of succession of lavas and pyroclastics of Cainozoic age overlying a foundation of folded Precambrian schists and gneisses of the Mozambique Belt. The stratigraphic succession of these rocks is as follows:

- Limuru Trachytes and Quartz Trachytes
- Upper and middle Kerichwa Valley Series (Tuff)
- Lower Kerichwa Valley Tuffs
- Nairobi Trachytes (lower trachyte division)
- Kiambu Trachyte
- Kapiti Phonolite Series
- Basement undifferentiated crystalline rocks of the Mozambique belt.

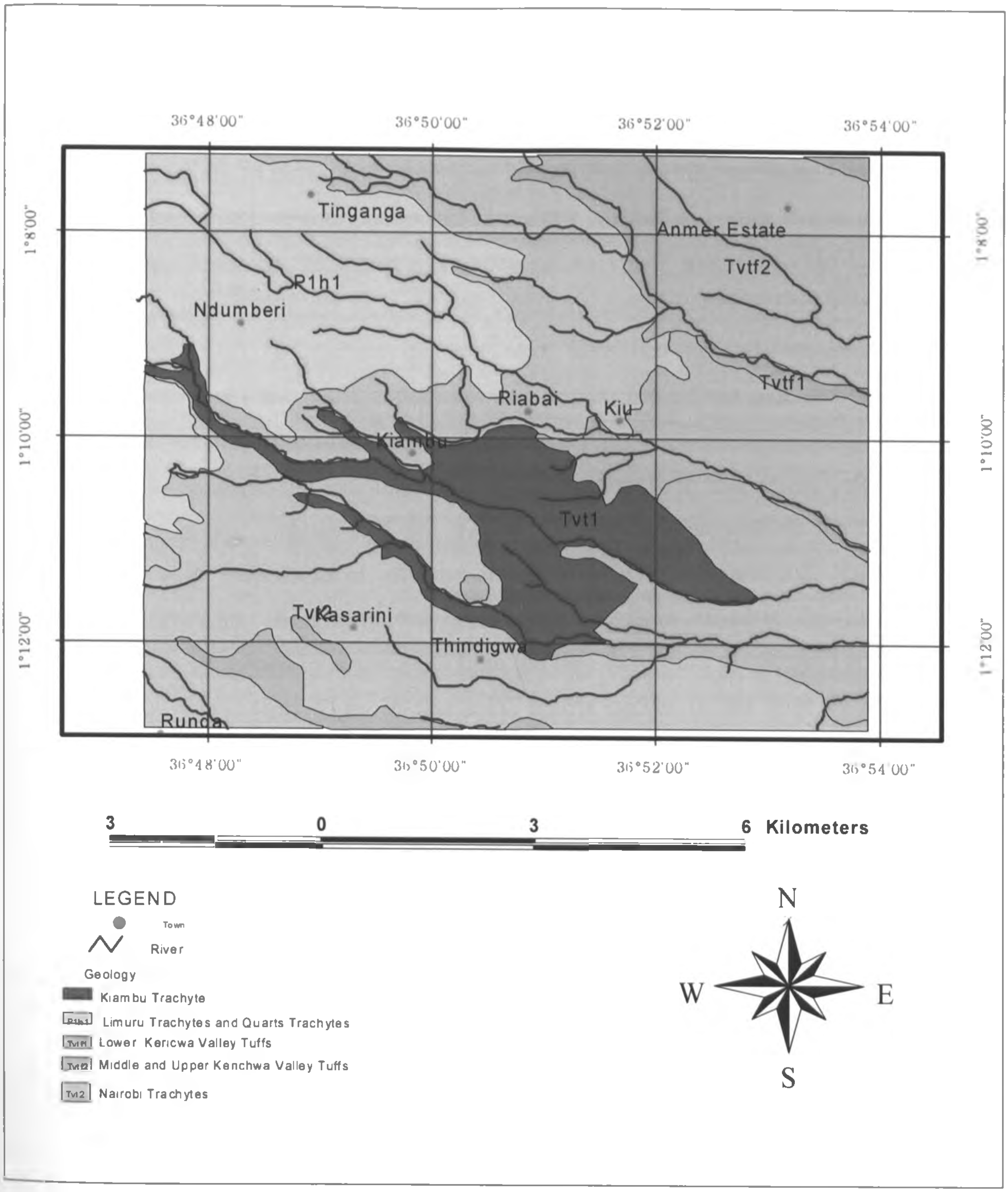


FIGURE1.4 Geological Map of the Study Area(Modified from Saggerson,1991)

1.2.1 Limuru Trachytes and Quartz Trachytes

The Limuru Trachyte is soft, but rarely fissile, and highly porphyritic with stumpy feldspars in a pale grey groundmass. Typically, the rock contains large anorthoclase phenocrysts in a matrix of untwinned orthoclase, kataphorite, aegirine-augite and rare cossyrite. The phenocrysts of anorthoclase are frequently cracked and range in size up to a centimetre, occurring as separate crystals or as small glomeroporphyritic aggregates. Inclusions within the feldspars are common; some may be concentrated round the margins of the phenocrysts, and were identified as soda-pyroxene. Kataphorite is the dominant mafic constituent and is pleochroic from pale smoky-brown to yellow-green to purplish-brown.

Rare examples of zoning in the soda-amphibole with overgrowths in blue, surmounted by yellow-green zones, suggest late but distinct changes in composition during crystallisation to an amphibole of arfvedsonitic or riebeckitic composition. Such examples may indicate changes in the upper lavas to rocks of more rhyolitic composition and are typified by a specimen from the lava flow from the Ondiri Fault Scarp north of Sigona Golf Club. In this rock, quartz occurs in the base as an interstitial mineral, occasionally in patches with a sub-poikilitic relationship towards the other minerals, particularly-feldspar. This flow probably represents one of the latest in the volcanic history of the area and is equivalent to the soda-rhyolite extrusions on the Rift floor.

In Kiambu district Limuru trachytes build successive flows that have a gentle easterly dip, consequent upon the slope of the ground over which they flowed.

1.2.2 Kerichwa Valley Series

These are made up of sediments and tuffs. The tuffs consist mainly of thickly bedded impermeable strata except where fractured. The coarse pumiceous layers are characterised, in contrast with those of the Athi Series, by the presence of sporadic hexagonal flakes or thin booklets of dark mica (biotite) not more than 3mm across. The series includes several layers or 'claystone' which are dense, light grey or purplish flowtuffs often breaking, when fresh, with a conchoidal fracture and usually containing small fresh stumpy felspar crystals. Locally, one may find between the impermeable strata, thin bands of very weathered pebbly or sandy materials which are probable aquifers at outcrop.

1.2.3 Nairobi Trachyte

The stratigraphic relationship of the Nairobi Trachytes, the underlying Kiambu Trachyte, Mbagathi Phonolitic Trachyte, Nairobi Phonolite and the overlying trachytes and tuffs is proved in borehole records and in the many outcrops in stream courses in the immediate vicinity of Nairobi. These trachytes have a wide distribution, extending from the Dagoretti-Karen area as far east as Nairobi City and northwards to Kiambu and South Githunguri. In some places the rock forms conspicuous outcrops, particularly in the south where it forms a flat-topped plateau terminating in a low but prominent escarpment overlooking the Mbagathi valley and the National Park. Clearly the Mbagathi River is a lateral stream owing its later valley development to the trachyte outcrop. Boreholes in the Nairobi municipality have in places penetrated a continuous sequence of lavas, without interbedded sediment, totaling approximately 91 meters.

At Ruaraka the lava is about 60 meters thick. A number of thin flows each with a distinct topographic expression are recognisable in the western part of Nairobi area and roads leading into the centre of Nairobi from the west cross the Nairobi Trachyte. Small steps in the escarpment overlooking the town represent the outcrops of individual flows. Shallow boreholes sunk at the reservoir near the main hospital penetrated more than one flow each having a vesicular upper contact and, in borehole C 3001 at Mbagathi, three lava flows separated by sediments or tuffs were recognised. Within the Nairobi municipality the lava is separated from the underlying Nairobi Phonolite by a few feet of agglomeratic tuff exposed in a quarry in the South Hill estate representing the easterly outcrops of tuffs and sediments between the two lavas and proved in boreholes further west.

1.2.4 Kiambu Trachyte

The Kiambu Trachyte is exposed in the vicinity of Kiambu township where it crops out in the valleys of the Riara and Gatharaini rivers and underlies the coffee estates of Fairview and Kiu, south-east of Kiambu. Here a tongue of the lava extends eastwards to within 1.6 km of the Kamiti road. Boreholes in the district indicate that the lava with a maximum thickness of 46 m, is of limited lateral extent and does not stretch much beyond the area of outcrop mapped. It probably represents the earliest of the trachyte flows that succeeded the outpourings of phonolitic lava of the Nairobi area and is seen to be directly overlain by the Nairobi Trachyte in valley sections where the

Nairobi-Kiambu road crosses the Gatharaini River. No evidence was found to indicate more than one flow.

In hand specimen the rock is light grey with numerous megascopic phenocrysts of feldspar in a fine-grained groundmass. The lava is auto-brecciated and, at the most westerly outcrop on the Njunjo Estate, vesicular lava with green, chalcedony-filled amygdales were noted. Kataphorite, aegirine-augite and cossyrite, the principal dark constituents, are unevenly distributed through a base of oriented orthoclase crystals. In thin section the rock is thus similar to the succeeding Nairobi Trachyte, though a similarity to the later Kabete Trachyte is evident from the feldspar phenocrysts.

1.2.5 Kapiti Phonolite

This series lies directly on the Basement System. The phonolite is characterised by long slender insets of felspar, their maximum length being about 5 cm. There are several flows separated by strata that are usually argillaceous (Gevaerts ,1964).

1.2.6 Basement System

The rocks of the basement system consist of gneisses and schists. The Basement System comprises metamorphic rocks which are believed to be more than 500 millions years old. Exposures exist at the confluence of the Mbagathi, Mokoyeti and Sisan Rivers inside the Nairobi National Park (fine-grained schists and coarse gneisses), and southwards near the origins of Kitengela River (biotite gneisses). East of Athi River, at Lukenya hill, augen gneisses of the Basement system rise prominently out of the volcanic overburden. Towards the south, Basement rocks eventually outcrop at surface over wide area southwest and south of Isinya.

Numerous evidence points out that the lavas and sediments of Tertiary age were deposited unconformably on the pre-existing Miocene topography formed in the Precambrian rocks. As a result, the ancient landscape is more or less preserved. Often it is possible to reconstruct the former topography from the variable depths to Basement derived from borehole logs.

1.3 PREVIOUS WORKS

In 1893, Gregory (1896) made his journey through Kenya and returned in 1919 for a second journey through selected areas. His contributions to the geology and hydrogeology of the country were published two years later (Gregory, 1921). In this important account, he described lavas from the present area, naming and designating the Kapiti Phonolite as the oldest unit of the major volcanic series. Other lavas recognized include the trachytes, agglomerates and the building stone of the Nairobi metropolitan area and the basic lavas of the Ngong volcanic centre (the three units are major water holding layers).

Geological reports accompanying quarter degree maps have been produced by the Geological Survey of Kenya since 1933. These have to a certain extent, dealt with the occurrence of groundwater in Kenya. Sikes (1934) investigated groundwater conditions of Kenya. His investigations were based on geological logs of the existing boreholes, estimated yields and the quality of water in them. His conclusions were as follows:

- In metamorphic rocks, water is always found in soft siliceous and micaceous gneisses or schists if it occurs. In granitic gneisses, it is more fortuitous, although when well weathered, small supplies usually occur if the catchment area is good.
- In volcanic rocks, water is usually found in the disintegrated rock at old land surfaces (OLS) between sheets of lava and tuffs where it may be under considerable or negligible pressure. Lava streams which have flowed down pre-existing valleys especially if the lava is basic often have good yields, either below the lava or in the weathered zone near its surface.
- Sedimentary rocks of the coast were classified into Permo-Carboniferous sandstones as good water carriers but the water is liable to be bitter, and sometimes too saline for use. The Cenozoic series almost always yield water at shallow depths but water varies from slightly brackish to salty.

An account of the groundwater conditions in Kiambu area has been given in a technical report by Gevaerts (1964). In his technical report "Hydrogeology of the Nairobi area" he described the nature and occurrence of groundwater resources in

Nairobi and its environs. He briefly described the petrography of the formations occurring in the area together with the structural and relations of the rock formations. In his survey, he divided the study area into groundwater areas and zones on the basis of the different modes of occurrence of the main groundwater supplies. He also described the occurrence and extent of groundwater resource for each zone and illustrated it by means of hydrogeological sections and maps.

Saggerson (1991) describes the geology of the area bounded by latitudes 10 00' and 10 30' S and longitudes 360 30' and 370 00' E. In this important account, he covered Kiambu area which is part of the eastern flank of the Great Rift Valley and its geological history being dominated by wide spread volcanic activity of Cenozoic age. He noted that lavas, welded tuffs and other pyroclastics cover nearly the entire area and overlie a foundation of poorly-exposed, folded and metamorphosed Precambrian rocks of the Mozambique Belt. Superficial deposits are of Pleistocene and Recent age. All the volcanic rocks have undergone extensive faulting on more than one occasion during the formation of the Rift Valley.

Saggerson (1991) outlined water resources as follows: Most of the larger streams and rivers draining the Kikuyu highlands are perennial and there is no shortage of water in the northern and north-western parts of the area, east of the Rift Valley. On the lower ground to the east and south however, streams tend to dry up during periods of drought and supplies must be supplemented from dams and boreholes. The streams are frequently fed by springs that ensue within the forest belt, the principal occurrences being those at Kikuyu which feed the headwaters of the Nairobi River and the Mbagathi Springs feeding the Mbagathi River. Innumerable other small springs ensue from between lava flows with differing porosity and permeability as a result of differing degrees of vesicularity.

Japan International Co-operation Agency (JICA, 1992) carried out national drawdown analysis using recovery data and observed that recovery test data can be analysed only when the pre-pumping is done at a constant rate to estimate hydraulic characteristics of aquifers and drawdown of wells. Also time-recovery data for the pumped well are more accurate than time-drawdown data of the constant-rate pumping test. The methodology used in this research work was used in Burdur, Turkey and Pageru river basin, India, but unfortunately none has been applied in Kiambu district.

1.4 JUSTIFICATION AND SIGNIFICANCE

In 1953, Ruaraka Area (outside study area but to the south) and its immediate surroundings were declared a conservation area with an objective of maintaining a better control of groundwater resource. Then in 1958 its boundaries were extended to include the peri-urban areas around Nairobi and part of the Kamiti area in Kiambu (Gevaerts, 1964). However, due to lack of adequate knowledge of vertical distribution of water depth and aquifer hydraulic characteristics, more boreholes have continued to be authorized. Thus, this project seeks to address the following issues:

- The groundwater flow patterns to identify recharge and discharge areas. This will contribute towards preservation of recharge (catchment) areas.
- In determining the various depths at which different aquifers are encountered and their respective thicknesses as well as their areal extent will help in estimating the possible available groundwater resource in the area.
- Carrying out aquifer zonation will help to identify the groundwater rich areas and areas deficit of this resource. This will eventually help to control abstraction from these zones.

The results from this research are expected to be used in formulation of policies on groundwater management. Once the groundwater recharge zones have been delineated it will help in establishing policies to conserve the main water catchments.

1.5 OBJECTIVES

AIM:

The main aim of the study is to determine groundwater occurrence and distribution in Kiambu Town and its environs which will mainly be used in formulation of policies on groundwater management.

SPECIFIC OBJECTIVES

The specific objectives of the study are to:

- Determine geo-electric structure
- Deduce groundwater potential using GIS

CHAPTER 2: BASIC PRINCIPLES

2.1 GENERAL

In this study, integration of remote sensing and Geographic Information System (GIS) technique was combined using the DRASTIC model procedures (Aller, 1985) in order to produce a groundwater zone map using eight biophysical parameters. Thus was carried out using the equation 1.

GP=Rf+Lt+Lu+Te+Ss+Dd+Tm+Rm.. (1)

where:

Rf= Mean Annual Rainfall

Lt=Lithology

Lu=Land use

Te=Topography (Elevation

Ss=Slope Steepness

Dd= Drainage

Tm=Transmissivity

Rm=Resistivity Measurements

Numerical weighting and rating system similar to those applied in the DRASTIC model were used in this study. The model factors are weighted from 1 to 5 according to their relative importance to each other with regard to groundwater potential. Each factor is then divided into ranges or media types and assigned a rating from 1 to 10 based on their significance on groundwater potential. The rating for each factor is selected based on available information and professional judgment. The selected rating for each factor is multiplied by the assigned weight for each factor. These numbers are summed to calculate groundwater potential index.

2.2 Geophysical method (electrical resistivity method)

The electrical resistivity method is a major geophysical tool used in groundwater exploration efforts. Resistivity, the inverse of electrical conductivity, is defined as the ratio of the voltage gradient to the current density over a small, thin, surface element of a medium. Stated more simply, it is the resistance of the geologic medium to current flow when a potential (voltage) difference is applied,

$R = V/I$ .... (2)

where R is the resistance, V is the voltage, and I is the current. For a given material with a characteristic resistivity, the resistance is proportional to the length of material being measured and inversely proportional to its cross-sectional area:

$R = pl/A$ or $p=RA/L$ .... (3)

where p is the characteristic resistivity of the geologic medium, A is the unit cross-sectional area and L is its length. Units of resistivity are given in Ohm-metre.

In a resistivity survey, a direct current or low-frequency alternating current is sent through the ground between two metal electrodes. Because earth materials offer resistance to the passage of a current, some voltage loss will occur as the current flows from one electrode to another. The voltage loss (drop in potential) that occurs as the current moves through the ground is measured at other electrodes placed between the current electrodes. The ability of a rock unit to conduct an electrical current depends primarily on three factors:

- the amount of open space between particles (porosity)
- the degree of interconnection between those open spaces
- the volume and conductivity of the water in the pores (Minning, 1973).

The presence of water and its chemical character are the principal controls on the flow of the electric current because most rock particles offer high resistance to electrical flow. Thus, resistivity decreases as porosity, hydraulic conductivity, water content, and water salinity increase. Clay and shale have low resistivities, and dry sand and gravel have higher resistivities than do saturated sand and gravel.

During a resistivity sounding, the separation between electrodes is increased in steps (Schlumberger array), which causes the flow of current to penetrate progressively to greater depths.

By plotting the observed resistivity values against depth on the double logarithmic paper, a resistivity curve is formed, depicting the variation of resistivity with depth. By computer modeling, using resistivity analysis software, the true ground resistivities and their corresponding depths are calculated and then interpreted in terms of geology and hydrogeology.

2.3 Geographic Information System (GIS)

A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Today, a variety of software tools are available to perform this activity. However, they can differ from one another quite significantly, in part because of the way they represent and work with geographic data, but also because of the relative emphasis they place on these various operations.

The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. When rainfall information is collected, it is important to know where the rainfall is located. This is done by using a location reference system, such as longitude and latitude, and perhaps elevation. Comparing the rainfall information with other information, such as the location of marshes across the landscape, may show that certain marshes receive little rainfall. This fact may indicate that these marshes are likely to dry up, and this inference can help us make the most appropriate decisions about how humans should interact with the marsh. A GIS, therefore, can reveal important new information that leads to better decision making.

2.4 Remote Sensing

It is the science and art of obtaining information about features or a phenomenon from data acquired by a device that records reflected, emitted, or diffracted electromagnetic energy, and is not in direct contact with the features or phenomena under investigation. Vegetation can be distinguished using remote sensing data from most other (mainly inorganic) materials by virtue of its notable absorption in the red and blue segments of the visible spectrum, its higher green reflectance and, especially, its very strong reflectance in the near-Infra Red. Different types of vegetation show often distinctive variability from one another owing to such parameters as leaf shape and size, overall plant shape, water content, and associated background e.g., soil types and spacing of the plants (density of vegetative cover within the scene). Even marine/lake vegetation can be detected. Use of remote sensing to monitor crops, in terms of their identity, stage of growth, predicted yields (productivity) and health is a major endeavor. This is an excellent example of the value of multitemporal observations, as several looks during the growing season allows better crop type determination and estimates of output. Vegetation distribution and characteristics in forests and grasslands also are readily determinable.

The main scopes of Remote Sensing are:

- Data collection or acquisition: from aerial, space and other platforms
- Processing to increasing accuracy and interpretability of images
- Interpretation: Deriving thematic information
- Application: Applying to solve real problems

CHAPTER 3: METHODOLOGY

The six steps adopted in the production of the groundwater potential zone map are as follows:

- Satellite and Ancillary Data Acquisition
- Processing and Analysis of satellite Data.
- Analysis of Geophysical (vertical electrical sounding) data
- Preparing Spatial Baseline Database in GIS
- Spatial Data Analysis
- Integration of Results

The methodology flow chart is indicated in Figure 3.1

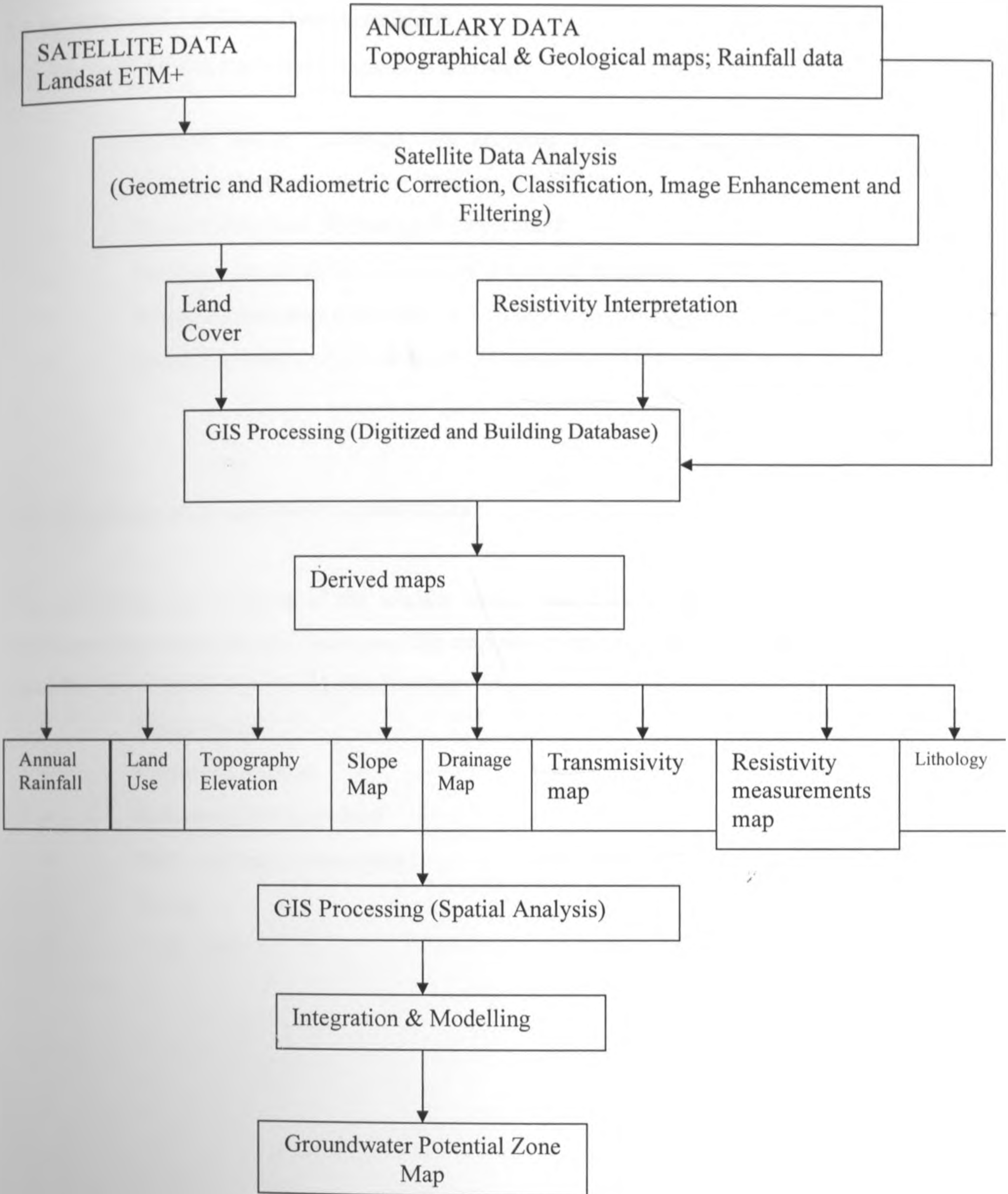


Figure: 3 .1 Methodology flow chart

3.1 Satellite and Ancillary Data Acquisition

The data used for this study were sourced as follows:

- Satellite Image (LandSat) was acquired from Regional Center for Mapping Resources for Development (RCMRD)
- Rainfall data from Metrological Department
- Borehole data from the Ministry of Water and Irrigation
- Topographical map sheet148/2 at 1:50,000 scale from Survey of Kenya
- Geological map sheet 51 at 1:125,000 scale from Mines Department

3.2 Processing and Analysis of satellite Data.

The processing and analysis of the satellite image was done to produce landuse-landcover map using ERDAS Software. The map was prepared from PAN sharpened Land-Sat image using supervised classification, for which 6 classes were identified.

- Water bodies
- Coffee Plantations
- Settlement and farm-land
- Built- up land (settlements)
- Quarry
- Farm-land.

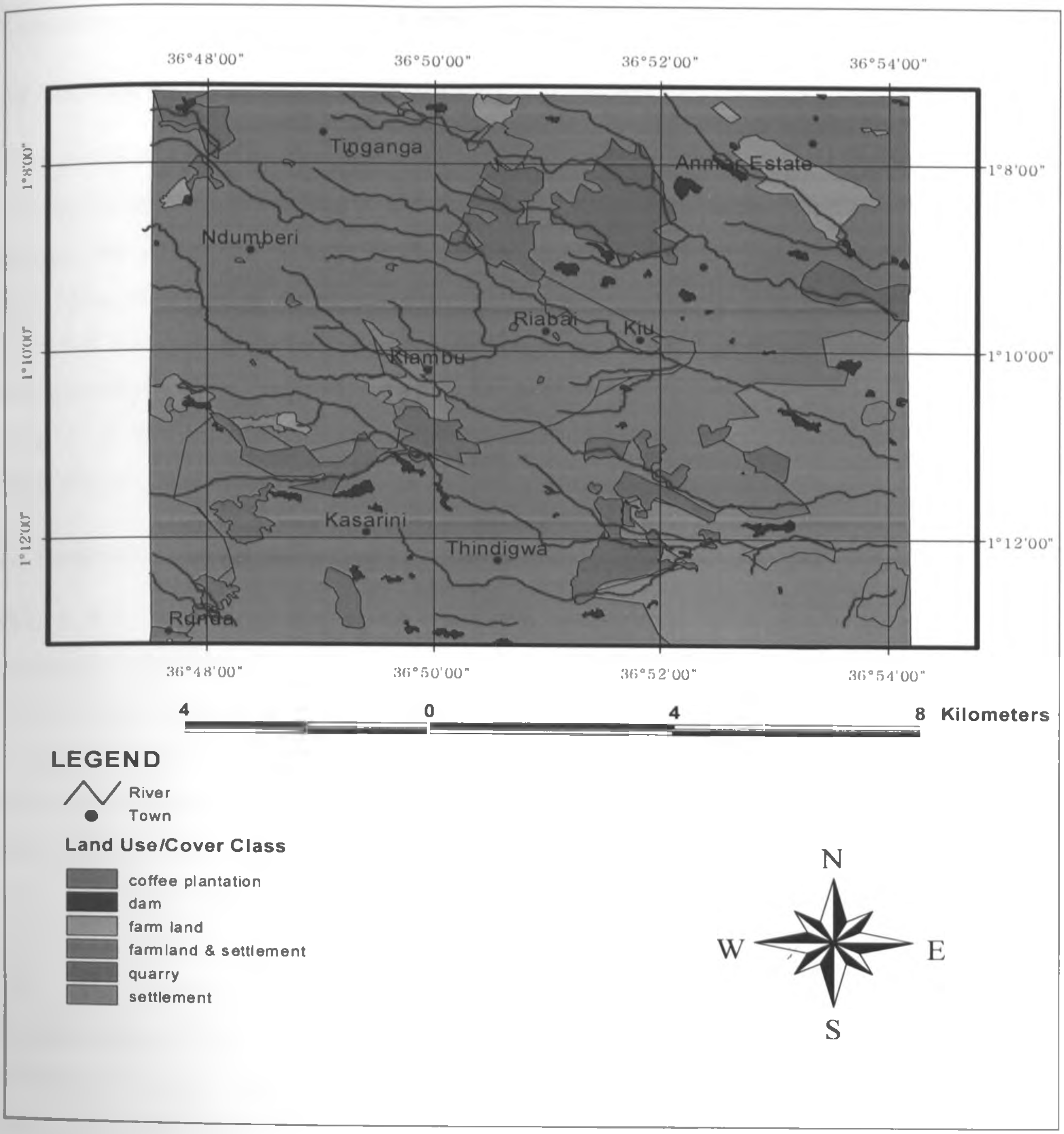


Figure 3.2: Land use- cover map

3.3 Acquisition and Analysis of Geophysical (vertical electrical sounding) data

3.3.1 Acquisition of Geophysical (vertical electrical sounding) data

Electrical resistivity survey using vertical electrical sounding method was employed to determine resistivity variations of the geological formations. During a resistivity sounding, the separation between electrodes is increased in steps (Schlumberger array), which causes the flow of current to penetrate progressively to greater depths. By plotting the observed resistivity values against depth on the double logarithmic paper, a resistivity curve is formed, depicting the variation of resistivity with depth.
A total of 34 Vertical Electrical soundings were carried out as shown in figure 3.5 using SYSCAL_R2 resistivity meter.

3.3.2 Geophysical Equipment

SYSCAL_R2 resistivity meter was used in acquiring geophysical data. It is a unique configuration that places the R2 resistivity meter in a class by itself. It is a powerful DC resistivity system that is powered by an external 12V battery and a very accurate system featuring the SYSCAL resistivity meter of two channel design that permits simultaneous measurement of both voltage and current. The SYSCAL R2 system consists of three components;

- The combined transmitter/receiver unit;
- A DC/DC or AC/DC converter;
- A power source, of 12 V battery.

The transmitter/receiver features a noise monitoring system for pre-induction control consisting of a DC digital voltmeter function. A line check/ground resistance measurement allows the operator to check that all electrodes are properly connected and grounded. Low pass analog filters reduce the effect of higher frequency natural and cultural noise.
The R2 resistivity meters will monitor the input noise signal between the two receiving electrodes so that noisy conditions may be noted. At the start of each measurement the SP value is displayed. This value is also stored with each reading. SP compensation is automatic, with linear drift correction, using digital filtering. The SP value is recalculated at every third stack, which provides excellent correction of the SP drift.

The R2 resistivity meters have automatic gain ranging for both voltage and current. Digital stacking is used for noise reduction, with a maximum of 250 stacks. During stacking the operator can monitor either the instantaneous reading, or the cumulative average value.

Resolution after stacking is 1μV. The standard deviation of each reading is also displayed and stored. The R2 calculates apparent resistivity based on the type of array and geometrical parameters that have been entered. Up to 1,000 readings may be stored. Data transfer is by serial link.

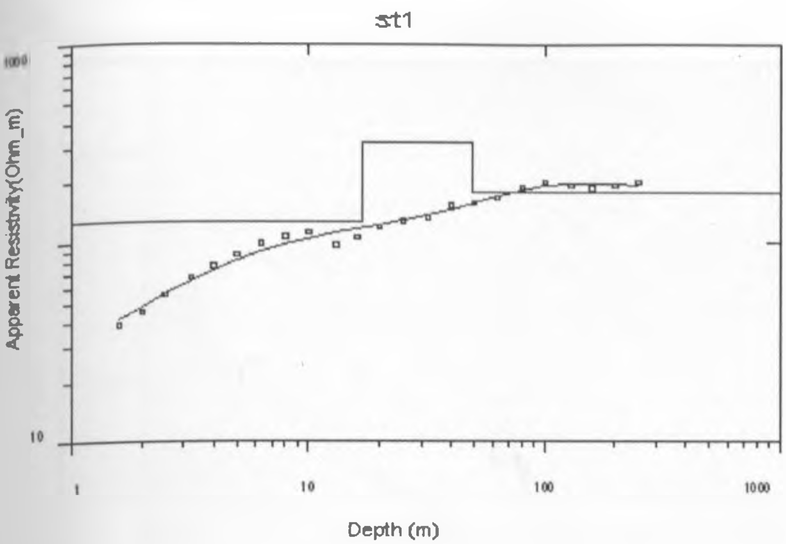
The second component of a Syscal R2 electrical resistivity system is the power converter. This may be either a DC/DC converter, or a motor generator powered AC/DC converter. At the lower power range is a 125W DC/DC converter, powered by external 12V. With a marginal increase in weight the next step up is a 250W DC/DC converter that is still powered by a 12 V battery. The final step is a motor generator powered AC/DC converter with maximum 1,200W output. The third component making up the system is the power source itself, either 12V, or 220V; either battery or motor generator supplied.

The Syscal R2 resistivity meter is truly a unique system able to handle the deepest resistivity applications, to depths of 2,000 meters or more. The R2 may be utilized with the Intelligent Node automated switching system.

3.3.3 Analysis of Geophysical (vertical electrical sounding) data

Data intepretation was done using the IX1D Software from Interpex Ltd in computation of the true ground resistivity and corresponding depth (Fig 3.3, Fig 3.4) which further was interpreted in terms of geology and hydrogeology (others results are shown in the appendices).

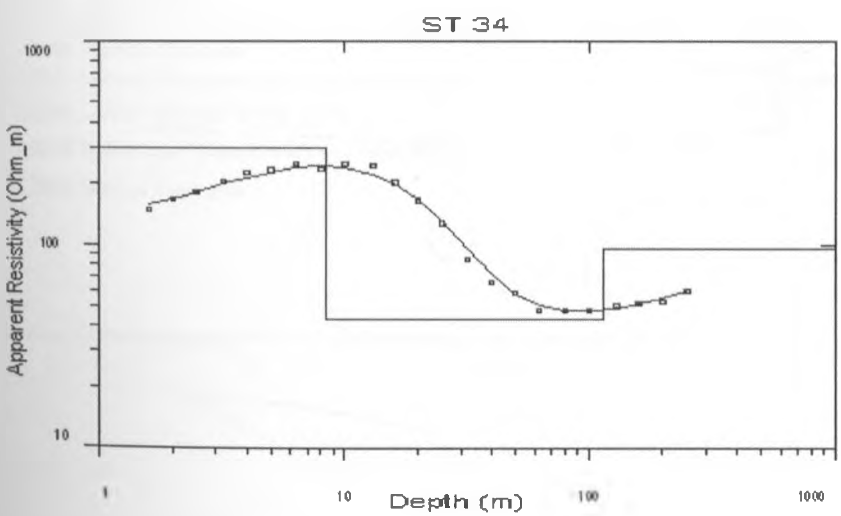
IX1D is a software package for Windows 9x which allows for forward and inverse modeling of resistivity data from Schlumerger, Wenner and Dipole -Dipole arrays. It allows data to be imported from generic ASCII files and used to carryout forward and inverse modeling of layered (1-D) models, equivalence analysis and automatic estimation of layered and smooth models.



Model: 1

True Resistivity	Thickness	Depth
126.5	16.9	16.9
320.2	32.4	49.3
179		

Figure 3.3: Resistivity curve at station 1



Model: 2

True Resistivity	Thickness	Depth
300.90	8.00	8.00
43.30	107.00	115.00
96.30		

Figure 3.4: Resistivity curve at station 34

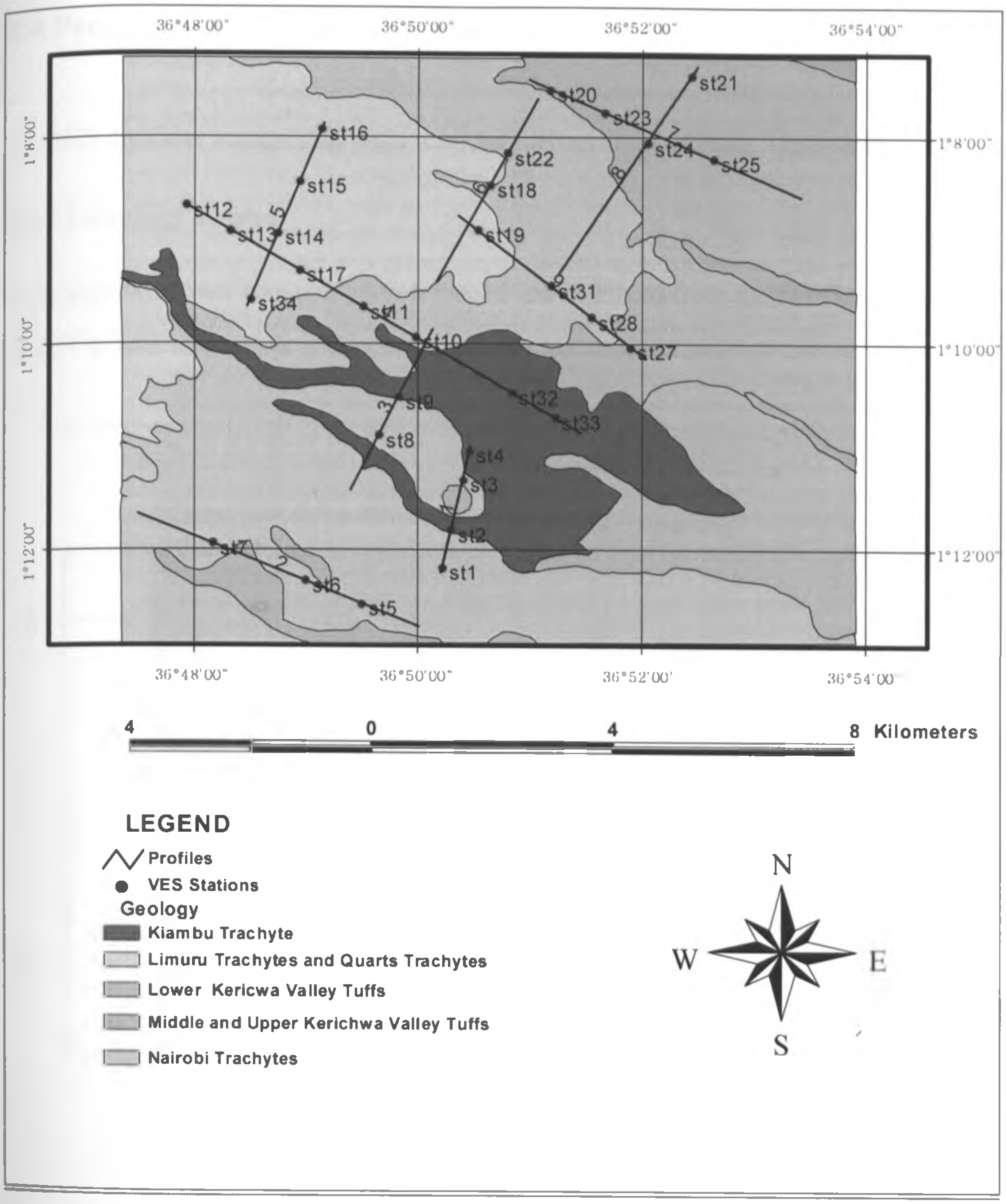


Figure 3.5: Profile & Vertical Electrical Sounding Station
(Showing profile and Vertical Electrical Sounding Station that were selected to assess the resistivity of the sub surface.)

3.4 Preparation of Spatial Baseline Database in GIS

The GIS database comprising eight relevant themes were created. These are:

3.4.1 Lithology Theme

Lithology layer was scanned, georeferenced and digitized from the existing geological map (Fig.3.6).

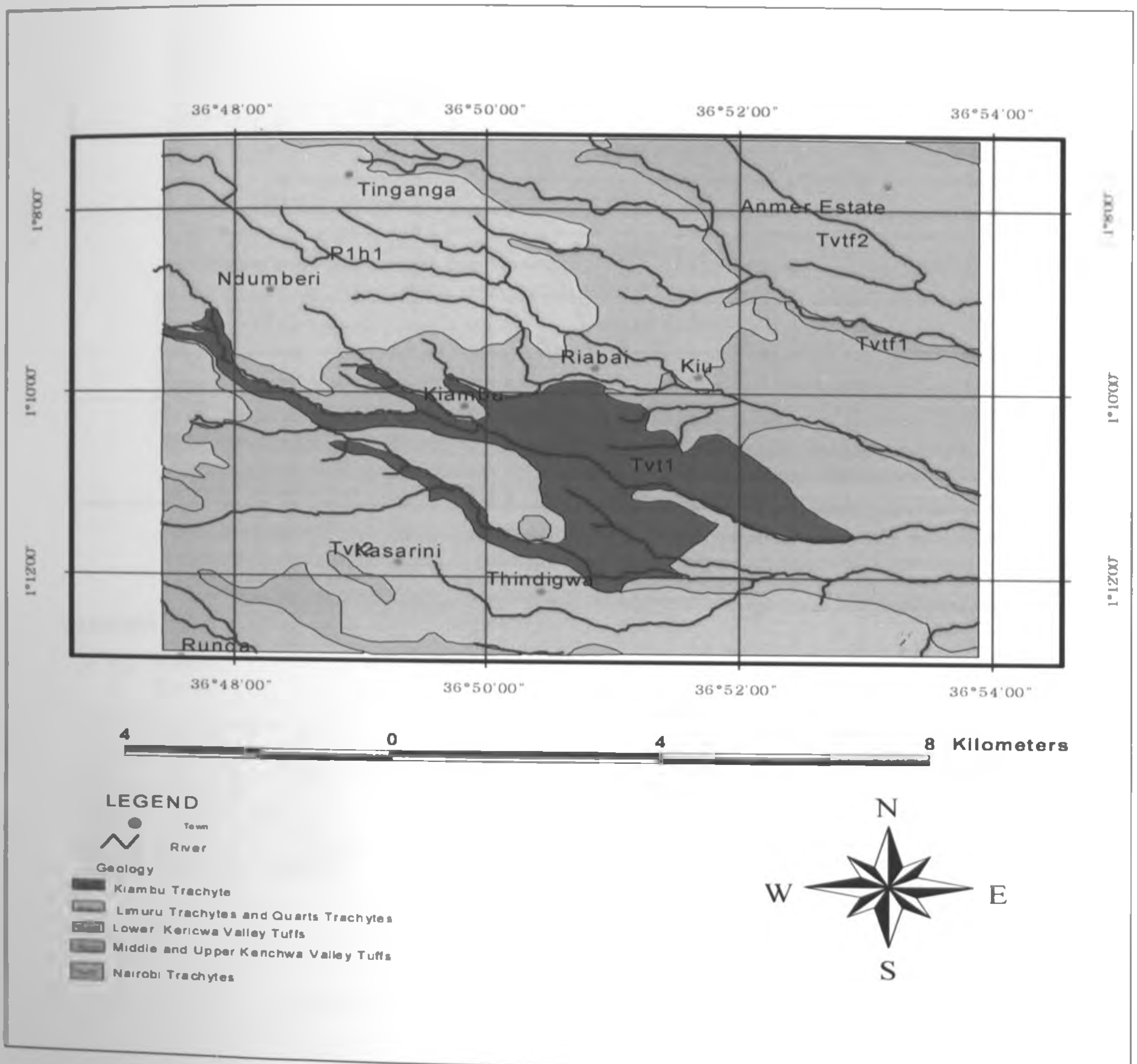


Figure 3.6: Lithology layer
(showing the distribution of different geological formations in the study area)

3.4.2: Elevation Theme

Elevation layer was produced from the Digital Elevation Model (DEM) generated from digitized contour lines from the existing topographical map (Fig.3.7).The elevation of the project area is generally high and it ranges from 1560 to 1840meters.

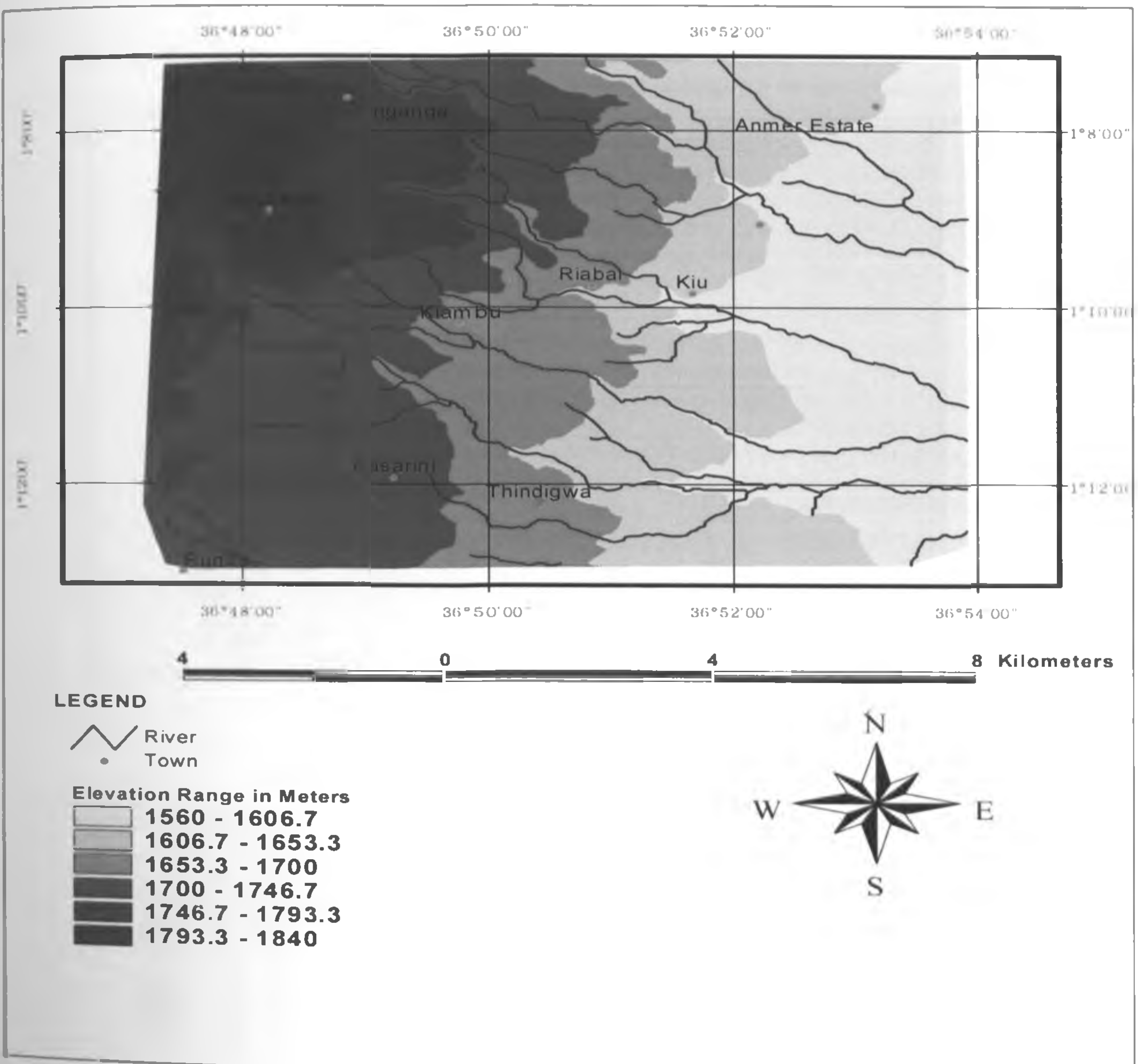


Figure 3.7: Elevation Layer

(Showing the range in altitude in the study area)

3.4.3: Slope Theme

Slope layer was derived from the DEM (Fig.3.8). A DEM was generated using the input of elevation contours vector layer taken from the 1:50,000 Scale top sheet. The study area encompasses generally very gentle slope (<15), gentle slope (15-30), moderately slope (30-45), moderate slope (45-60) steep slope (60-75) and very steep slope 75-90).In general, DEM profiles show an increase in slope towards the western part.

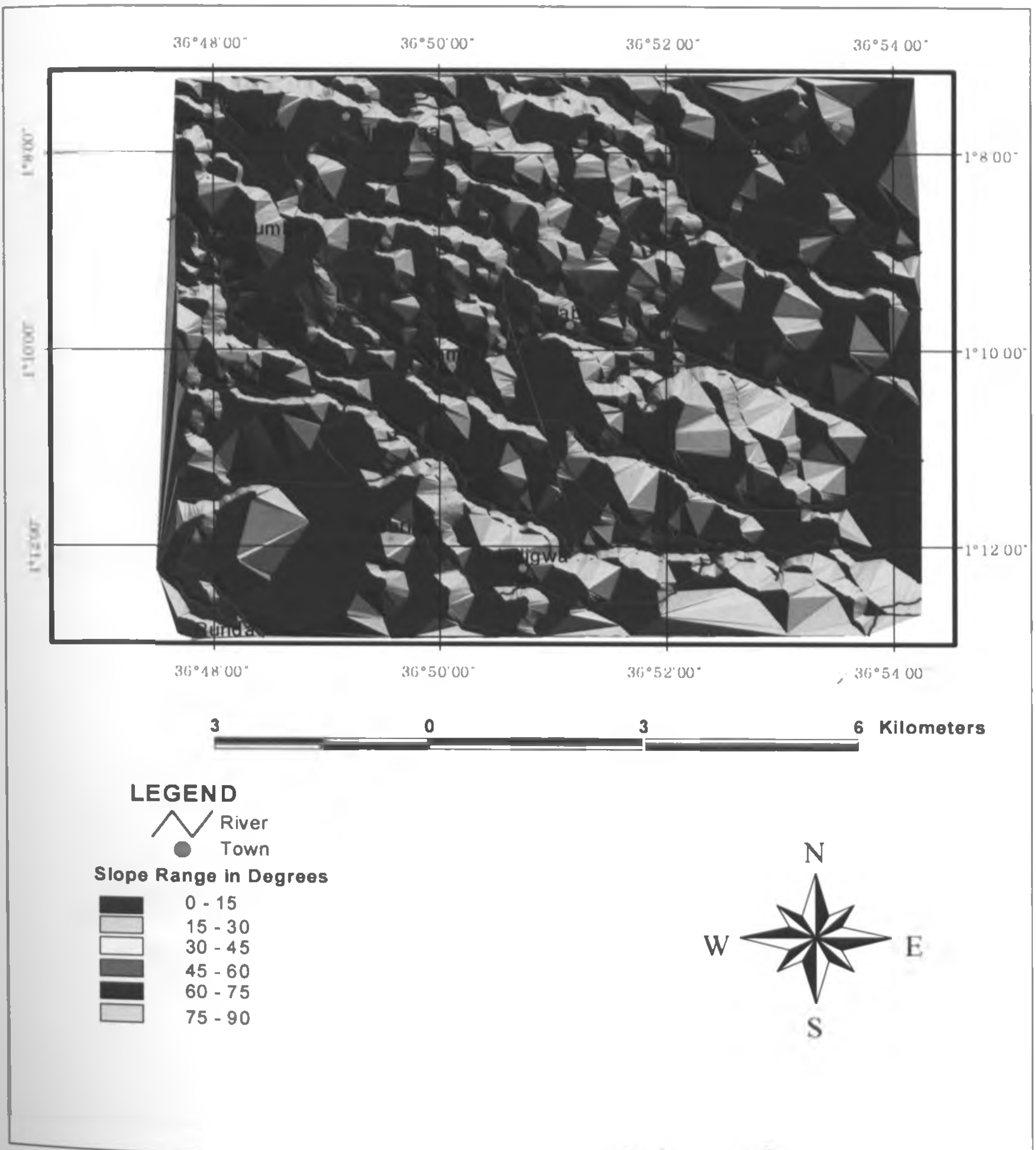


Figure 3.8: Slope Layer (Showing the range in slope in the study area)

3.4.4: Drainage Theme

Drainage layer was digitized from the topographical map (Fig.3.9).The rivers flows from western to eastern direction that is from areas of high altitudes to low altitude areas.

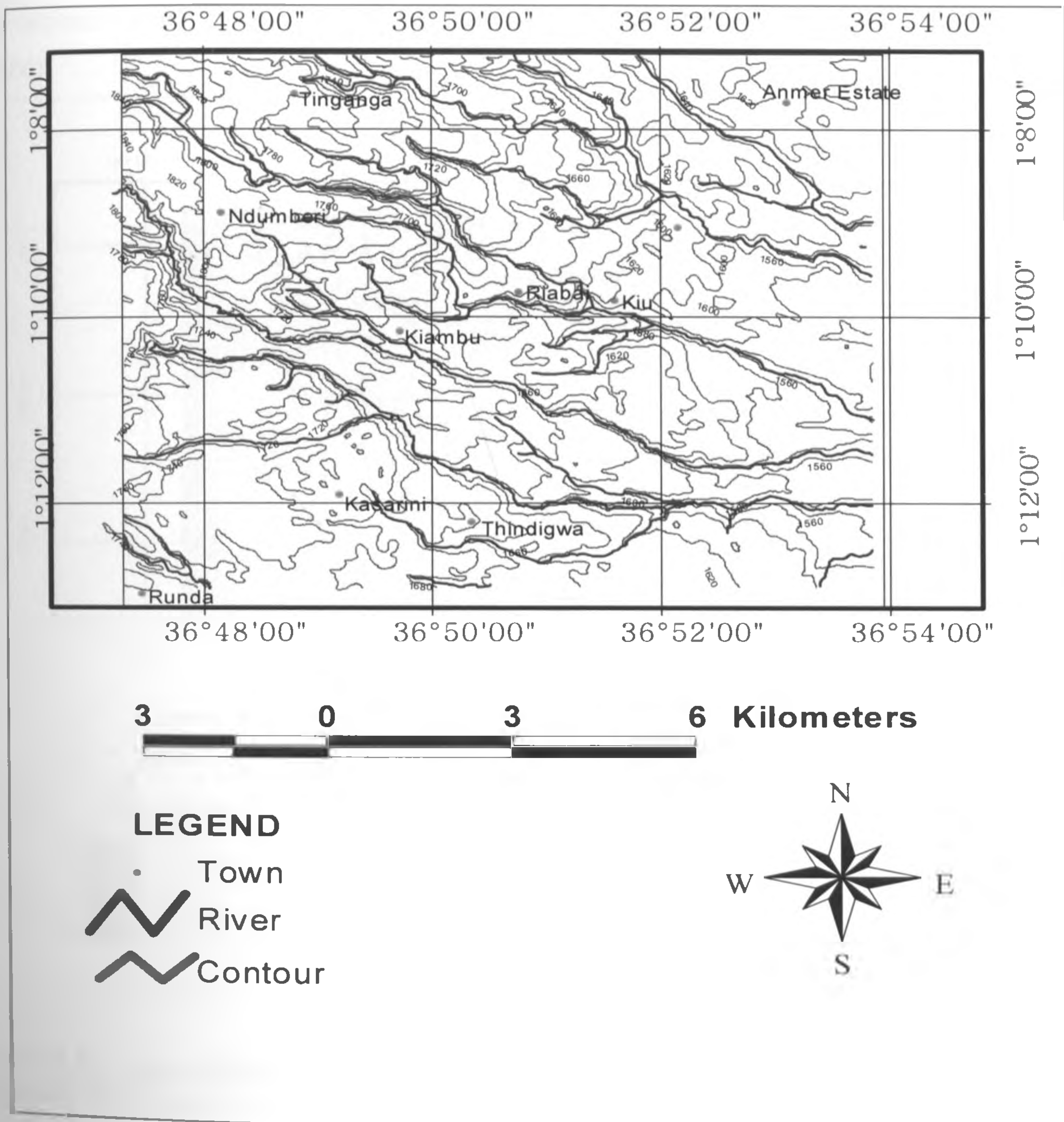


Figure 3.9: Drainage Layer
(showing the rivers in the study)

3.4.5: Rainfall Theme

The theme was generated from mean annual rainfall (MAR) data from the rainfall stations in the study area. Interpolation of data was done using Arcview GIS 3.2 software which produced rainfall layer as shown on figure 3.10. Mean rainfall ranges from 1140 to 1191.98 millimeters. High altitude areas on the western part of the study area indicate that they receive high rainfall while the eastern region receives moderate rainfall.

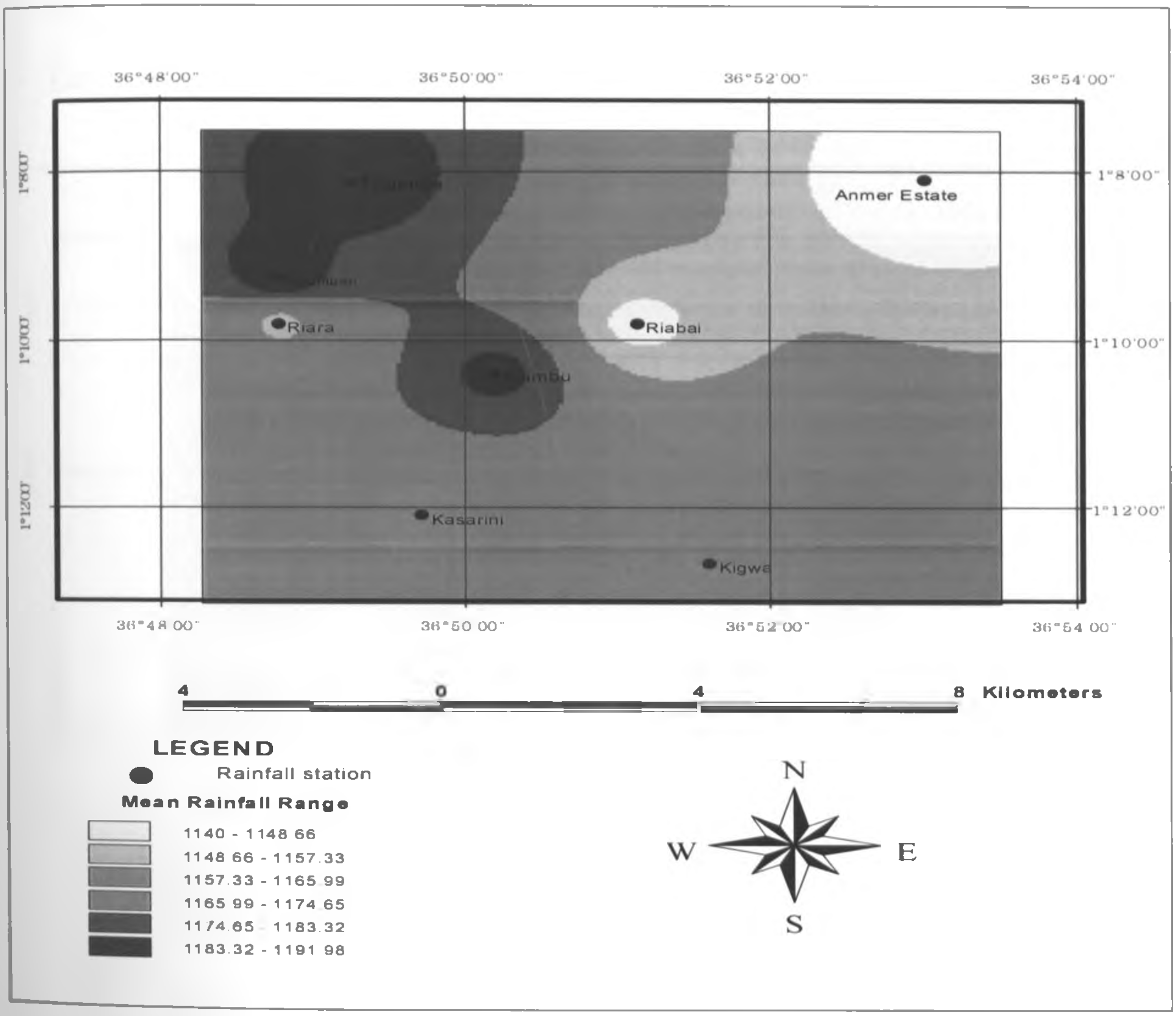


Figure 3.10: Annual Rainfall Layer
(Showing Mean Annual Rainfall from rainfall stations in the study area)

3.4.6: Land Use-Cover Theme

The land use-cover map was prepared from PAN sharpened Land- Sat image using supervised classification, for which 6 classes were identified (Fig.3.11).

- Water bodies cover 5% of the area and mainly represented by the man-made dam.
- Coffee Plantations which in the recent past had dominated the land cover but now are being replaced by settlement areas occupies 20% of the area,
- settlement and farm-land areas occupies 50% of the area ,
- Built up land (settlement) occupies 15% of the study area.
- Quarry occupies 1%.
- Farm-land occupies 9%

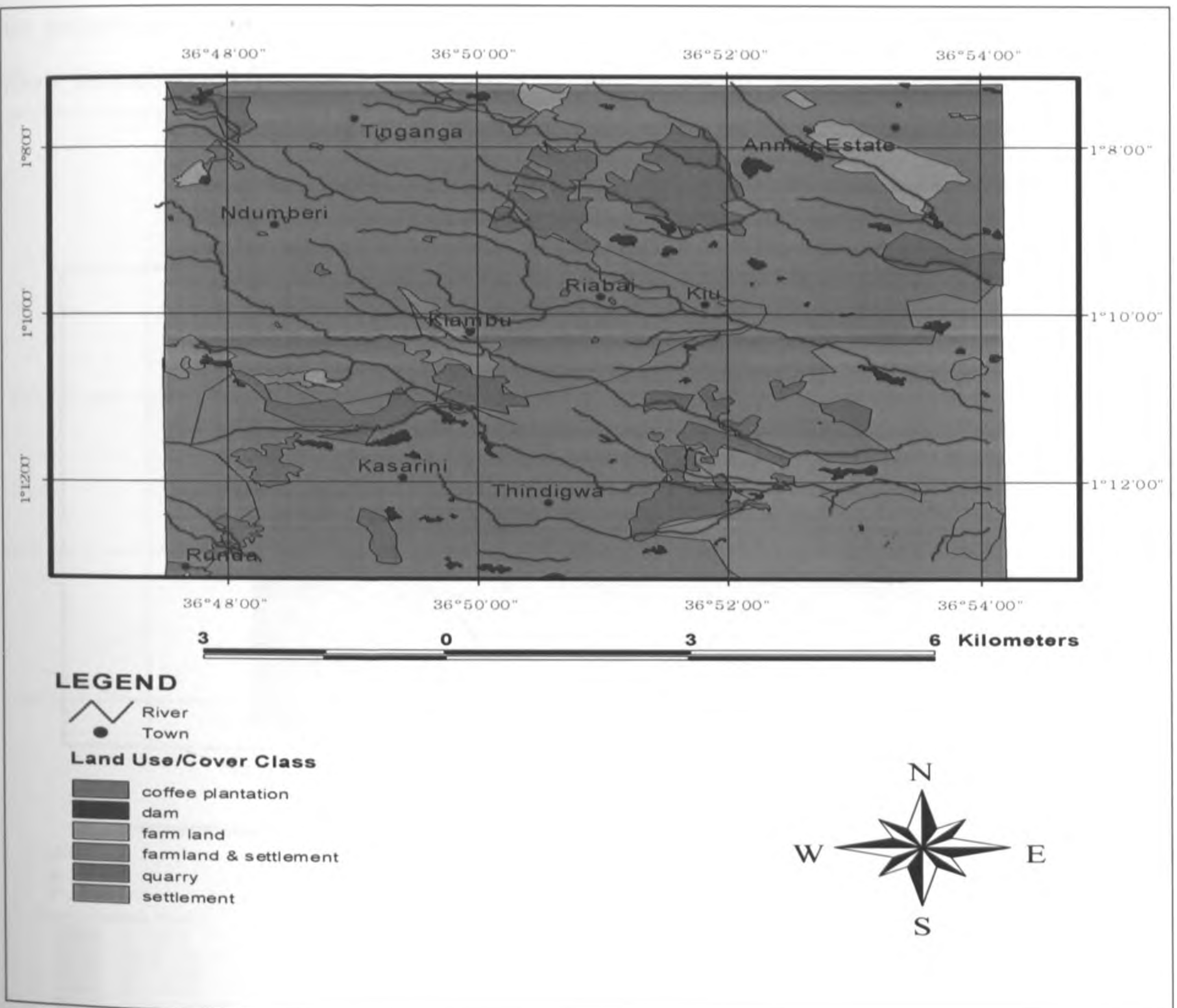


Figure 3.11: Land use-cover Layer
(Showing different classes in land use in the study area)

3.4.7: Transmissivity Theme

Transmissivity layer generated through GIS interpolation (Fig.3.12). Transmissivity is the rate at which water flows through a vertical strip of the aquifer 1m wide and extending through the full saturated thickness under hydraulic gradient of 1(100%). In the International System of Units, transmissivity units are cubic meters per day per meter (m^3/day/m) or square meters per day (m^2/day). (Driscoll F.G,1986). Three general methods are used to determine transmissivity:

- Using data collected during pumping tests
- Analysing the hydraulic properties of aquifer material
- Calculations based on laboratory tests

In this project trasmissivity was determined using data collected during pumping test. Borehole data obtained from the Ministry of Water and Irrigation

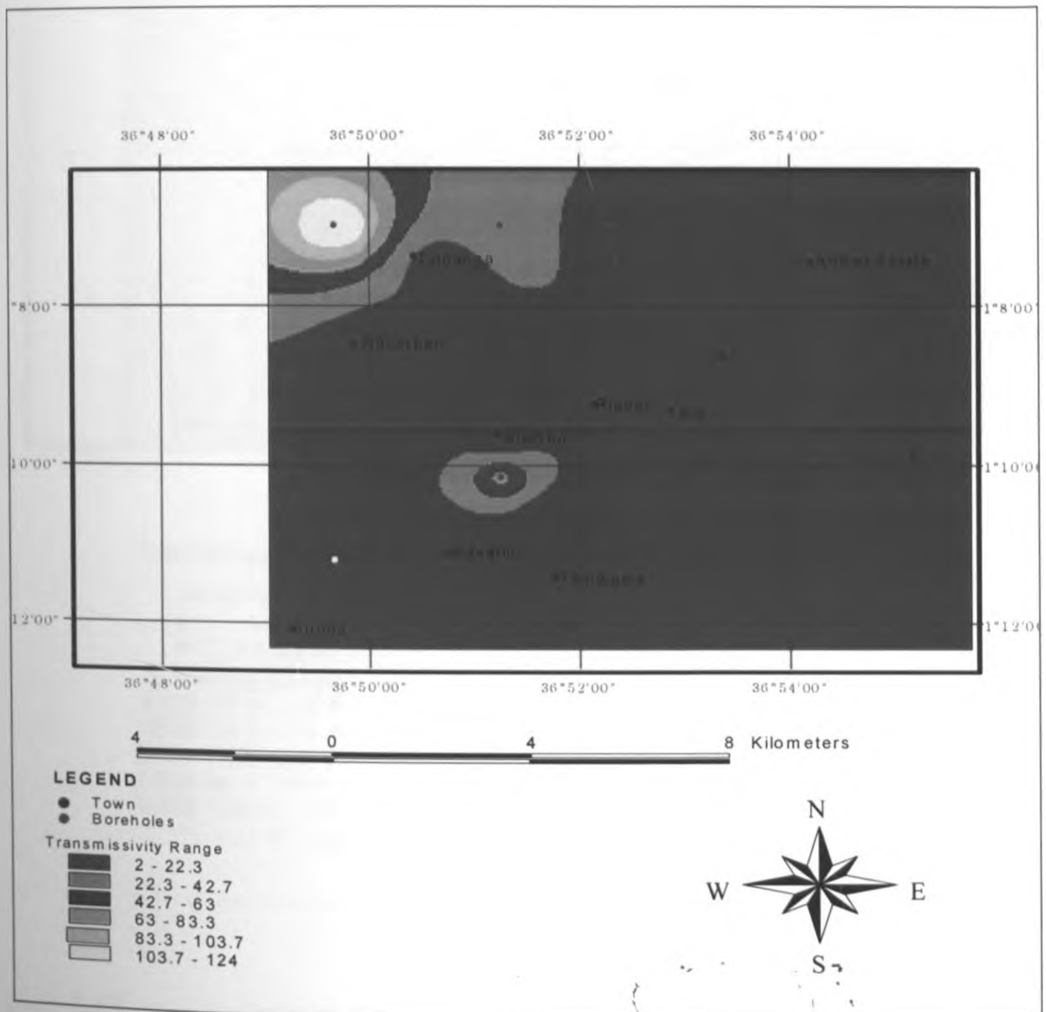


Figure 3.12: Transmissivity Layer
(Showing Transmissivity range in the study area)

3.4.8: Resistivity measurements Theme

Four resistivity measurements layers were generated through GIS interpolation of resistivity data from all stations at a depth of 50,100,200 and 250 meters. (Fig.3.13, 3.14, 3.15and 3.16 respectively)

3.4.8.1: Iso resistivity AB/2=50 Layer

The apparent resistivities range from 31.3 to 159 ohm-metre. Low-medium resistivity zones characterize this layer especially to the eastern side of the layer (Fig.3.13).

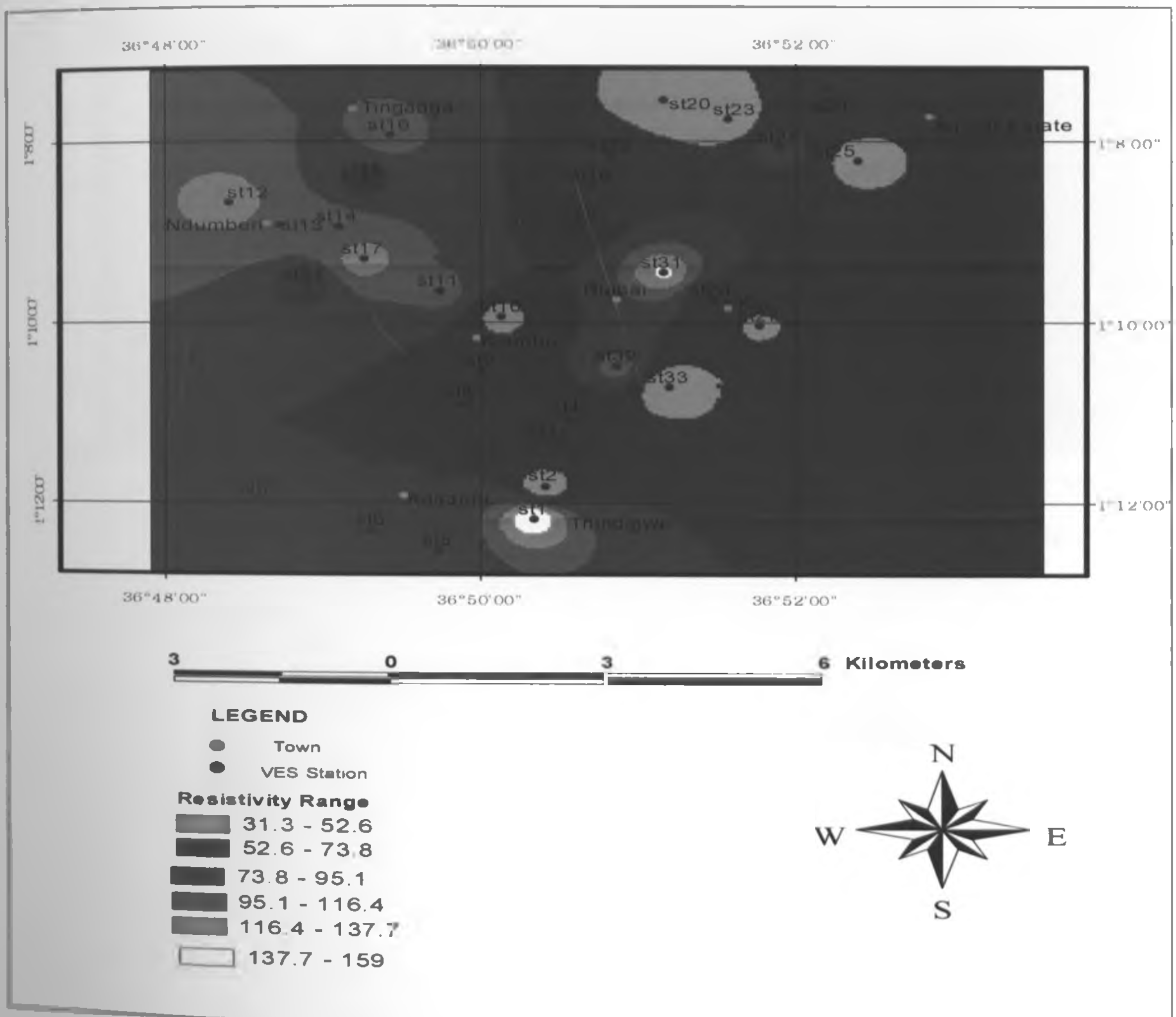


Figure 3.13: Iso resistivity AB/2=50 Layer

3.4.8.2: Iso resistivity AB/2=100 Layer

The apparent resistivities range from 28.7 to 202 ohm-metre. Medium resistivity zones ranging 86-115ohm-metre charactrises large part at 100m depth. A low resistivity zone occupies the North eastern, Eastern, South east and part of central region (Fig.3.14).

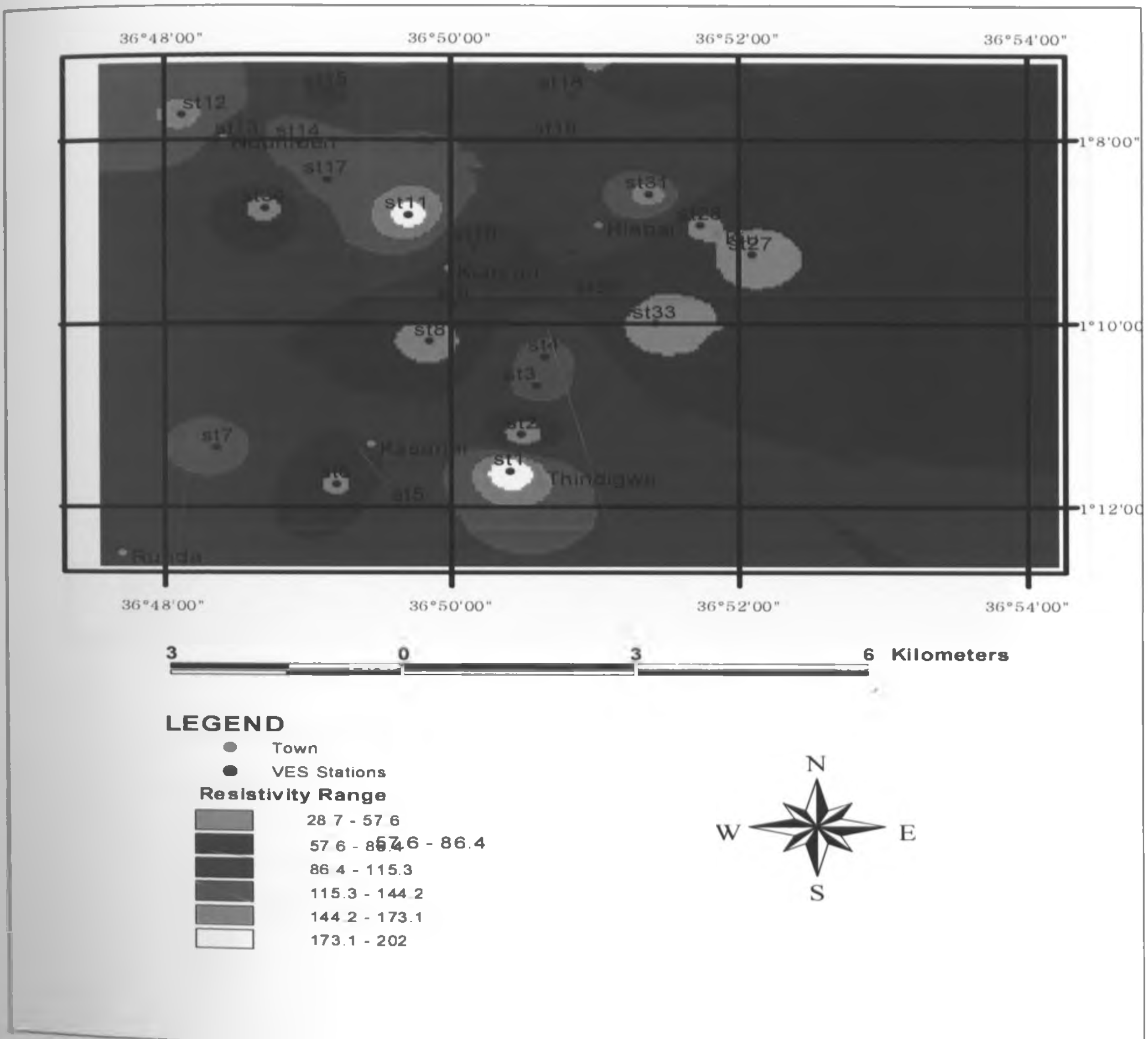


Figure 3.14: Iso resistivity AB/2=100 Layer

3.4.8.3: Iso resistivity AB/2=200 Layer

The apparent resistivities range from 25.1 to 233.7ohm-m. The layer is mainly characterized by zones of low to medium resistivity. This signifies that there exists a main aquifer at this depth (200 m) (Fig.3.15).

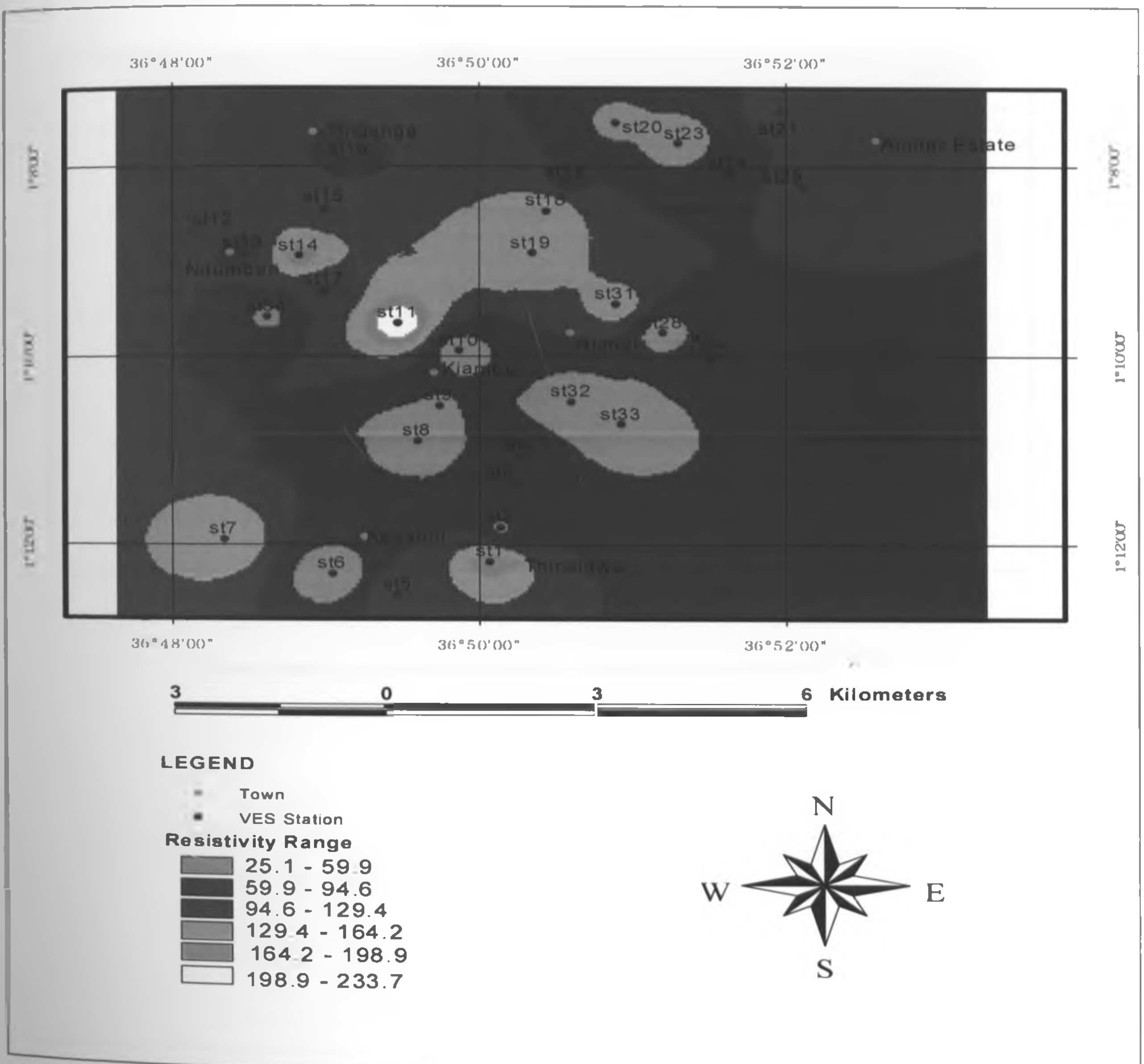


Figure 3.15: Iso resistivity AB/2=200 Layer

3.4.8.4: Iso resistivity AB/2=250 Layer

The apparent resistivities range from 25.0 to 200 ohm-m. The layer is also characterized by zones of low to medium resistivity. This signifies that there exists an aquifer at this depth (250 m) but small than the aquifer at the depth of 200 m (Fig.3.16).

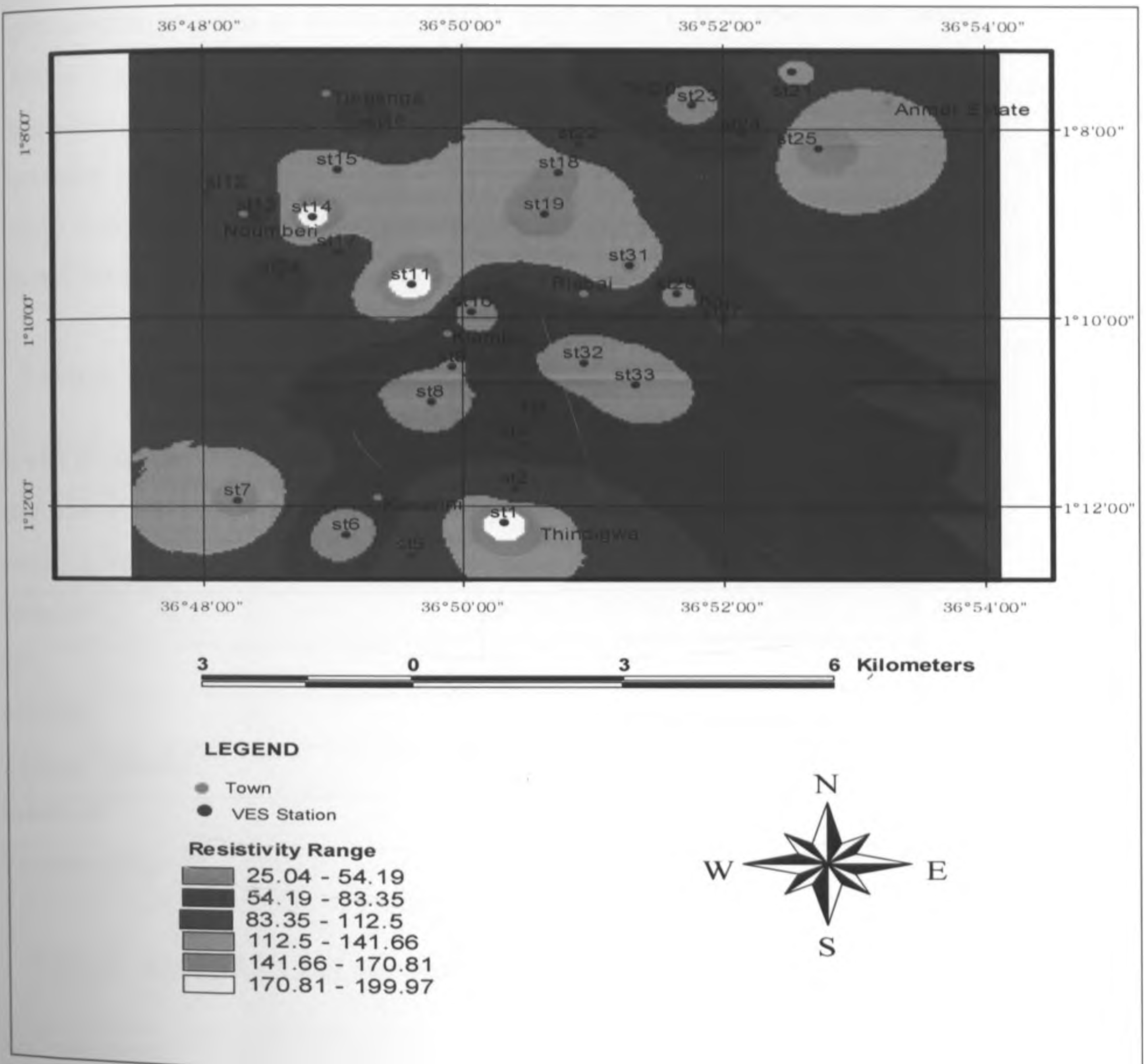


Figure 3.16: Iso resistivity AB/2=250 Layer

The above baseline results were integrated spatially in a one system environment with standardization in scale, map projection and metadata.

3.5 Spatial Data Analysis

Eight thematic layers were selected for determination of groundwater potential zones for the project area as indicated in the flow chart (Fig 3.1). The model factors are weighted from 1 to 5 according to their relative importance to each other with regard to groundwater potential as shown on table 1. Each factor is then divided into ranges or media types and assigned a rating from 1 to 10 based on their significance on groundwater potential. The rating for each factor is selected based on available information and professional judgment as shown in tables 2 to 7. The selected rating for each factor is multiplied by the assigned weight for each factor. These numbers are summed to calculate groundwater potential index.

Table 1: Weight for Model factors

DRASTIC factor	Weight
Land use-cover	3
Annual Rainfall	4
Elevation	3
slope	2
Lithology	5
Drainage Density	3
Resistivity	4
Transmissivity	3

Table 2: Rating for Land use-cover

Land use-cover	Rating
Water bodies	6
Coffee Plantations	4
settlement	1
settlement and farm-land	3

Farm-land	5
Quarry occupies	2

Table 3: Rating for Annual Rainfall

Annual Rainfall(mm)	Rating
1350-1500 (High)	6
1200-1350 (Medium)	5
1050-1200 (Low)	4
900-1050(Very low)	3

Table 4: Rating for Elevation

Elevation (m)	Rating
1560-1660	5
1660-1760	3
1760-1860	1

Table 5: Rating for slope

Slope	**Rating**
0-5	5
5-15	4
15-35	3
35-45	2
>45	1

Table 6: Rating for Lithology

Lithology	Rating
Limuru Trachytes and Quarts Trachytes (Plh1)	5
Middle and Upper Kerichwa Valley Tuffs (Tvtf2)	7
Lower Kerichwa Valley Tuffs (Tvtf1)	6
Nairobi Trachytes (Tvt2)	4
Kiambu Trachyte (Tvt1)	3

Table 7: Rating for Drainage Density

Drainage Density (Km/Km$^{2)}$	**Rating**
>0.0055	1
0.0040-0.0055	2
0.0025-0.0040	3
0.0010-0.0025	4
<0.0010	5

Table 8: Rating for Resistivity

Resistivity	Rating
25-60	8
60-95	7
95-130	5
130-165	4
165-199	3
199-234	2

Table 9: Rating for Transmissivity

Transmissivity	Rating
2-22.3	1
22.3-42.7	2
42.7-63	3
63-83.3	5
83.3-103.3	7
103.3-124	8

3.6 Integration of Results

Groundwater potential zoning was done using the parameters, weight and rates determined in spatial data analysis. The formula is as shown below

GP=Rf+Lt+Lu+Te+Ss+Dd+Tm+Rm

where:

Rf= Mean Annual Rainfall

Lt=Lithology

Lu=Land use

Te=Topography (Elevation)

Ss=Slope Steepness

Dd= Drainage

Tm=Transmissivity

Rm=Resistivity Measurements

CHAPTER 4: DISCUSSIONS OF RESULTS

4.1 Groundwater Potential Map

The groundwater potential map of the study area is shown on figure 4.1. Four classes of groundwater potential zones were adopted. Zones of very high groundwater potential are located on low altitude and low drainage density areas while low groundwater potential zones are found in areas of high altitudes and high drainage density.

The very high groundwater potential zone covers the southeast side and grades through high, medium, low potential in the northwestern side. The zones were as follows: (i) very high potential zone covers spatially about 13% of the total area and characterized discharge zones. It occurs as isolated perches within high potential zones (ii) high potential zones covers about 70% of the entire area i.e Kiambu Township (iii) medium zone covers about 15% and characterizes the catchment area (iv) low potential zone are less than 2% and occur as small isolated ports to the northwest of the study area.

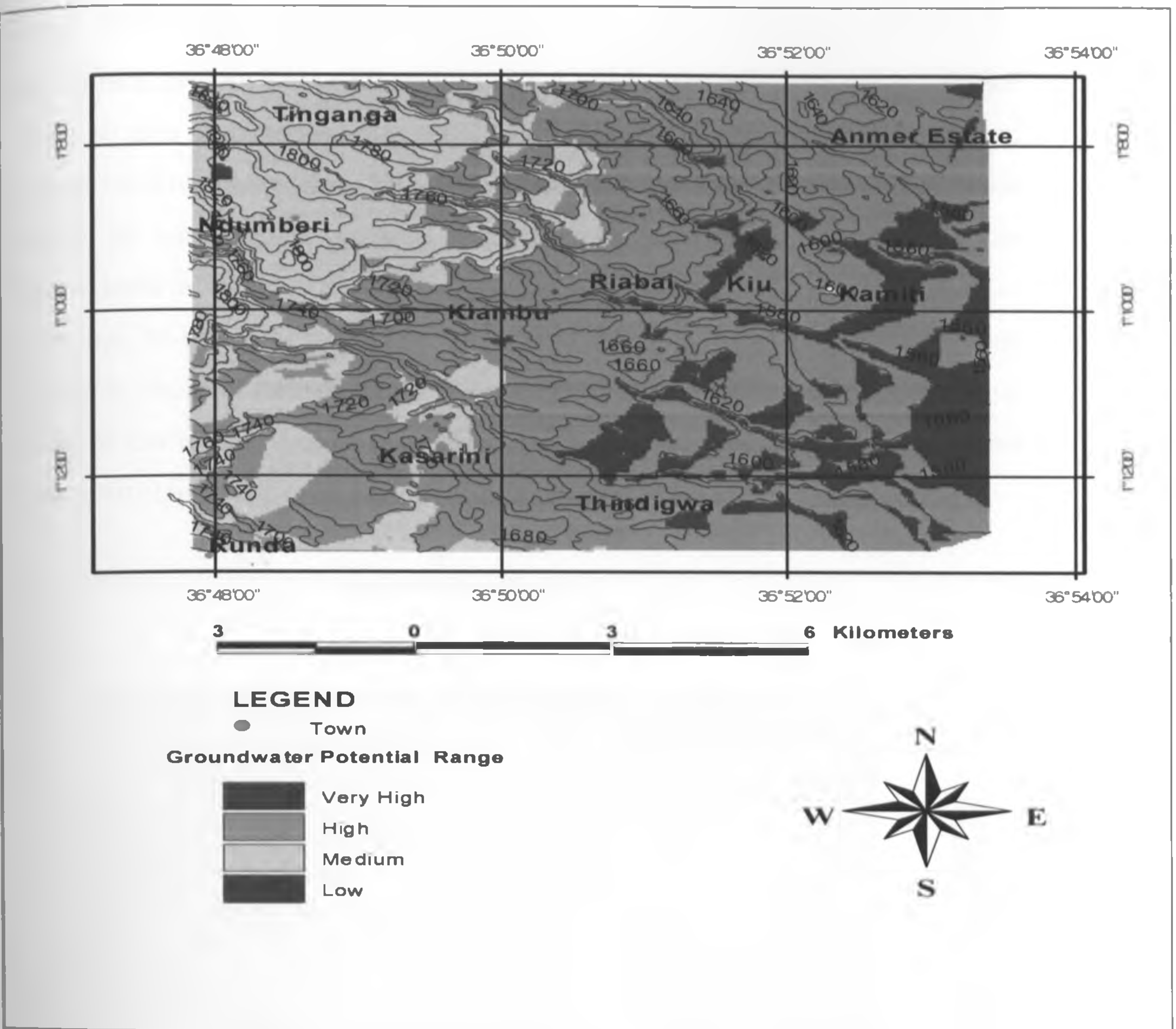


Figure 4.1: Groundwater potential map of the study area

4.2 Pseudo Sections and their Relationship to Groundwater Potential

4.2.1: Pseudo Sections

In this study pseudo-sections were generated from electrical sounding data using Sulfer 8 software. In the software, distance between stations across a cross-section (Profile) was used as X-axis; electrical sounding depth (AB/2) which is indicated as Pseudo-depth on the pseudo-sections was used on Y-axis; and resistivity measurements obtained from electrical sounding was used as Z-axis resulting to nine (9) pseudo-sections (Fig. 4.2, Fig. 4.3, Fig. 4.4, Fig. 4.5, Fig. 4.6, Fig. 4.7, Fig. 4.8, Fig. 4.9 and Fig 4.10) along the nine traverses (see Figure 3.5)

4.2.1.1: Profile 1 (St. 1, 2, 3, 4)

The profile runs from SW to NE stations 1, 2, 3 and 4. Low resistivities vary between 40 and 60 ohm characterized the central and the eastern side of the profile separated by high resistivities reaching 130 ohm. These low resistivities zones which could possibly be buried faults indicates zones of high groundwater potential. On the shallow depth less than 40 meters of the profile it is characterized by high resistivities of between 90-190 ohms meter. This may be contributed by the geology in the area i.e. Nairobi trachytes formation on shallow depth. Station 4(st 4) penetrates through a section of low resistivity from the surface which decreases with depth from 80 ohms meter to 40 ohms meter up to a depth of 250 meters (Fig 4.2).

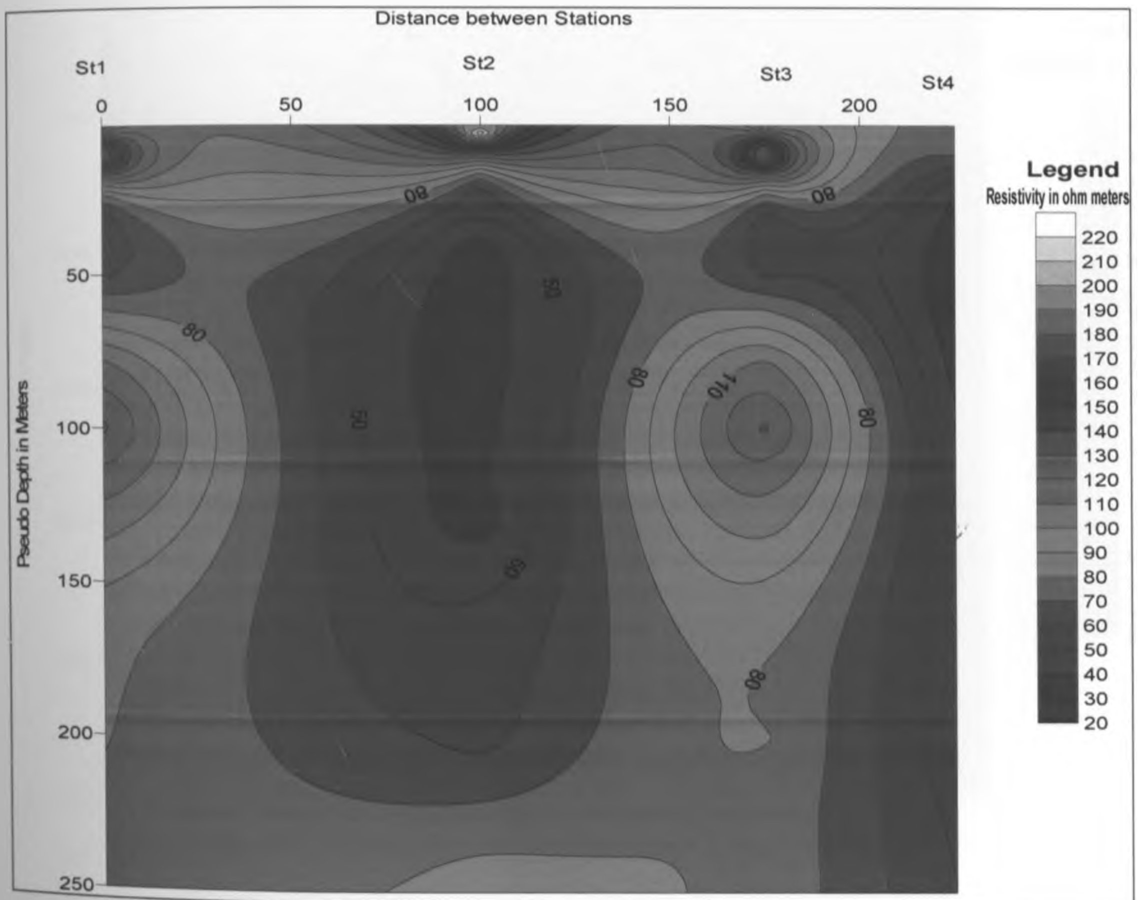


Figure 4.2 : Pseudo Section 1 (St. 1, 2, 3, 4)

4.1.2: Profile 2 (St. 7, 6, and 5)

The profile runs from NW to SE through station 7, 6 and 5. The Profile is characterized by low resistivity zone at the center between the depths of 90 – 180 meters near Kasarini area. This low resistivity zone could be a south west of the aquifer zone noted in profile 1. Resistivity increases both to the eastern and western side of the profile. High resistivity zone is observed at shallow depth at station 7 and 6. This could be contributed by the presence of Nairobi Trachytes lithology at shallow depth (Fig 4.3).

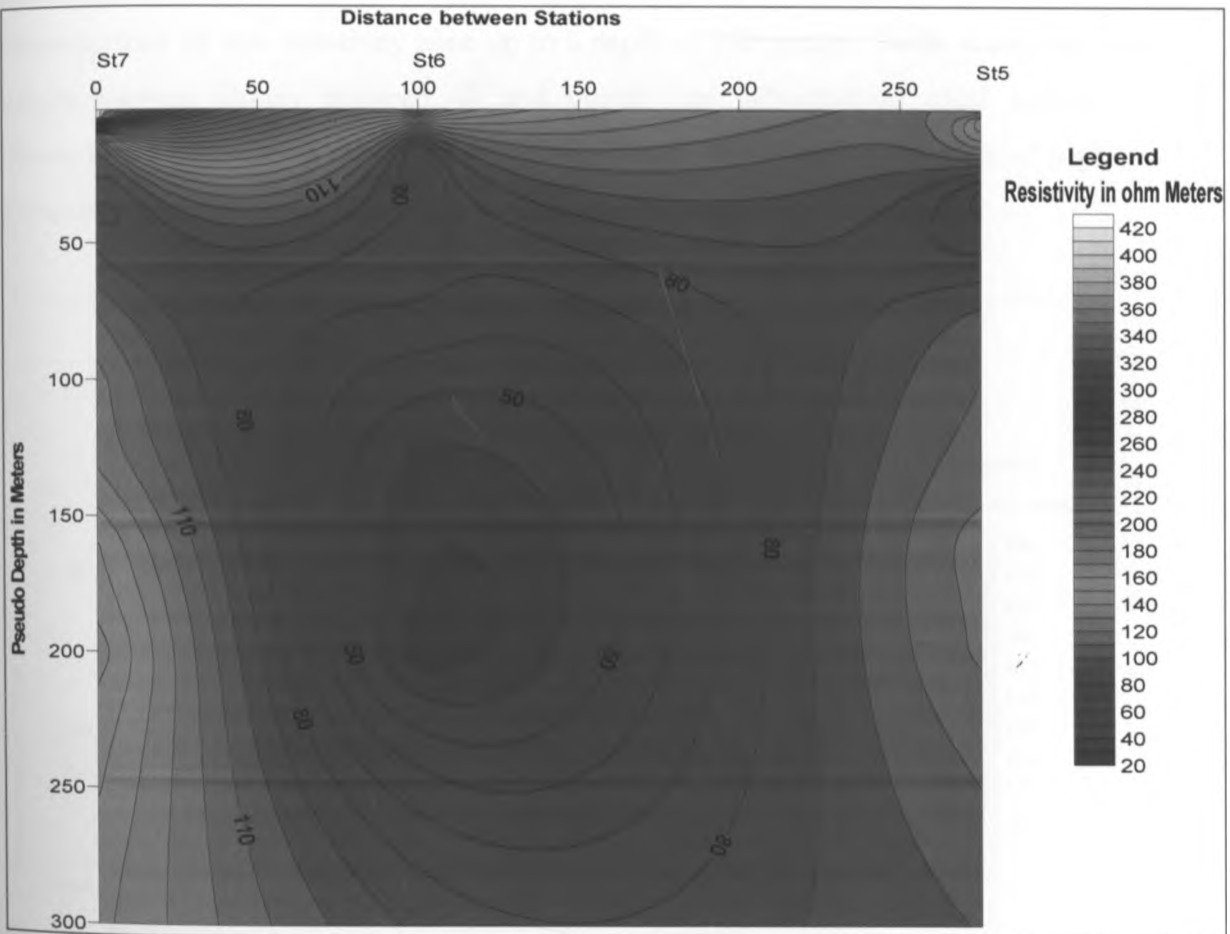


Figure 4.3: Pseudo Section 2 (St. 7, 6, and 5)

4.1.3: Profile 3 (VES 8, 9 and10)

The profile runs from SW to NE through stations 8, 9 and 10. This profile was executed as a follow-up of the low resistivity zone observed at the central part of the profile 2 with a target of mapping out the lateral extent of the aquifer. The resistivity values ranges from 20 -180 ohms meter. At station 8, it is characterized by high resistivity zone near ground surface up to a depth of about 50 meters. The changes in resistivity with depth is contributed by change of formations with depth i.e. from Nairobi trachyte contributing to high resistivity near surface and Kiambu Trachyte contributing to low resistivity at deeper depths at station 8. The rest of the profile 3 is characterized by low resistivity zone up to a depth of 250 meters. These resistivities values varying largely between 40 and 60ohm are indicative of ideal textural characteristics favouring occurrence of groundwater. This would be a zone of high groundwater potential (Fig 4.4).

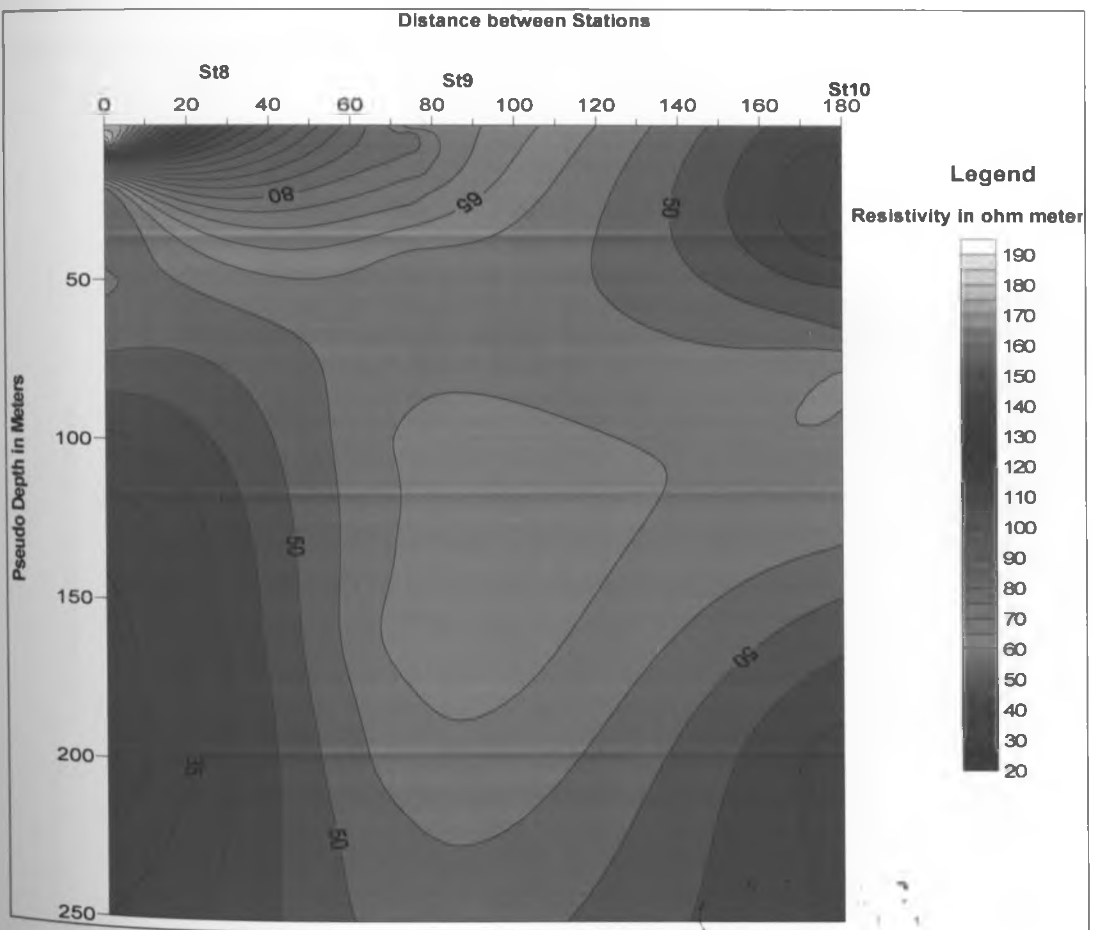


Figure 4.4: Pseudo Section 3 (VES 8, 9 and10)

4.1.4: Profile 4 (St 12, 13, 17, 11, 10, 32 and 33)

The profile runs in NW - SE direction through stations 12, 13, 17, 11, 10, 32, and 33. This profile was conducted to determine the width of the aquifer zone whose presence had already been confirmed by profile 3.The resistivity values ranges from 20-220 ohms meter. The central part of the profile is characterized by a high resistivity zone at a depth of 200 metres which decreases towards the eastern and the western direction. A very low resistivity zone (less that 40 ohms meter) is also observed between station 32 and Station 33 at a depth of between 200-300 meters. This could be the same aquifer at profile 3 interfaced by a low resistivities zone. The aquifer in profile 3 is wedged-out to a narrow elongated zone by two anomalously high resistivity zones. The variation of resistivity with depth is attributed by the variation of formation with depth. At St 12, 13, 17 and 11, Nairobi trachyte has contributed towards high resistivity at depth while with the other stations 10, 32 and 33 has low resistivity. The low resistivities are as a result of Kiambu Trachytes near ground surface followed by middle and upper Kerichwa valley tuffs at depth (Fig 4.5).

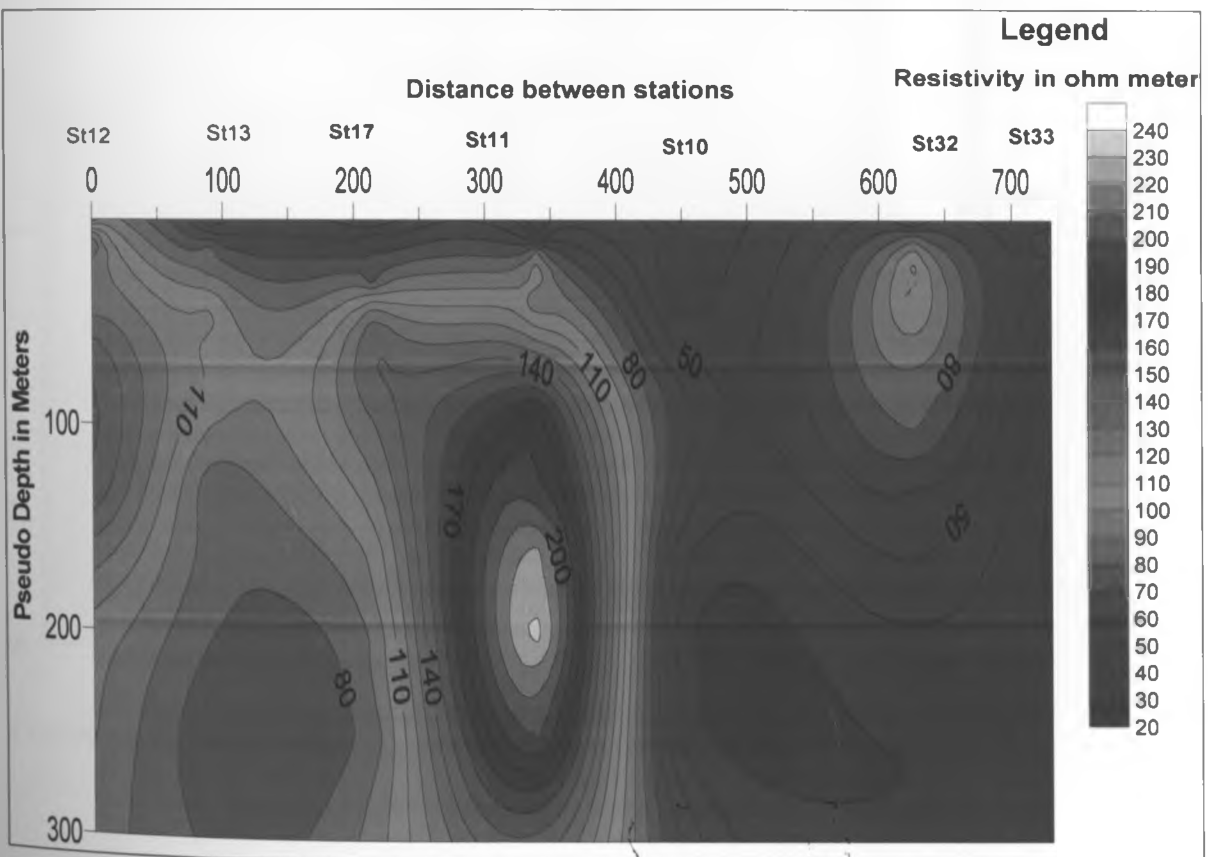


Figure 4.5: Pseudo Section 4 (St 12, 13, 17, 11, 10, 32 and 33)

4.1.5: Profile 5 (st 34, 14, 15 and 16)

The profile runs in SW - NE direction through stations 34, 14, 15 and 16. The resistivity values ranges from 30-230 ohms meter. The central part of the profile is characterized by a high resistivity zone from a depth of 50-250 metres. This could possibly be a lava flow massive and compact. Low resistivity areas are observed near surface depth above 50metres and between 200-250 meters at station 16 and at station 34 between 50-250 metres. This eastern and western edge indicates high groundwater potential (Fig 4.6).

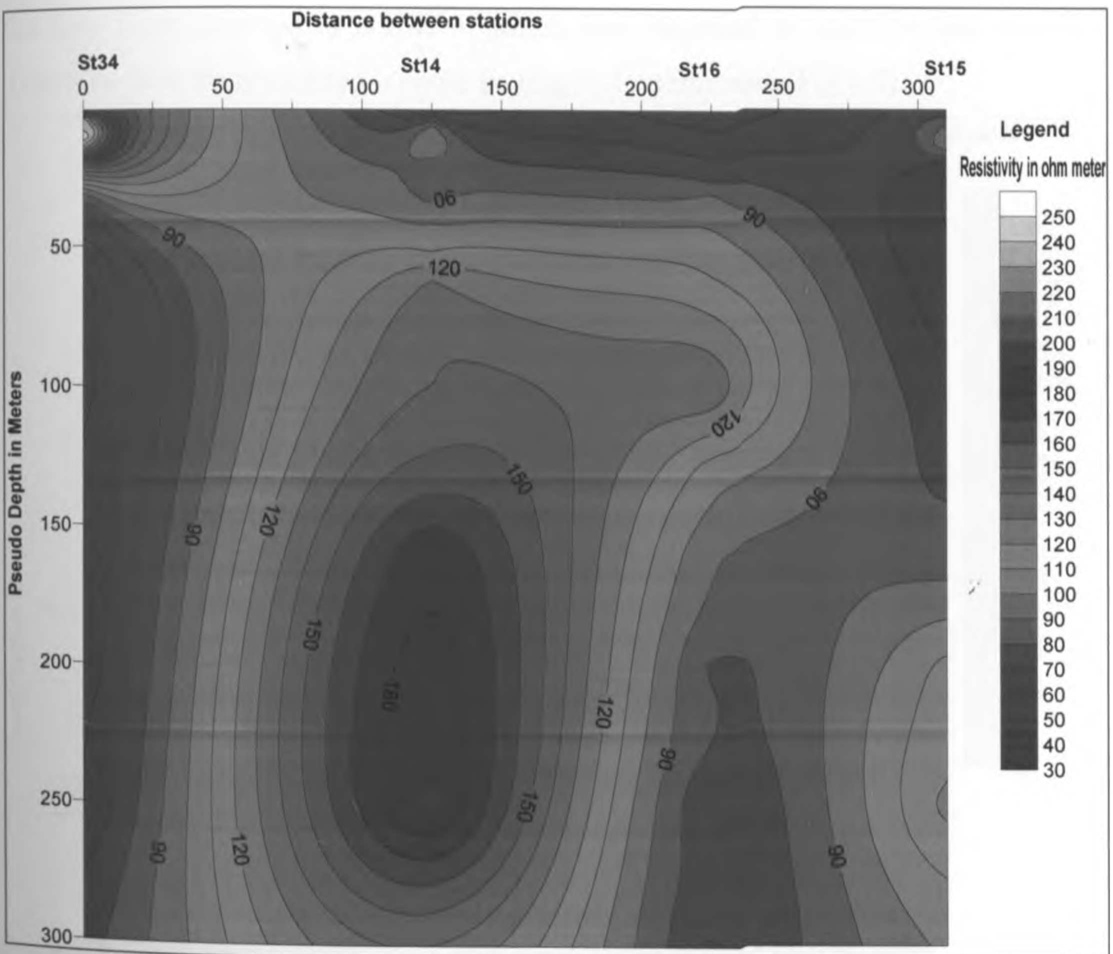


Figure 4.6: Pseudo Section Profile 5 (St 34, 14, 15 and 16)

4.1.6: Profile 6 (St. 18, 22, 20)

The profile runs from SW to NE through stations 18, 22 and 20. Low resistivity characterizes the eastern part of the profile from station 22 to station 20 from ground surface to a depth of 250 metres. This could be attributed by the fact that the Nairobi trachytes formation is thin towards the end of the profile and much of the zone is covered by Kerichwa Valley Tuffs which is reflected by the low resistivity of 70 ohms – meter and below.

High resistivity zone is observed on north western part of the profile which is between Station 18 and Station 22. The resistivity increases with depth at this zone to a maximum of 160 ohms metres at a depth of 250 metres. This could be an extension of the lava flow observed in profile 5, which was described as compact and massive. This lava flow if unfractured it could be largely impermeable (Fig 4.7).

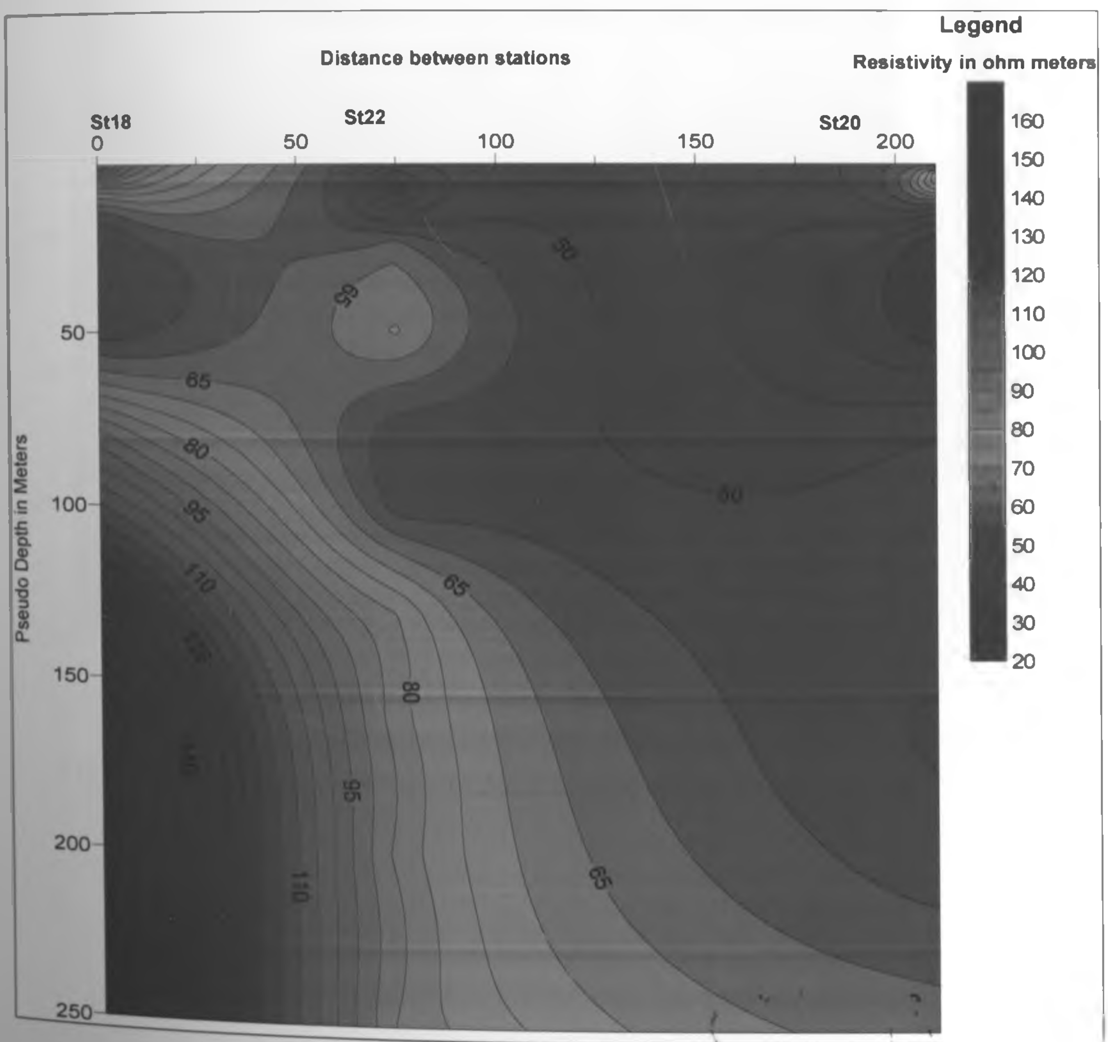


Figure 4.7: Pseudo Section 6 (St. 18, 22, 20)

4.1.7: Profile 7 (st20, 23, 24 and 25)

Profile 7 runs through station 20, 23, 25, and26. The resistivity values ranges from 30 to 160 ohm-meters. Low resistivity zone characterize the profile between 20 and 50metres which enhances infiltration and percolation contributing to recharge of deeper aquifers. High resistivity zone could be characterized by slightly fractured and weathered rocks. A low resistivity zone could possibly be a fault line extending to a depth of 300 metres hence forming part of a deep seated aquifer (Fig 4.8).

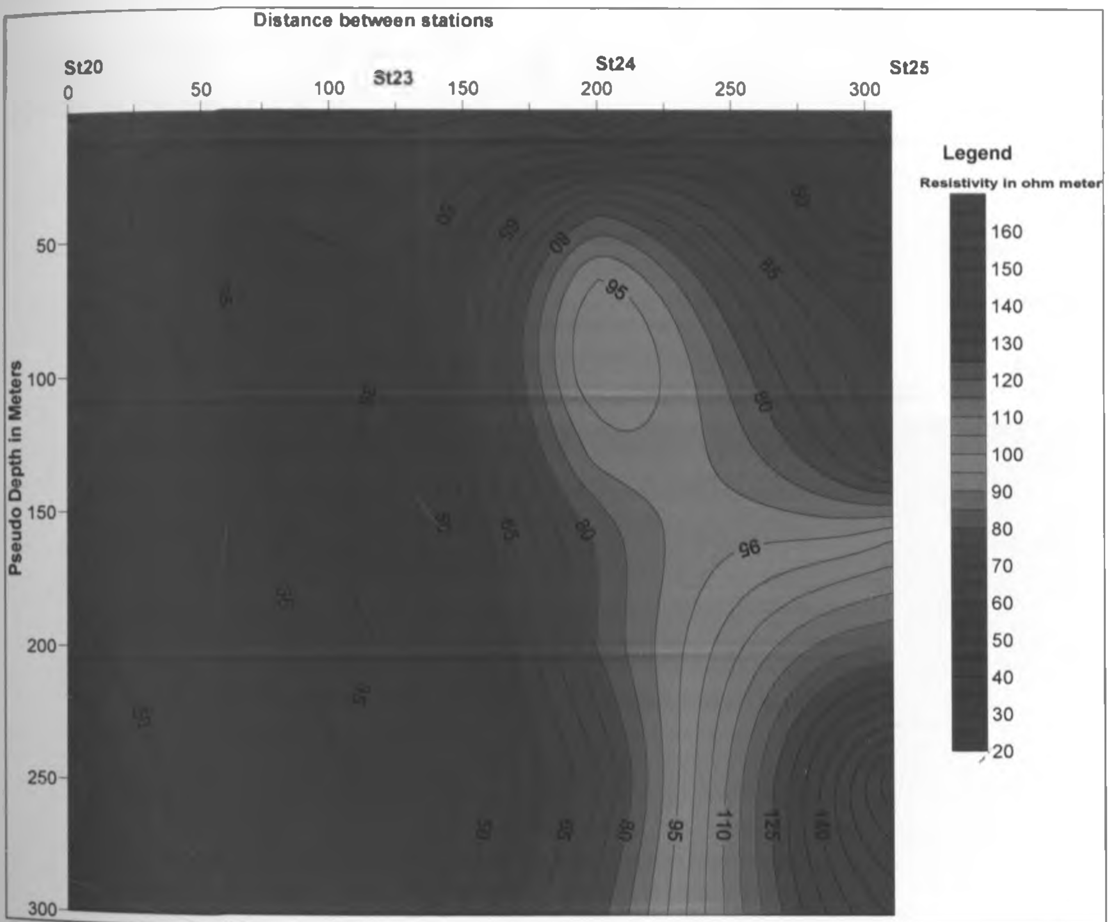


Figure 4.8: Pseudo Section 7 (st20, 23, 24 and 25)

4.1.8: Profile 8 (St. 29, 24 and 21)

The profile runs in SW- NE direction through stations 29, 24 and 21. The resistivity values ranges from 30-150 ohms metres. Between station 29 and 24 resistivity increases with depth from 40-90 ohms – meters. At station 21 high resistivity zone of about 150 ohms – meter is characterized from ground surface to a depth of less than 50 metres. It is followed by a low resistivity zone (40-60 ohms) and then resistivity increases to 100 ohms meter to a depth of 250 metres. All these resistivity valves are indicates of textural properties ideal for groundwater occurrence forming part of the aquifer in the area (Fig 4.9).

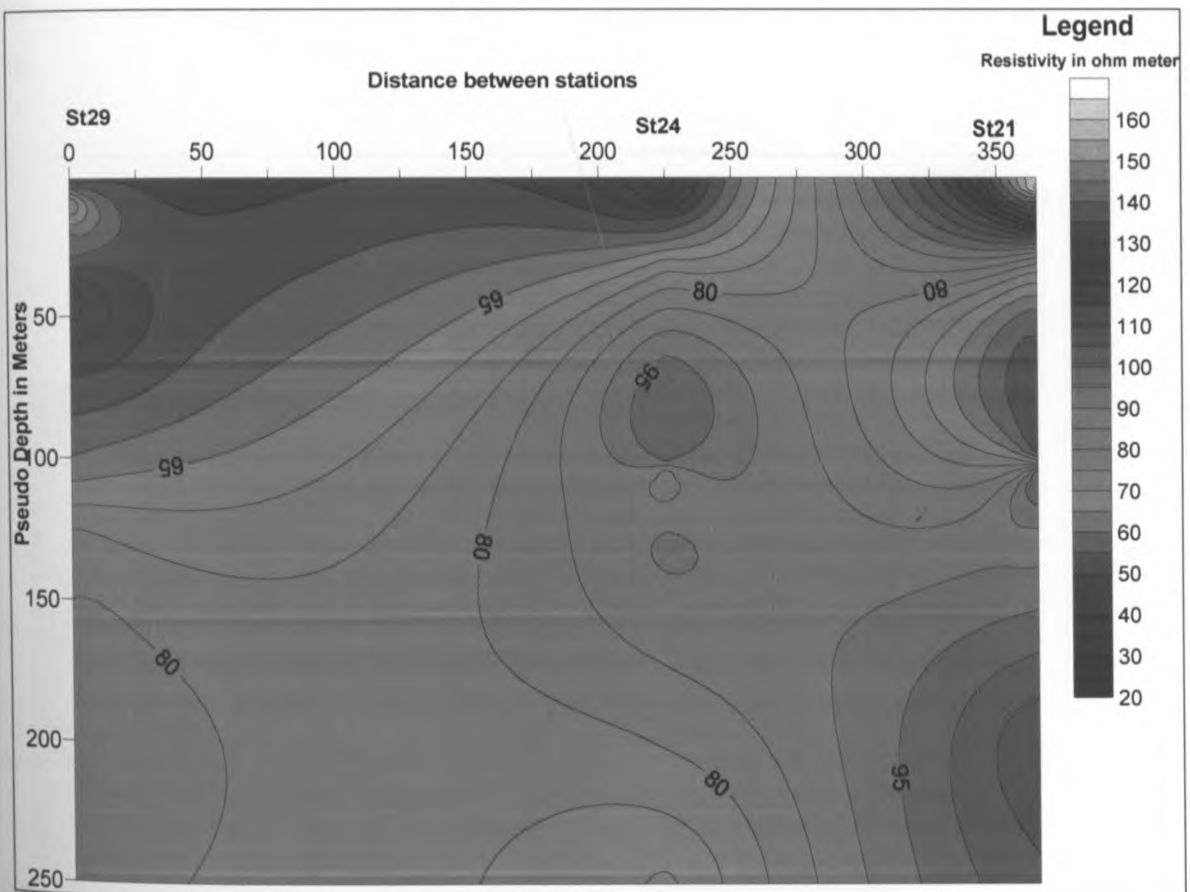


Figure 4.9: Pseudo Section 8 (St. 29, 24 and 21)

4.1.9: Profile 9 (St.19, 31, 28 and 27)

The profile runs in NW and SE direction through stations 19, 31, 28 and 27. The resistivity values ranges from 10-170 ohms-metre. Low resistivity zone is characterized on the western part of the profile between station 28 and 27. The resistivities between these two stations increase from 10-80 ohms – metres with depth up to a depth of 250 metres. This low resistivity zone is part of the low resistivity corridor in the project area. Geologically this could be attributed by the presence of Kerichwa Valley Tuffs which dominate the zone. The eastern side of the profile is characterized by a high resistivity zone that increases with depth up to a resistivity of 160 ohms metres. The resistivity on this zone increases with depth from 60-160 ohms-metre to a depth of 250 metres. This could be attributed to Nairobi Trachytes formation which may have dominated this zone to depths of about 250 metres (Fig 4.10).

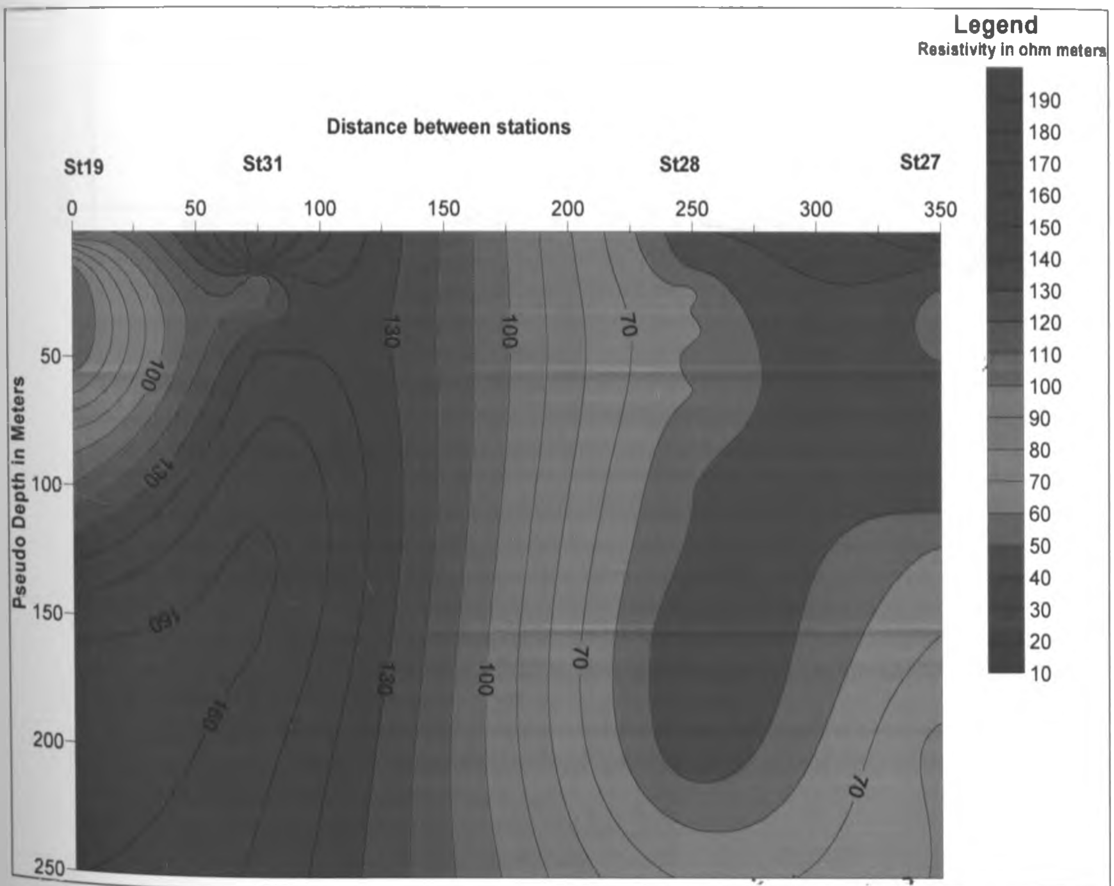


Figure 4.10: Pseudo Section 9 (St.19, 31, 28 and 27)

4.2: RELATIONSHIP TO GROUNDWATER POTENTIAL

The Pseudo-Sections correspond with groundwater potential map in that areas whose resistivity is relatively low on the Pseudo-Section, on the groundwater potential map the same area lies on zones of high to very high groundwater potential zones while areas of high resistivity on the pseudo section lies on areas of low to medium groundwater potential zone.

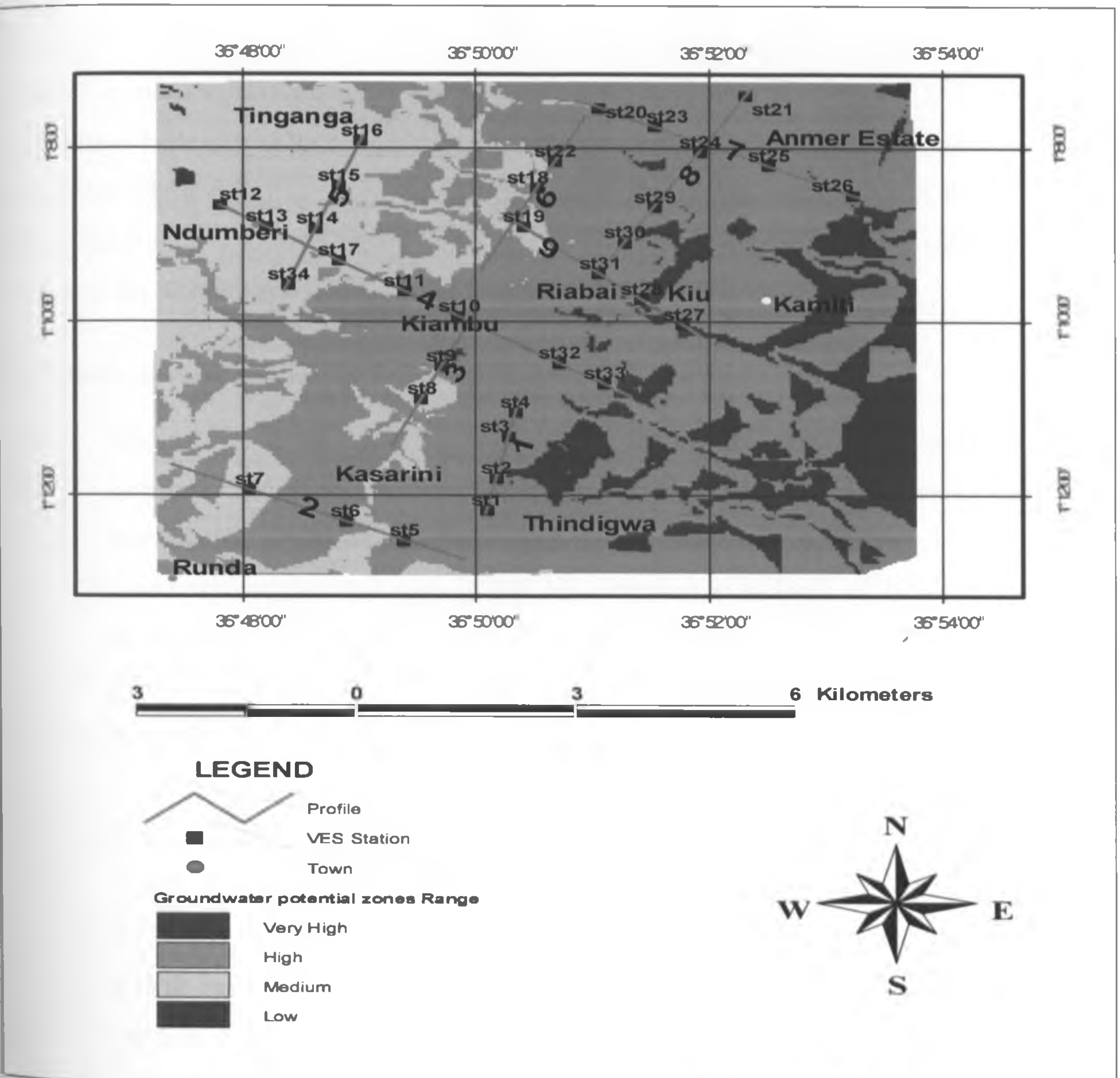


Figure 4.11: Profile, Vertical Electrical Sounding Station & Groundwater potential map

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The summarized conclusion from the hydrogeological investigations is discussed in the following sections:

The geology of the study area comprises a succession of lava and pyroclastics of Cainozoic age overlying a foundation of folded Precambrian schists and gneisses of the Mozambique Belt.

The climate of the study area is of tropical type with bimodal rainfall distribution pattern. The mean annual rainfall is 1200mm with mean temperatures of about 25^0 C. The drainage pattern is more or less dendritic with many small tributaries joining the main rivers. The rivers flow from west to East controlled by the topography of the project which slopes towards eastern side. The western part altitude is about 1800 meters and the Eastern side is about 1400 meters.

The methods adopted include the following techniques:

(i) Vertical electrical sounding: soundings which were executed aligned largely in northeast – southwest direction across geological structures of interest. The results indicated that the project area is characterized by a low resistivity corridor that runs in SW-NE direction at a depth of 100-250 metres. The Shape of the aquifer (the low resistivity corridor) start from Pseudo Section 2 (St 6) with high resistivity of 140 ohms (lowers with depth to 40 m) running across Pseudo Section 4 St 33, resistivity starting at 60 ohms meter and reduces with depth to less than 20 ohms meter. At Pseudo Section 9 between St 25 and St 27 the corridor becomes shallow at a depth of 225 m and curves towards SE direction. At Pseudo Section 7 (St 20-23) the aquifer starts from the surface (almost like an artesian well) to deep depths beyond 300 meters.

(ii) Satellite images (landsat) were processed and interpreted in terms of spartial distribution of land use - land cover. The spartial distribution identified 6 classes: Water bodies cover 5%, Coffee Plantations 20%, settlement and farm-land areas occupies 50%, Built up land (settlement) occupies 15%, Quarry occupies 1% and Farm-land occupies 9%.

(iii) Hydrogeological data processing: all available borehole data in the study area was collected. Specific capacity and transmissivity of the aquifers were determined. The moderate transmissivity values ranging from 42 – 83 m^2/day covers the largest area and corresponds to high groundwater potential zone.

From this data the following sets of thematic layers were produced namely: lithology, land use-cover, drainage patterns, slope, topography, transmissivity, resistivity measurements and rainfall which were used as inputs parameters in the model.

From the results of the study four groundwater potential zones were delineated ranging from low to very high zones. The very high groundwater potential zone covers the southeast side and grades through high, medium, low potential in the northwestern side. The zones were as follows: (i) very high potential zone covers spatially about 13% of the total area and characterized discharge zones. It occurs as isolated perches within high potential zones (ii) high potential zones covers about 70% of the entire area i.e Kiambu Township (iii) medium zone covers about 15% and characterizes the catchment area (iv) low potential zone are less than 2% and occur as small isolated ports to the northwest of the study area.

In summary, therefore, the area falls under a high groundwater potential zone. Therefore, the method adopted for this study proved very successfully in meeting the objectives set and is an improvement to the methods previously used in delineating groundwater potential that focused on single parameter independently i.e transmissivity or resistivity values.

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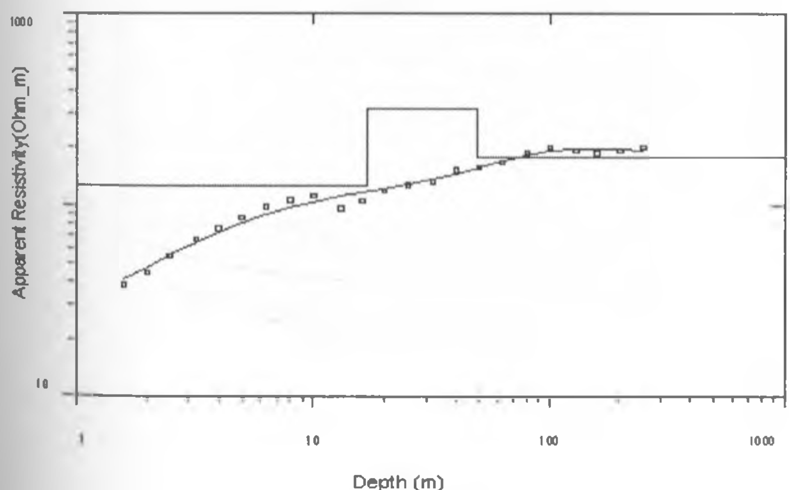
APPENDICES

Geophysical Data

Station 1

AB/2	MN	Apparent Resistivity
1.6	0.5	38.81
2	0.5	45.04
2.5	0.5	54.64
3.2	0.5	66.59
4	0.5	76.4
5	0.5	86.51
6.3	0.5	99.17
8	0.5	107.14
10	0.5	113.68
13	0.5	97.34
16	0.5	106.63
20	0.5	120.01
25	0.5	128.18
32	0.5	133.9
40	10	152.9
50	10	159.2
63	10	167.7
80	10	188.6
100	10	202.2
130	10	195
160	10	188
200	10	192
250	10	200

st1

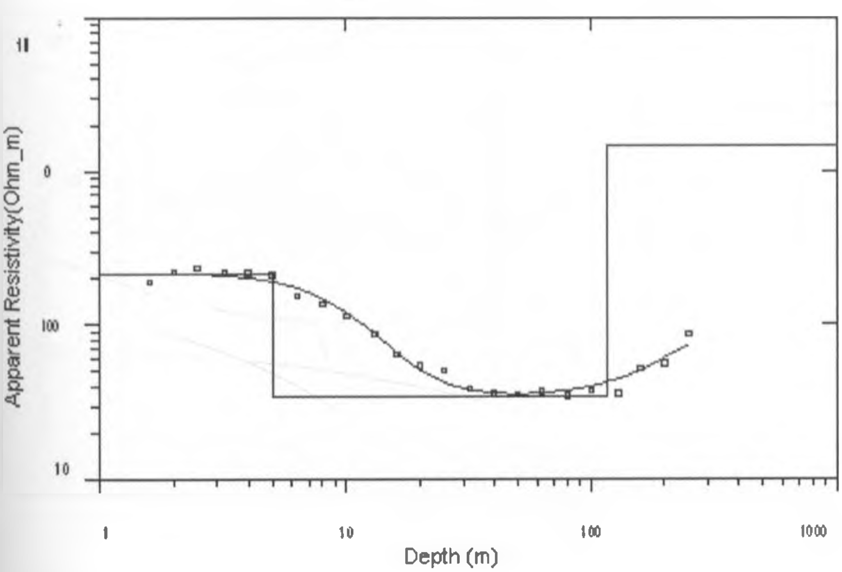


True Resistivity	Thickness	Depth
126.5	16.9	16.9
320.2	32.4	49.3
179		

Station 2

AB/2	MN	Apparent Resistivity
1.6	0.5	189.52
2	0.5	218.94
2.5	0.5	235.71
3.2	0.5	218.31
4	0.5	216.89
5	0.5	211.19
6.3	0.5	152.82
8	0.5	138.26
10	0.5	113.43
13	0.5	87.48
16	0.5	64.07
20	0.5	55.1
25	0.5	50.75
32	0.5	38.6
40	0.5	35.9
50	10	35.6
63	10	37.1
80	10	35
100	10	37.4
130	10	36
160	10	51.9
200	10	56.8
250	10	86.6

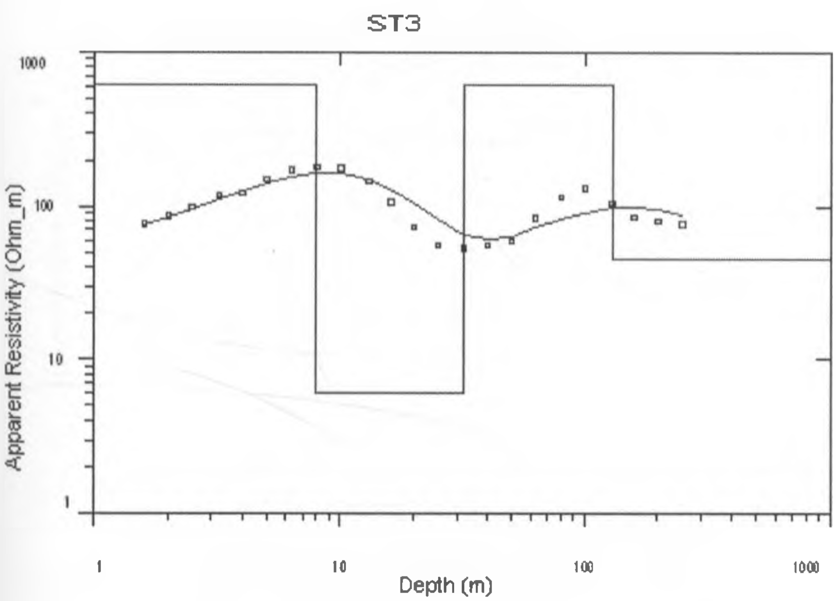
ST2



True Resistivity	Thickness	Depth
215.7	5.0	5.0
34.0	111.5	116.5
1461.0		

Station 3

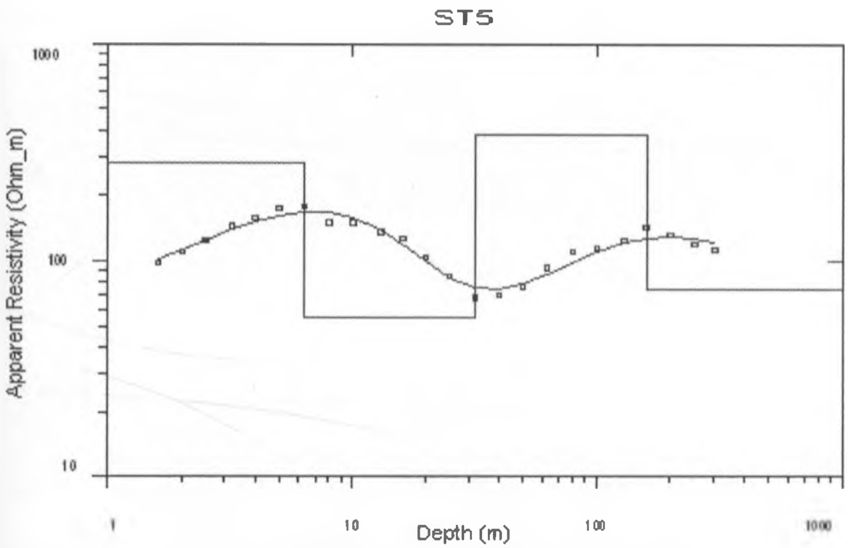
AB/2	MN	Apparent Resistivity
1.6	0.5	76.9
2	0.5	86.48
2.5	0.5	99.64
3.2	0.5	118.98
4	0.5	120.61
5	0.5	150.31
6.3	0.5	171.51
8	0.5	179.25
10	0.5	177.6
13	0.5	145
16	0.5	106.41
20	0.5	72.55
25	0.5	56.11
32	0.5	53.3
40	10	55.5
50	10	59.1
63	10	83.3
80	10	114
100	10	132.1
130	10	104.8
160	10	85.2
200	10	80.6
250	10	77



True Resistivity	Thickness	Depth
606.00	8.00	8.00
6.00	24.00	32.00
606.00	98.00	130.00
44.60		

Station 5

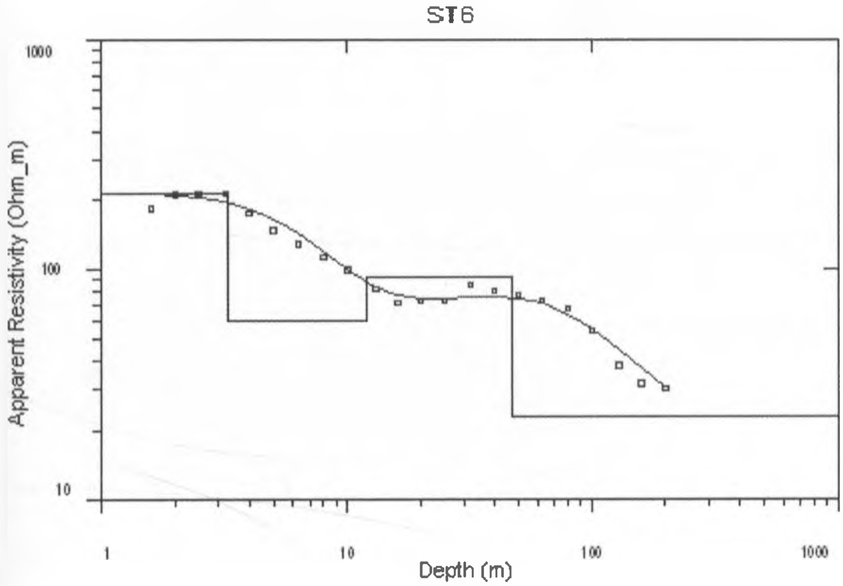
AB/2	MN	Apparent Resistivity
1.6	0.5	98.52
2	0.5	109.73
2.5	0.5	123.85
3.2	0.5	145.3
4	0.5	157.05
5	0.5	175.16
6.3	0.5	177.31
8	0.5	151.12
10	0.5	150.04
13	0.5	136.46
16	0.5	128.05
20	0.5	103.59
25	0.5	85.48
32	0.5	67.8
40	0.5	69.7
50	10	76.4
63	10	93.1
80	10	110.8
100	10	115
130	10	125
160	10	142.2
200	10	121.8
250	10	110
300	10	89.5



True Resistivity	Thickness	Depth
281.5	3.8	3.8
52.5	26.2	30.0
377.8	71.0	101.0
30		

Station6

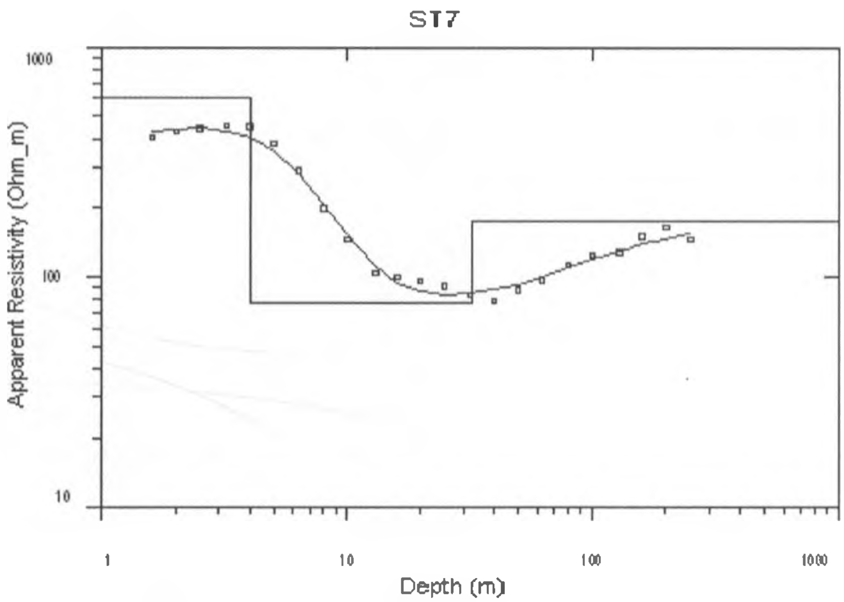
AB/2	MN	Apparent Resistivity
1.6	0.5	183.78
2	0.5	211.81
2.5	0.5	215.35
3.2	0.5	213.8
4	0.5	173.92
5	0.5	148
6.3	0.5	128.28
8	0.5	113.44
10	0.5	98.82
13	0.5	81.31
16	0.5	71.01
20	0.5	72.45
25	0.5	73.11
32	0.5	85.3
40	0.5	80.3
50	10	76.9
63	10	73.2
80	10	67.1
100	10	53.9
130	10	37.9
160	10	31.6
200	10	30.1



True Resistivity	Thickness	Depth
215.3	3.0	3.0
59.4	9.0	12.0
92.0	35.0	47.0
22.8		

Station7

AB/2	MN	Apparent Resistivity
1.6	0.5	405.41
2	0.5	426.55
2.5	0.5	443.84
3.2	0.5	458.83
4	0.5	450.76
5	0.5	383.13
6.3	0.5	291.67
8	0.5	199.06
10	0.5	146.03
13	0.5	103.76
16	0.5	100.63
20	0.5	95.77
25	0.5	91.33
32	0.5	83
40	10	78.4
50	10	88
63	10	97.2
80	10	112.8
100	10	124
130	10	128.4
160	10	150.6
200	10	165.2
250	10	145.9

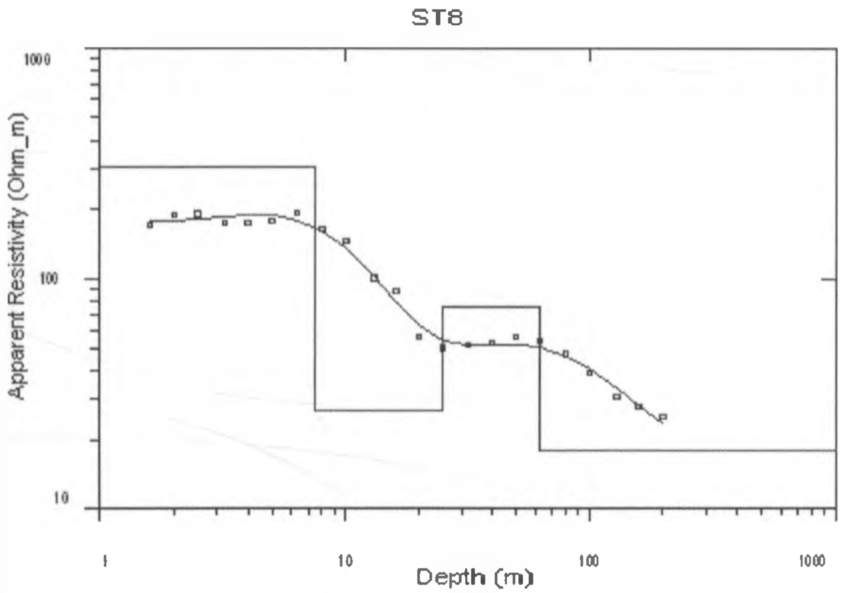


MODEL

True Resistivity	Thickness	Depth
608.0	4.0	4.0
76.7	28.8	32.0
174.0		

Station8

AB/2	MN	Apparent Resistivity
1.6	0.5	172.82
2	0.5	188.62
2.5	0.5	191.52
3.2	0.5	174.92
4	0.5	175.84
5	0.5	179.56
6.3	0.5	192.45
8	0.5	164.81
10	0.5	146.58
13	0.5	100.93
16	0.5	88.74
20	0.5	55.75
25	0.5	50.32
32	0.5	51.6
40	10	53
50	10	56
63	10	53.6
80	10	47.2
100	10	38.9
130	10	30.6
160	10	27.9
200	10	25.1

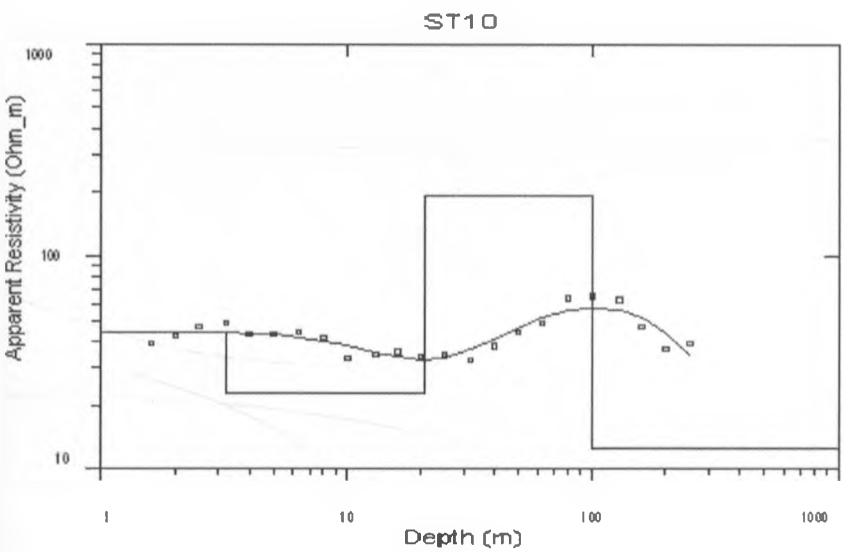


MODEL

True Resistivity	Thickness	Depth
304.4	7.5	7.5
26.9	17.5	25.0
75.5	38.0	63.0
18.1		

Station 10

AB/2	MN	Apparent Resistivity
1.6	0.5	38.91
2	0.5	42.39
2.5	0.5	46.52
3.2	0.5	48.59
4	0.5	43.14
5	0.5	43.14
6.3	0.5	44.17
8	0.5	41.73
10	0.5	33.27
13	0.5	34.4
16	0.5	35.62
20	0.5	34.21
25	0.5	34.49
32	0.5	32.8
40	10	37.9
50	10	44.3
63	10	48.5
80	10	63.9
100	10	65.1
130	10	62.7
160	10	46.5
200	10	36.7
250	10	39.1

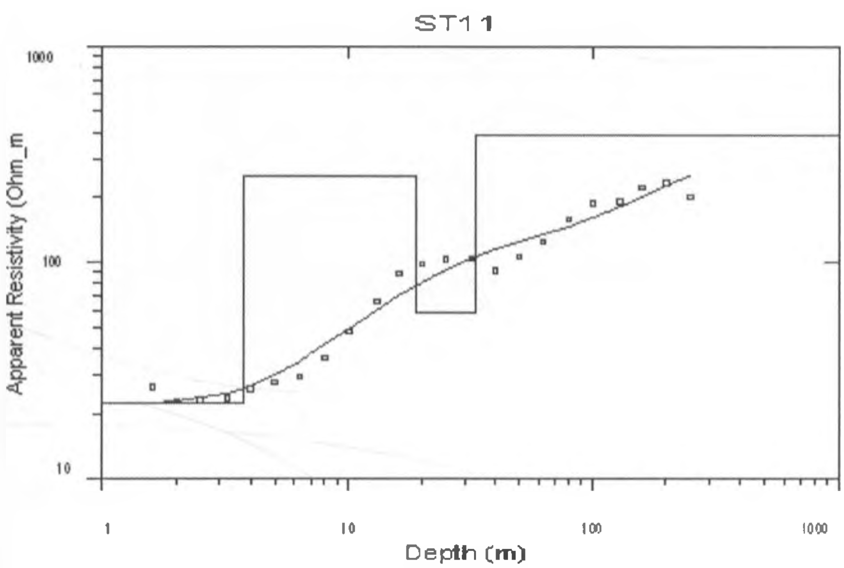


MODEL

True Resistivity	Thickness	Depth
44.3	3.2	3.2
22.9	17.8	21.0
194.3	79.0	100.0
12.4		

Station 11

AB/2	MN	Apparent Resistivity
1.6	0.5	26.36
2	0.5	22.91
2.5	0.5	23.08
3.2	0.5	23.37
4	0.5	25.96
5	0.5	27.74
6.3	0.5	29.47
8	0.5	36.14
10	0.5	47.31
13	0.5	66.07
16	0.5	88.81
20	0.5	97.84
25	0.5	103.02
32	0.5	103.6
40	10	91.3
50	10	105.8
63	10	125.6
80	10	157.9
100	10	187.6
130	10	191.6
160	10	222.2
200	10	233.7
250	10	200

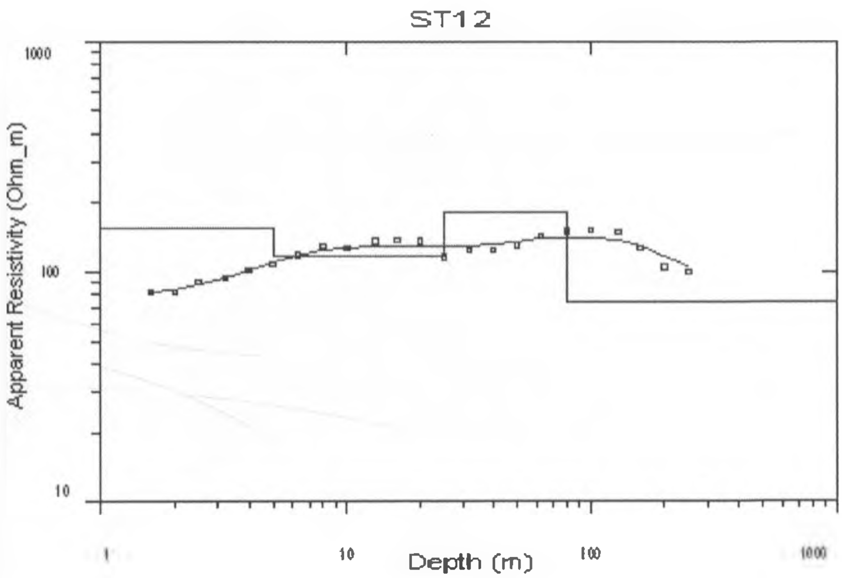


MODEL

True Resistivity	Thickness	Depth
22.2	3.8	3.8
251.1	14.9	18.7
58.4	14.5	33.2
387.4		

Station 12

AB/2	MN	Apparent Resistivity
1.6	0.5	82.41
2	0.5	82.41
2.5	0.5	90.11
3.2	0.5	94.73
4	0.5	101.86
5	0.5	108.31
6.3	0.5	118.42
8	0.5	129.2
10	0.5	127.66
13	0.5	136.23
16	0.5	138.06
20	0.5	136.03
25	0.5	116.49
32	0.5	124
40	10	125.1
50	10	131.1
63	10	144.3
80	10	150.3
100	10	152
130	10	149
160	10	126.7
200	10	105.5
250	10	100.7

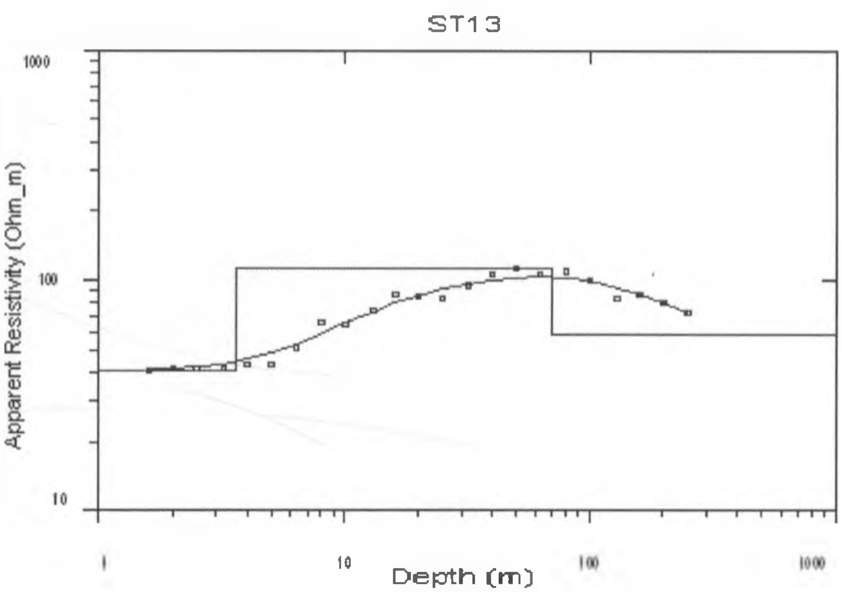


MODEL

True Resistivity	Thickness	Depth
156.40	6.00	6.00
117.80	19.00	25.00
182.00	56.00	81.00
73.60		

Station 13

AB/2	MN	Apparent Resistivity
1.6	0.5	40.45
2	0.5	41.49
2.5	0.5	41.34
3.2	0.5	41.27
4	0.5	42.91
5	0.5	42.91
6.3	0.5	51.14
8	0.5	66.09
10	0.5	64.15
13	0.5	73.64
16	0.5	87.17
20	0.5	85.31
25	0.5	83.88
32	0.5	94.8
40	10	106.1
50	10	113.3
63	10	105.7
80	10	109.4
100	10	100.7
130	10	83.2
160	10	86.7
200	10	80.9
250	10	72.1

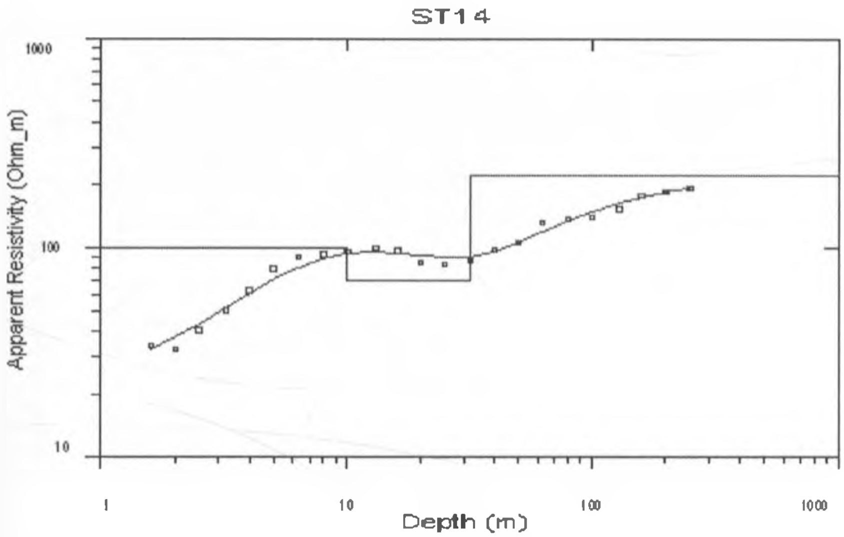


MODEL

True Resistivity	Thickness	Depth
40.90	4.00	4.00
113.70	67.00	71.00
57.70		

Station 14

AB/2	MN	Apparent Resistivity
1.6	0.5	33.7
2	0.5	32.44
2.5	0.5	40.23
3.2	0.5	50.26
4	0.5	62.34
5	0.5	79.19
6.3	0.5	90.49
8	0.5	93.32
10	0.5	96.53
13	0.5	99.94
16	0.5	96.73
20	0.5	85.53
25	0.5	83.29
32	0.5	86.5
40	10	98.4
50	10	106.3
63	10	131.7
80	10	138.1
100	10	140
130	10	153.5
160	10	179.3
200	10	185.7
250	10	193.8

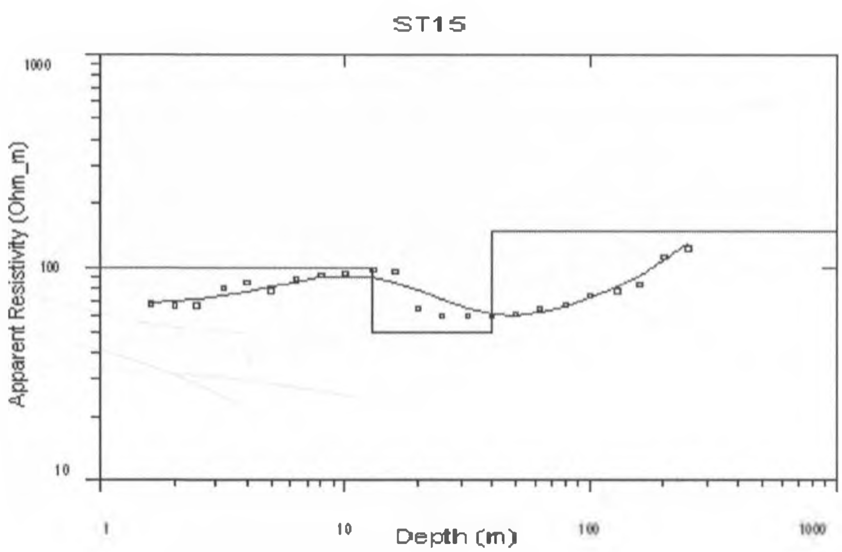


MODEL

True Resistivity	Thickness	Depth
100	10	10
70	22	32
221.7		

Station 15

AB/2	MN	Apparent Resistivity
1.6	0.5	67.74
2	0.5	66.28
2.5	0.5	66.28
3.2	0.5	79.96
4	0.5	85.17
5	0.5	78.16
6.3	0.5	88.91
8	0.5	91.84
10	0.5	93.8
13	0.5	97.7
16	0.5	95.92
20	0.5	64.81
25	0.5	59.11
32	0.5	59.6
40	10	59.7
50	10	60.6
63	10	64.5
80	10	67.4
100	10	74.5
130	10	77.6
160	10	83.9
200	10	113
250	10	123

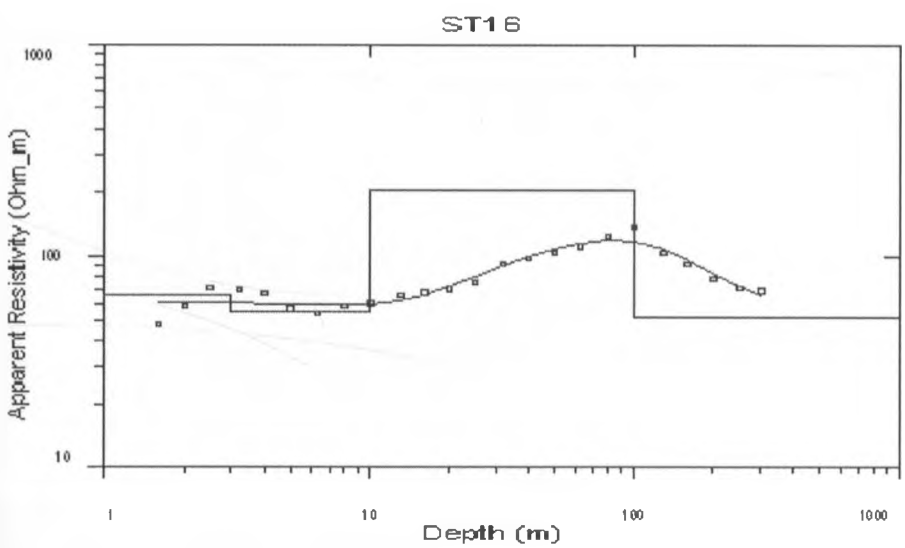


MODEL

True Resistivity	Thickness	Depth
68	2.8	2.8
140.3	4.8	7.6
45.3	24.1	31.7

Station 16

AB/2	MN	Apparent Resistivity
1.6	0.5	47.4
2	0.5	58
2.5	0.5	71.2
3.2	0.5	70
4	0.5	67.2
5	0.5	56.6
6.3	0.5	53.9
8	0.5	58.3
10	0.5	60.1
13	0.5	65.9
16	0.5	67.5
20	0.5	70.6
25	0.5	76.1
32	0.5	92.4
40	10	97.6
50	10	104.2
63	10	111.6
80	10	124.8
100	10	138.6
130	10	104.3
160	10	91.7
200	10	78.9
250	10	70.7
300	10	69.2

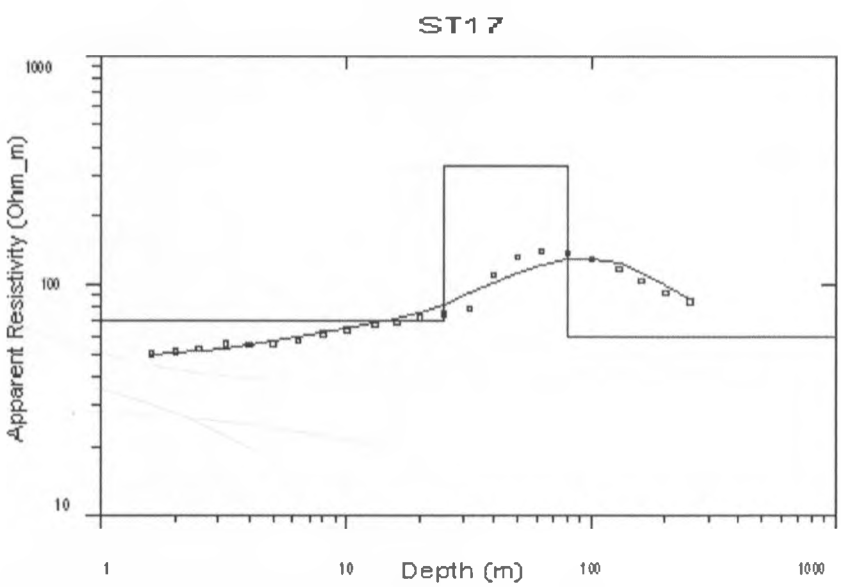


MODEL

True Resistivity	Thickness	Depth
65.00	3.00	3.00
54.40	7.00	10.00
206.60	90.00	100.00
51.20		

Station 17

AB/2	MN	Apparent Resistivity
1.6	0.5	50
2	0.5	51.28
2.5	0.5	52.45
3.2	0.5	55.45
4	0.5	54.8
5	0.5	55.55
6.3	0.5	57.05
8	0.5	61.43
10	0.5	63.46
13	0.5	66.56
16	0.5	68.37
20	0.5	71.9
25	0.5	75.1
32	0.5	78.2
40	10	110
50	10	133
63	10	140
80	10	138
100	10	129.2
130	10	117.6
160	10	103.8
200	10	92.4
250	10	84.5

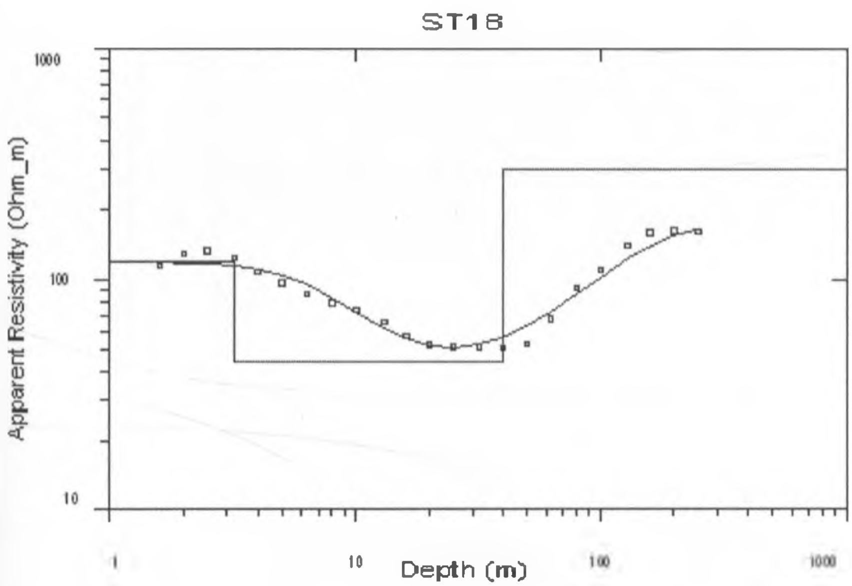


MODEL

True Resistivity	Thickness	Depth
69.30	25.00	25.00
329.70	55.00	80.00
59.90		

Station 18

AB/2	MN	Apparent Resistivity
1.6	0.5	114.61
2	0.5	129.24
2.5	0.5	134.01
3.2	0.5	125.49
4	0.5	107.78
5	0.5	97.02
6.3	0.5	86.62
8	0.5	79.55
10	0.5	73.51
13	0.5	65.65
16	0.5	57.24
20	0.5	52.23
25	0.5	51.32
32	0.5	51.2
40	10	50.9
50	10	52.8
63	10	67.6
80	10	92.3
100	10	110.3
130	10	140
160	10	160
200	10	163.4
250	10	160.2

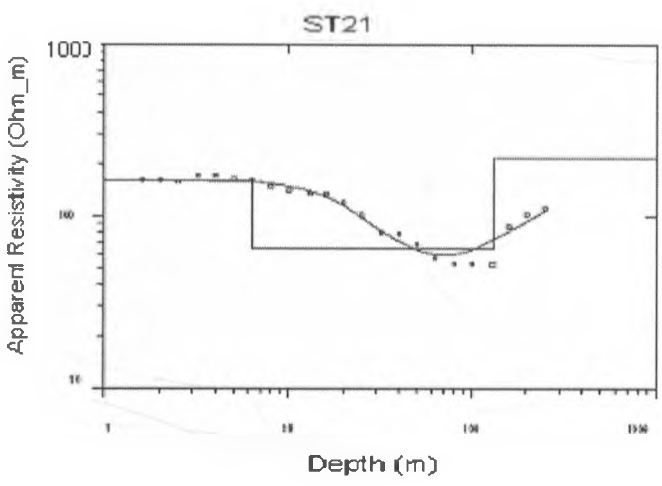


MODEL

True Resistivity	Thickness	Depth
120.30	3.20	3.20
44.00	36.80	40.00
300.00		

Station 21

AB/2	MN	Apparent Resistivity
1.6	0.5	160.1
2	0.5	161.8
2.5	0.5	159.4
3.2	0.5	170.5
4	0.5	171.3
5	0.5	165.3
6.3	0.5	162.5
8	0.5	149.2
10	0.5	140.5
13	0.5	135
16	0.5	134.9
20	0.5	120
25	0.5	101.2
32	0.5	80.3
40	10	79
50	10	68.4
63	10	57.7
80	10	53
100	10	53
130	10	52.2
160	10	87
200	10	102
250	10	110

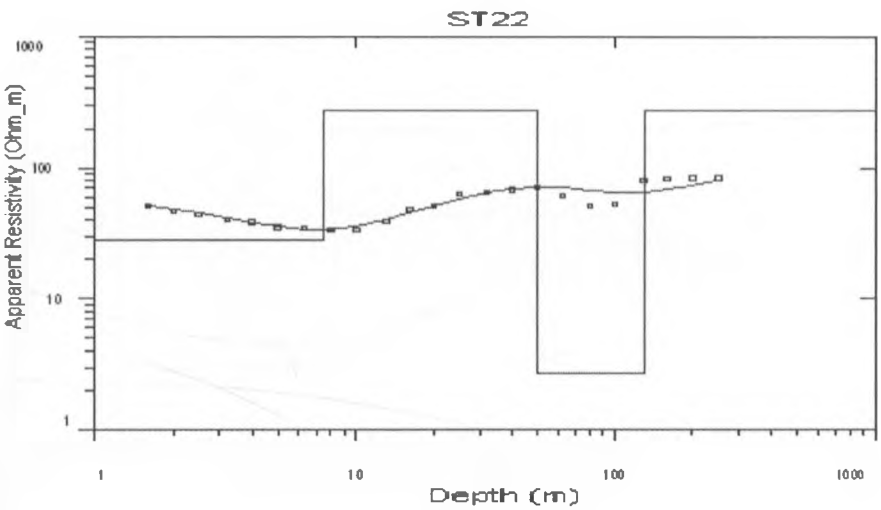


MODEL

True Resistivity	Thickness	Depth
161.00	6.30	6.30
64.20	123.70	130.00
215.70		

Station 22

AB/2	MN	Apparent Resistivity
1.6	0.5	51.63
2	0.5	46.62
2.5	0.5	44.43
3.2	0.5	40.26
4	0.5	38.44
5	0.5	35.29
6.3	0.5	34.35
8	0.5	33.26
10	0.5	33.3
13	0.5	39.25
16	0.5	47.75
20	0.5	51.37
25	0.5	63.25
32	0.5	65.5
40	10	67.8
50	10	70.7
63	10	61.1
80	10	51.4
100	10	52.7
130	10	79.8
160	10	82
200	10	83.2
250	10	84

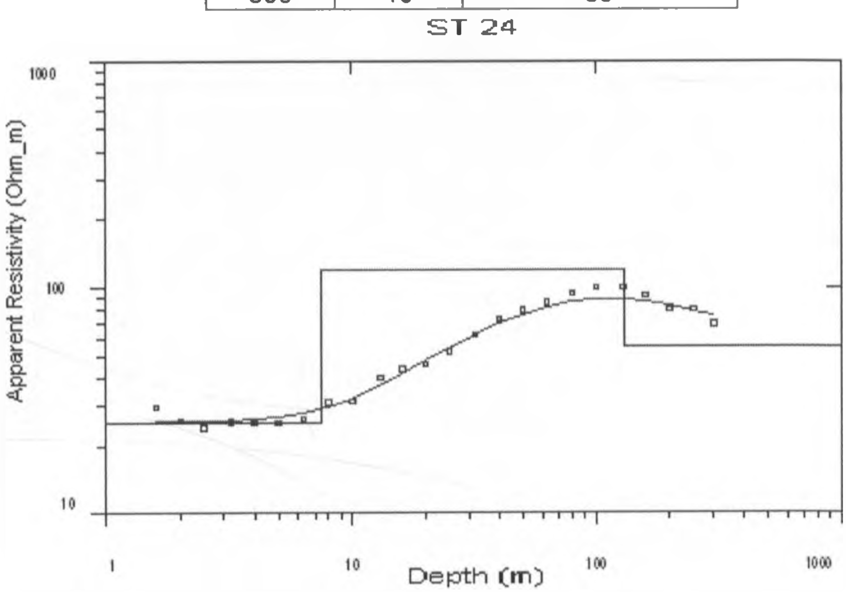


MODEL

True Resistivity	Thickness	Depth
27.70	7.50	7.50
269.40	42.50	50.00
50.00	80.00	130.00
269.60		

Station 24

AB/2	MN	Apparent Resistivity
1.6	0.5	29.6
2	0.5	25.7
2.5	0.5	24
3.2	0.5	25.5
4	0.5	25.1
5	0.5	25.2
6.3	0.5	26.1
8	0.5	31
10	0.5	31.5
13	0.5	39.9
16	0.5	43.8
20	0.5	46
25	0.5	52.2
32	0.5	61.6
40	10	72.5
50	10	79.7
63	10	86.4
80	10	94.7
100	10	99.3
130	10	99.8
160	10	91.6
200	10	80.8
250	10	80.6
300	10	69

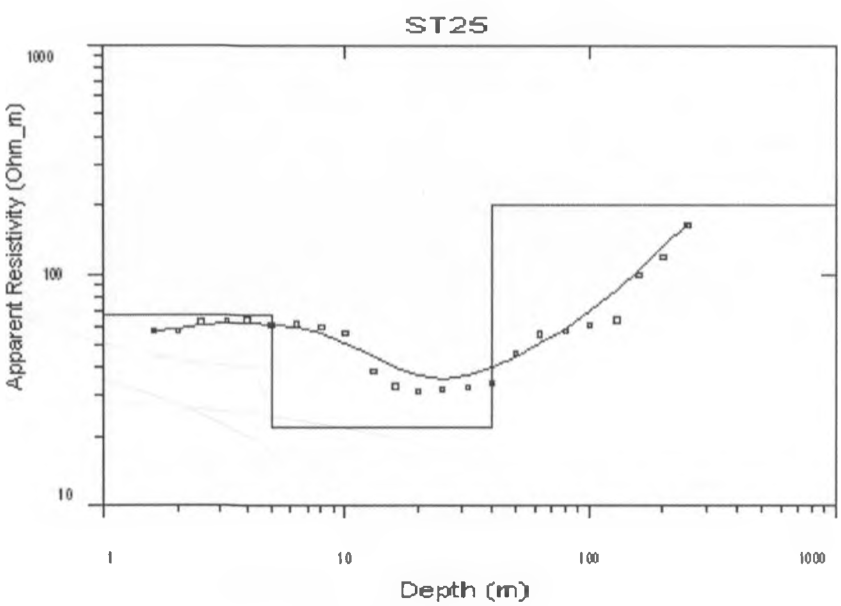


MODEL

True Resistivity	Thickness	Depth
25.40	7.40	7.40
119.80	122.00	130.00
54.90		

Station 25

AB/2	MN	Apparent Resistivity
1.6	0.5	57.46
2	0.5	57.3
2.5	0.5	62.48
3.2	0.5	62.79
4	0.5	63.51
5	0.5	61.04
6.3	0.5	61.2
8	0.5	58.97
10	0.5	56.03
13	0.5	38.12
16	0.5	33.03
20	0.5	31.44
25	0.5	32.09
32	0.5	32.8
40	10	33.9
50	10	45.9
63	10	55.5
80	10	57
100	10	60.6
130	10	63.8
160	10	99.7
200	10	120
250	10	164.4

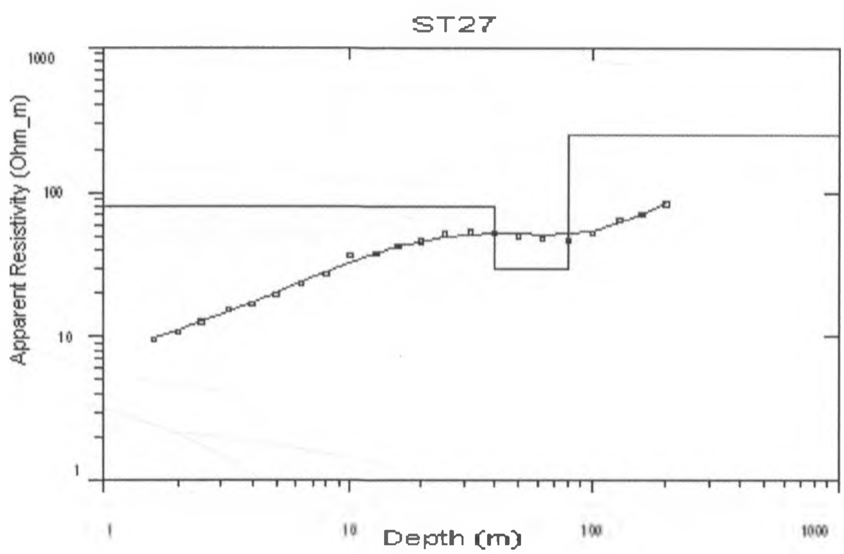


MODEL

True Resistivity	Thickness	Depth
67.40	5.00	5.00
21.90	35.00	40.00
200.00		

Station 27

AB/2	MN	Apparent Resistivity
1.6	0.5	9.5
2	0.5	10.75
2.5	0.5	12.72
3.2	0.5	15.39
4	0.5	16.88
5	0.5	19.55
6.3	0.5	23.47
8	0.5	27
10	0.5	36.58
13	0.5	38.31
16	0.5	42.62
20	0.5	46
25	0.5	51.81
32	0.5	53.3
40	10	52
50	10	50.2
63	10	48.4
80	10	46.8
100	10	52
130	10	65.2
160	10	70.9
200	10	83.8

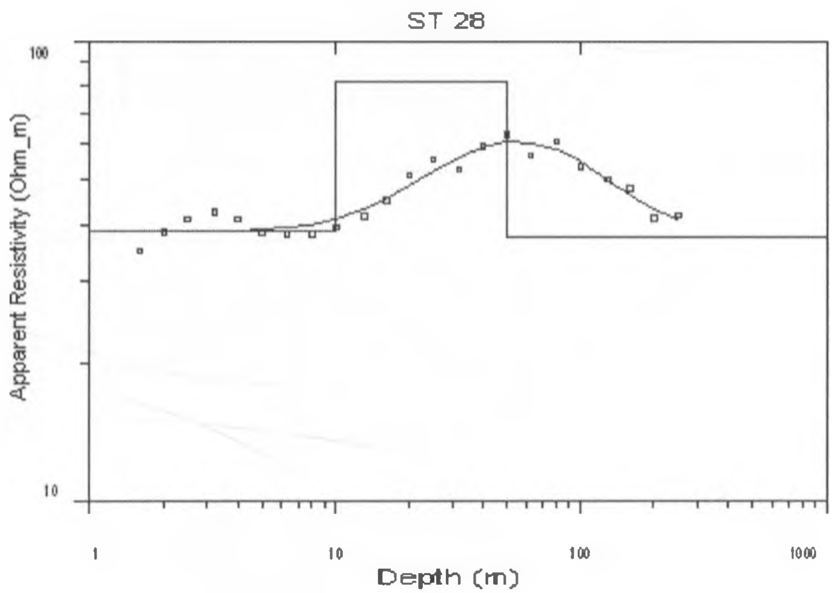


MODEL

True Resistivity	Thickness	Depth
80.00	40.00	40.00
30.00	40.00	80.00
250.00		

Station 28

AB/2	MN	Apparent Resistivity
1.6	0.5	35
2	0.5	38.5
2.5	0.5	40.9
3.2	0.5	42.5
4	0.5	40.9
5	0.5	38.3
6.3	0.5	38.1
8	0.5	38.1
10	0.5	39.5
13	0.5	41.6
16	0.5	45.1
20	0.5	51.1
25	0.5	55.3
32	0.5	52.7
40	10	59.1
50	10	62.7
63	10	56.4
80	10	60.5
100	10	53.5
130	10	50.1
160	10	47.8
200	10	41.1
250	10	41.9

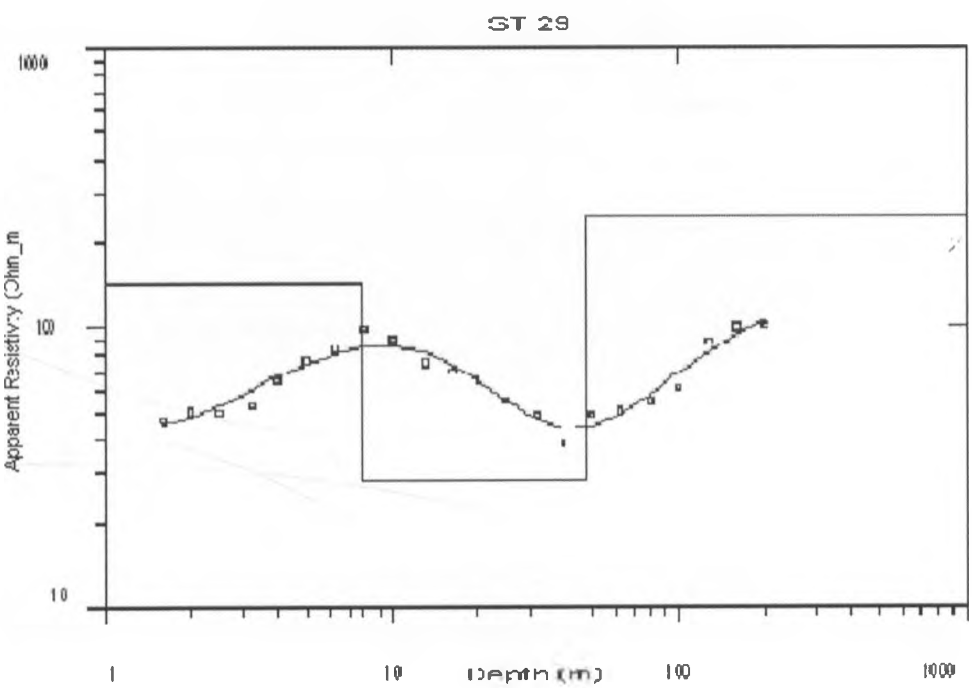


MODEL

True Resistivity	Thickness	Depth
38.50	10.00	10.00
82.00	40.00	50.00
37.50		

Station 29

AB/2	MN	Apparent Resistivity
1.6	0.5	47.1
2	0.5	50.1
2.5	0.5	49.8
3.2	0.5	52.4
4	0.5	64.1
5	0.5	76.2
6.3	0.5	84.2
8	0.5	98.5
10	0.5	90.9
13	0.5	75
16	0.5	70
20	0.5	64.3
25	0.5	55
32	0.5	49
40	10	38
50	10	49
63	10	50
80	10	54.6
100	10	61
130	10	89.3
160	10	99.2
200	10	100.1

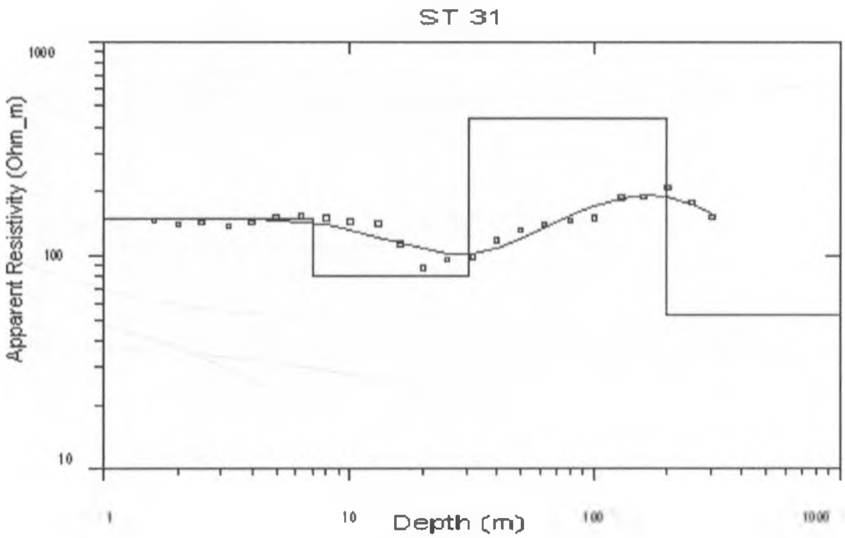


MODEL

True Resistivity	Thickness	Depth
143.50	8.00	8.00
28.40	40.00	48.00
250.00		

Station 31

AB/2	MN	Apparent Resistivity
1.6	0.5	145.5
2	0.5	139.4
2.5	0.5	142.2
3.2	0.5	138.2
4	0.5	144.1
5	0.5	152.4
6.3	0.5	154
8	0.5	150.5
10	0.5	145.4
13	0.5	142
16	0.5	113.8
20	0.5	87.7
25	0.5	96
32	0.5	99.1
40	10	118.8
50	10	132.8
63	10	141
80	10	146.6
100	10	151
130	10	187.1
160	10	190.3
200	10	210.1
250	10	177.3
300	10	151.8

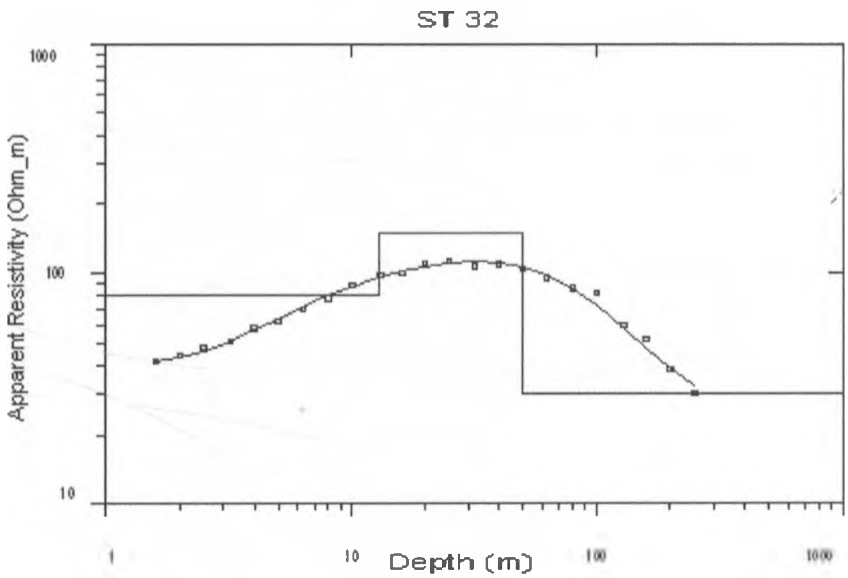


MODEL

True Resistivity	Thickness	Depth
150.20	7.00	7.00
80.00	23.50	30.00
436.60	169.50	200.00
52.40		

Station 32

AB/2	MN	Apparent Resistivity
1.6	0.5	41.81
2	0.5	44.19
2.5	0.5	47.65
3.2	0.5	50.88
4	0.5	57.79
5	0.5	61.87
6.3	0.5	69.86
8	0.5	78.16
10	0.5	88.23
13	0.5	97.6
16	0.5	100.68
20	0.5	109.74
25	0.5	113.28
32	0.5	106.9
40	10	109.1
50	10	104.6
63	10	95
80	10	85.9
100	10	82
130	10	59.4
160	10	52.1
200	10	38.4
250	10	30.2

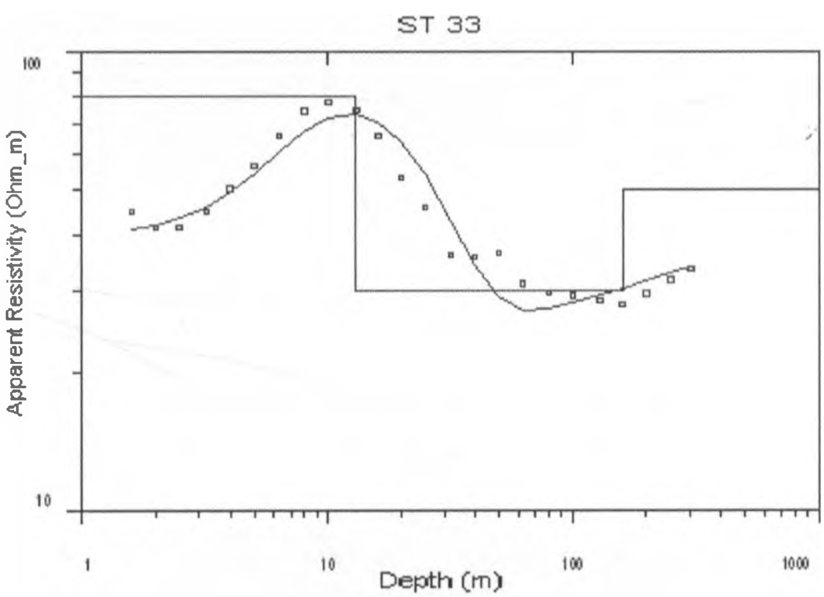


MODEL

True Resistivity	Thickness	Depth
80.00	13.00	13.00
150.00	37.00	50.00
30.00		

Station 33

AB/2	MN	Apparent Resistivity
1.6	0.5	45
2	0.5	41.5
2.5	0.5	41.3
3.2	0.5	44.8
4	0.5	50.4
5	0.5	56.4
6.3	0.5	65.5
8	0.5	74.3
10	0.5	77.9
13	0.5	74.7
16	0.5	65.6
20	0.5	53.1
25	0.5	45.7
32	0.5	36.1
40	10	35.7
50	10	36.3
63	10	31.2
80	10	29.8
100	10	29.3
130	10	28.6
160	10	28
200	10	29.6
250	10	31.8
300	10	33.7

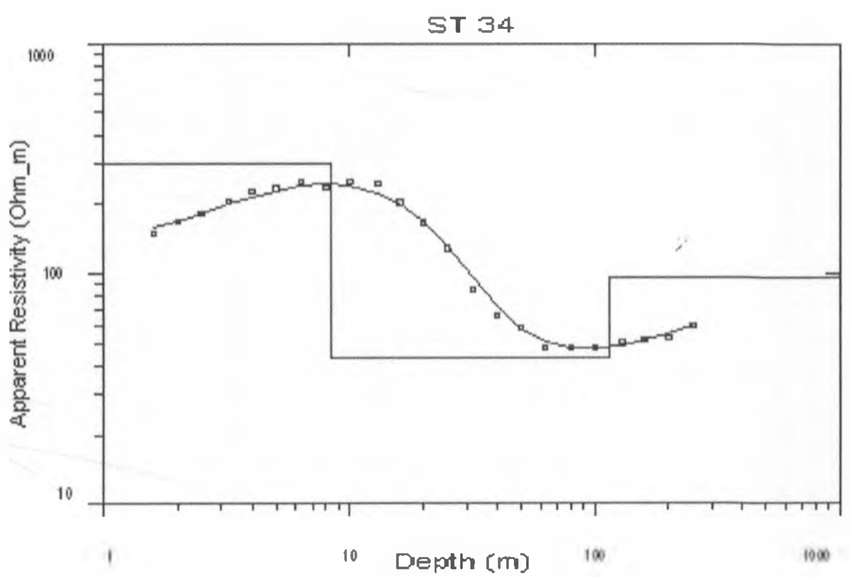


MODEL

True Resistivity	Thickness	Depth
80.00	13.00	13.00
30.00	147.00	160.00
50.00		

Station 34

AB/2	MN	Apparent Resistivity
1.6	0.5	149.33
2	0.5	167.26
2.5	0.5	182.07
3.2	0.5	204.8
4	0.5	226.91
5	0.5	234.21
6.3	0.5	248.6
8	0.5	235.25
10	0.5	250.89
13	0.5	245.47
16	0.5	203.34
20	0.5	166.85
25	0.5	128.26
32	0.5	85.3
40	10	66
50	10	58.4
63	10	47.9
80	10	47.5
100	10	47.5
130	10	50.6
160	10	51.5
200	10	53.1
250	10	59.6



MODEL

True Resistivity	Thickness	Depth
300.90	8.00	8.00
43.30	107.00	115.00
96.30		

Data of the Borehole in the Study Area

B/H No.	ALT	T Depth	M_WSL	O_WSL1	O_WSL2	WRL	Yield	Drawdown
C263	1687	64	61	-	-	7	0.3	-
C426	1715	199	200		-	56	9.48	-
C448	1707	174	154	-	-	44	7.02	-
C460	1676	122	62	-	-	11	5.4	-
C521	1676	134	35	-	-	19	7.02	-
C559	1660	89	85	-	-	1	40.8	18
C710	1707	120	116	-	-	21	9.84	-
C963	1707	61	56	36	-	16	1.38	-
C1058	1079	122	116	83	53	30	16.62	-
C1184	1710	189	183	115	67	25	15.78	-
C1185	1608	122	113	-	-	11	15.78	-
C1205	1652	162	155	143	54	12	9.6	-
C1257	1634	111	90	106	33	38	9.12	-
C1284	1645	110	70	-	-	18	9.48	-
C1350	1813	191	186	20		20	9.12	-
C1354	1813	200	198	182	161	56	10.92	-
C1418	1638	124	113	-	-	35	12.72	-
C1449	1615	162	37	-	-	15	5.22	-
C1506	1655	134	94	-	-	43	12	-
C1594	1714	91	45	-	-	17	4.08	-
C1656	1711	123	104	48	-	38	7.02	-
C1686	1649	176	172	-	-	36	18.96	-
C1828	1623	128	121	76	50	26	11.4	37
C1933	1716	137	131	121	60	43	4.32	-
C2057	1738	147	122	108	48	36	2.46	-
C2127	1676	147	134	-	-	38	9.06	22.9
C2141	1646	128	119	100	-	45	9.06	42.4
C2374	1615	113	102	39	28	35	13.62	18.2
C2554	1623	150	147	-	-	20	13.08	14.6
C2642	1707	146	137	-	-	85	2.52	-
C2668	1722	162	158	54	-	68	32.76	23.1
C2842	1524	219	73	216	-	50	6.3	99
C2909	1707	181	125	106	-	107	4.56	18.2
C2988	1615	93	82	48	-	58	12.72	3
C3091	1737	306	244	57	30	24	21.66	56
C3291	1800	55	43	-	-	32	2.28	-
C3994	1585	155	20	154	147	28	9	30.9
C4027	1768	130	102	20	56	33.5	9.9	21
C4036	1615	182	-	-	-	25	15.48	89.2
C4795	-	250	141	-	-	22	10.2	106
C5171	1650	201	140	-	-	21	9	65
C6381	1670	180	100	24	178	59.1	2.58	84.6
C7295	-	151	73	14	-	52	26.44	44
C11016	1750	160	120	26	-	156	4.5	33.6
C11270	1780	202	140	32	130	100.5	5	46.2
C11271	1770	175	158	36	101	39.8	5.22	110

B/H No.: Borehole Number
ALT : Altitude
T Depth: Total Depth

O_WSL: Other Water Struck Level
WRL : Water Rest Level
M_WSL: Main Water Struck Level

Transmisivity Data

B_H_NO	X COORD	Y COORD	SPECIFIC CAPACITY	TRANSMISIVITY
C 559	258891	9869124	54.4	66.37
C 1828	260745	9876491	7.39	9.02
C 2127	270014	9883875	9.58	11.69
C 2141	258890	9870960	5.13	6.26
C 2374	264454	9874658	17.96	21.91
C 2554	257036	9878336	25.5	31.11
C 2668	258886	9876490	34.04	41.53
C 2729	259825	9868067	1.55	1.9
C 2819	257750	9871750	4.71	5.74
C 2842	257044	9867275	1.53	1.87
C 2909	258893	9867277	6.01	7.33
C 2988	255178	9876487	101.76	124.15
C 3091	253323	9870955	9.28	11.32
C 3994	266314	9872812	6.99	8.53
C 4027	257039	9874653	5.8	7.08
C 4034	264750	9874750	7.99	9.74
C 4035	264625	9874750	17.36	21.18
C 4036	264454	9874658	4.17	5.09
C 4097	265825	9872825	1.14	1.39
C 4795	259125	9866750	2.31	2.82
C 5171	259475	9867125	3.32	4.05
C 6381	259750	9866750	0.73	0.89
C 7295	258100	9869625	13.88	16.93
C 11016	254500	9869125	3.21	3.92
C 11270	255825	9872813	2.6	3.17
C 11271	256125	9871750	1.39	1.7
C 11597	256625	9873100	22.44	27.38
C 11625	260150	9867500	14.27	17.42

Rainfall data

Met. station	X-Cord	Y Cord	Mean Rainfall
Riara	36.80	-1.16	1154.80
Kigwa	36.86	-1.21	1170.50
Kiambu	36.83	-1.17	1186.00
Kasarini	36.82	-1.20	1165.00
Anmer Est.	36.89	-1.13	1140.00
Kiu	36.86	-1.16	1145.00
Riabai	36.85	-1.16	1146.00
Tinganga	36.81	-1.13	1190.00
Ndumberi	36.80	-1.15	1192.00

Pseudo Sections Data

X: Distance between stations across a cross-section (Profile)
Y: Electrical sounding depth (AB/2) which is indicated as Pseudo-depth on the Pseudo-sections.
Z: Resistivity measurements obtained from electrical sounding.

Profile 1 Data

X	Y	Z	X	Y	Z	X	Y	Z
0	1.6	76.9	100	130	36	225	50	32
0	2	86.5	100	160	51.9	225	63	33.7
0	2.5	99.6	100	200	56.8	225	80	37
0	3.2	119	100	250	86.6	225	100	39.5
0	4	120.6	175	1.6	76.9	225	130	39.9
0	5	150.3	175	2	86.5	225	160	40
0	8	171.5	175	2.5	99.6	225	200	42
0	10	179.2	175	3.2	118.9	225	250	50
0	13	177.6	175	4	120.6			
0	16	145	175	5	150.3			
0	20	106.4	175	8	171.5			
0	25	72.5	175	10	179.2			
0	32	56.1	175	13	177.6			
0	32	53.1	175	16	145			
0	40	55.5	175	20	106.4			
0	50	59	175	25	72.5			
0	63	83.3	175	32	56.1			
0	80	114	175	32	53.3			
0	100	132.1	175	40	55.5			
0	130	104.8	175	50	59			
0	160	85.1	175	63	83.3			
0	200	80.5	175	80	114			
0	250	77	175	100	132.1			
100	1.6	189.5	175	130	104.8			
100	2	218.9	175	160	85.2			
100	2.5	235.7	175	200	80.6			
100	3.2	218.3	175	250	77			
100	4	216.3	225	1.6	71			
100	5	211.2	225	2	68			
100	8	152.8	225	2.5	65.9			
100	10	138.3	225	3.2	64.1			
100	13	113.4	225	4	71.2			
100	16	87.2	225	5	72.1			
100	20	64.1	225	8	73.8			
100	25	55.1	225	10	72.9			
100	32	50.8	225	13	65.3			
100	32	38.6	225	16	56.2			
100	40	35.9	225	20	46.6			
100	50	35.5	225	25	38.9			
100	63	37	225	32	37.3			
100	80	35	225	32	35			
100	100	37	225	40	34			

Profile 2 Data

X	Y	Z	X	Y	Z
0	1.6	405.41	275	4	149.05
0	2	426.55	275	5	157.16
0	2.5	443.84	275	6.3	163.31
0	3.2	458.83	275	8	151.12
0	4	450.76	275	10	150.04
0	5	383.13	275	13	136.46
0	6.3	291.67	275	16	128.05
0	8	199.06	275	20	103.59
0	10	146.03	275	25	85.48
0	13	103.76	275	32	67.8
0	16	100.63	275	40	69.7
0	20	95.77	275	50	76.4
0	25	91.33	275	63	89.1
0	32	83	275	80	105.8
0	40	78.4	275	100	110
0	50	88	275	130	115
0	63	97.2	275	160	125.2
0	80	112.8	275	200	121.8
0	100	124	275	250	110
0	130	128.4	275	300	100.5
0	160	150.6			
0	200	165.2			
0	250	150.9			
100	1.6	213.78			
100	2	211.81			
100	2.5	209.35			
100	3.2	201.8			
100	4	173.92			
100	5	148			
100	6.3	128.28			
100	8	113.44			
100	10	98.82			
100	13	81.31			
100	16	71.01			
100	20	72.45			
100	25	73.11			
100	32	77.3			
100	40	79.3			
100	50	75.9			
100	63	73.2			
100	80	67.1			
100	100	53.9			
100	130	37.9			
100	160	31.6			
100	200	25.1			
275	1.6	98.52			
275	2	109.73			
275	2.5	123.85			
275	3.2	140.3			

Profile 3 Data

X	Y	Z	X	Y	Z
0	1.6	172.82	180	4	43.14
0	2	188.62	180	5	43.14
0	2.5	191.52	180	6.3	44.17
0	3.2	174.92	180	8	41.73
0	4	175.84	180	10	33.27
0	5	179.56	180	13	34.4
0	6.3	192.45	180	16	35.62
0	8	164.81	180	20	34.21
0	10	146.58	180	25	34.49
0	13	100.93	180	32	32.8
0	16	88.74	180	40	37.9
0	20	55.75	180	50	44.3
0	25	50.32	180	63	48.5
0	32	51.6	180	80	60.9
0	40	53	180	100	59.1
0	50	56	180	130	55.7
0	63	53.6	180	160	46.5
0	80	47.2	180	200	36.7
0	100	38.9	180	250	39.1
0	130	30.6			
0	160	27.9			
0	200	25.1			
75	1.6	70.88			
75	2	69.74			
75	2.5	70.41			
75	3.2	77.43			
75	4	80.86			
75	5	81.96			
75	6.3	82.52			
75	8	83.04			
75	10	80.34			
75	13	76.49			
75	16	79.19			
75	20	71.49			
75	25	70.98			
75	32	65.8			
75	40	60.3			
75	50	55.1			
75	63	57.8			
75	80	59.1			
75	100	61.4			
75	130	61.1			
75	160	63.6			
75	200	58.5			
75	250	53.5			
180	1.6	38.91			
180	2	42.39			
180	2.5	46.52			
180	3.2	48.59			

Profile 4 Data

X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
0	1.6	82.41	215	3.2	55.45	445	6.3	44.17	730	13	74.7
0	2	82.41	215	4	54.8	445	8	41.73	730	16	65.6
0	2.5	90.11	215	5	55.55	445	10	33.27	730	20	53.1
0	3.2	94.73	215	6.3	57.05	445	13	34.4	730	25	45.7
0	4	101.86	215	8	61.43	445	16	35.62	730	32	36.1
0	5	108.31	215	10	63.46	445	20	34.21	730	40	45.7
0	6.3	118.42	215	13	66.56	445	25	34.49	730	50	36.3
0	8	129.2	215	16	68.37	445	32	32.8	730	63	31.2
0	10	127.66	215	20	71.9	445	40	37.9	730	80	29.8
0	13	136.23	215	25	75.1	445	50	44.3	730	100	29.3
0	16	138.06	215	32	78.2	445	63	48.5	730	130	28.6
0	20	136.03	215	40	110	445	80	63.9	730	160	28
0	25	116.49	215	50	133	445	100	65.1	730	200	29.6
0	32	124	215	63	140	445	130	62.7	730	250	31.8
0	40	125.1	215	80	138	445	160	46.5	730	300	32
0	50	131.1	215	100	129.2	445	200	36.7			
0	63	144.3	215	130	117.6	445	250	39.1			
0	80	150.3	215	160	103.8	625	1.6	41.81			
0	100	152	215	200	92.4	625	2	44.19			
0	130	149	215	250	84.5	625	2.5	47.65			
0	160	126.7	340	1.6	38.91	625	3.2	50.88			
0	200	105.5	340	2	22.91	625	4	57.79			
0	250	100.7	340	2.5	23.08	625	5	61.87			
90	1.6	40.45	340	3.2	23.37	625	6.3	69.86			
90	2	41.49	340	4	25.96	625	8	78.16			
90	2.5	41.34	340	5	27.74	625	10	88.23			
90	3.2	41.27	340	6.3	29.47	625	13	97.6			
90	4	42.91	340	8	36.14	625	16	100.68			
90	5	42.91	340	10	47.31	625	20	109.74			
90	6.3	51.14	340	13	66.07	625	25	113.28			
90	8	66.09	340	16	88.81	625	32	106.9			
90	10	64.15	340	20	97.84	625	40	109.1			
90	13	73.64	340	25	103.02	625	50	104.6			
90	16	87.17	340	32	103.6	625	63	95			
90	20	85.31	340	40	91.3	625	80	85.9			
90	25	83.88	340	50	105.8	625	100	82			
90	32	94.8	340	63	125.6	625	130	59.4			
90	40	106.1	340	80	157.9	625	160	52.1			
90	50	113.3	340	100	187.6	625	200	38.4			
90	63	105.7	340	130	191.6	625	250	30.2			
90	80	109.4	340	160	222.2	730	1.6	45			
90	100	100.7	340	200	233.7	730	2	41.5			
90	130	83.2	340	250	200	730	2.5	41.3			
90	160	86.7	445	1.6	38.91	730	3.2	44.8			
90	200	80.9	445	2	42.39	730	4	50.4			
90	250	72.1	445	2.5	46.52	730	5	56.4			
215	1.6	32.05	445	3.2	48.59	730	6.3	65.5			
215	2	51.28	445	4	43.14	730	8	74.3			
215	2.5	52.45	445	5	43.14	730	10	77.9			

Profile 5 Data

X	Y	Z	X	Y	Z
0	1.6	149.33	225	3.2	70
0	2	167.26	225	4	67.2
0	2.5	182.07	225	5	56.6
0	3.2	204.8	225	6.3	53.9
0	4	226.91	225	8	58.3
0	5	234.21	225	10	60.1
0	6.3	248.6	225	13	65.9
0	8	235.25	225	16	67.5
0	10	250.89	225	20	70.6
0	13	245.47	225	25	76.1
0	16	203.34	225	32	92.4
0	20	166.85	225	40	97.6
0	25	128.26	225	50	104.2
0	32	85.3	225	63	111.6
0	40	66	225	80	124.8
0	50	58.4	225	100	138.6
0	63	47.9	225	130	104.3
0	80	47.5	225	160	91.7
0	100	47.5	225	200	78.9
0	130	50.6	225	250	70.7
0	160	51.5	225	300	69.2
0	200	53.1	310	1.6	67.74
0	250	59.6	310	2	66.28
125	1.6	33.7	310	2.5	66.28
125	2	32.44	310	3.2	79.96
125	2.5	40.23	310	4	85.17
125	3.2	50.26	310	5	78.16
125	4	62.34	310	6.3	88.91
125	5	79.19	310	8	91.84
125	6.3	90.49	310	10	93.8
125	8	93.32	310	13	97.7
125	10	96.53	310	16	95.92
125	13	99.94	310	20	64.81
125	16	96.73	310	25	59.11
125	20	85.53	310	32	59.6
125	25	83.29	310	40	59.7
125	32	86.5	310	50	60.6
125	40	98.4	310	63	64.5
125	50	106.3	310	80	67.4
125	63	131.7	310	100	74.5
125	80	138.1	310	130	77.6
125	100	140	310	160	83.9
125	130	153.5	310	200	113
125	160	179.3	310	250	123
125	200	185.7			
125	250	193.8			
225	1.6	47.4			
225	2	58			
225	2.5	71.2			

Profile 6 Data

X	Y	Z	X	Y	Z
0	1.6	114.61	210	3.2	72.28
0	2	129.24	210	4	80.86
0	2.5	134.01	210	5	85.02
0	3.2	125.49	210	6.3	82.48
0	4	107.78	210	8	82.56
0	5	97.02	210	10	68.91
0	6.3	86.62	210	13	52.86
0	8	79.55	210	16	43.99
0	10	73.51	210	20	37.51
0	13	65.65	210	25	30.97
0	16	57.24	210	32	30.4
0	20	52.23	210	40	31.1
0	25	51.32	210	50	32.6
0	32	51.2	210	63	41.4
0	40	50.9	210	80	50
0	50	52.8	210	100	53.4
0	63	67.6	210	130	54
0	80	92.3	210	160	49
0	100	110.3	210	200	52
0	130	140	210	250	63.2
0	160	160			
0	200	163.4			
0	250	160.2			
75	1.6	51.63			
75	2	46.62			
75	2.5	44.43			
75	3.2	40.26			
75	4	38.44			
75	5	35.29			
75	6.3	34.35			
75	8	33.26			
75	10	33.3			
75	13	39.25			
75	16	47.75			
75	20	51.37			
75	25	63.25			
75	32	65.5			
75	40	67.8			
75	50	70.7			
75	63	61.1			
75	80	51.4			
75	100	52.7			
75	130	79.8			
75	160	82			
75	200	83.2			
75	250	84			
210	1.6	44.6			
210	2	52.3			
210	2.5	64.9			

Profile 7 Data

X	Y	Z	X	Y	Z
0	1.6	44.6	200	2.5	28.25
0	2	52.3	200	3.2	30.01
0	2.5	64.9	200	4	29.54
0	3.2	72.28	200	5	29.66
0	4	80.86	200	6.3	30.72
0	5	85.02	200	8	36.49
0	6.3	82.48	200	10	37.07
0	8	82.56	200	13	46.96
0	10	68.91	200	16	51.55
0	13	52.86	200	20	54.14
0	16	43.99	200	25	61.44
0	20	37.51	200	32	72.5
0	25	30.97	200	40	79.7
0	32	30.4	200	50	86.4
0	40	31.1	200	63	94.7
0	50	32.6	200	80	99.3
0	63	41.4	200	100	99.8
0	80	50	200	130	91.6
0	100	53.4	200	160	80.8
0	130	54	200	200	80.6
0	160	49	200	250	69
0	200	52	310	1.6	57.46
0	250	63.2	310	2	57.3
115	1.6	30.7	310	2.5	62.48
115	2	32.7	310	3.2	62.79
115	2.5	34.1	310	4	63.51
115	3.2	36	310	5	61.04
115	4	38.3	310	6.3	61.2
115	5	40.7	310	8	58.97
115	6.3	41.7	310	10	56.03
115	8	40	310	13	38.12
115	10	40.2	310	16	33.03
115	13	41	310	20	31.44
115	16	41.8	310	25	32.09
115	20	41.3	310	32	30.8
115	25	42.9	310	40	33.9
115	32	41.7	310	50	45.9
115	40	39.3	310	63	55.5
115	50	38.6	310	80	57
115	63	34.2	310	100	60.6
115	80	32.8	310	130	63.8
115	100	34.1	310	160	99.7
115	130	36.1	310	200	120
115	160	36.2	310	250	164.4
115	200	34.2			
115	250	35.1			
115	300	36.2			
200	1.6	34.84			
200	2	30.25			

Profile 8 Data

X	Y	Z	X	Y	Z
0	1.6	37.52	365	4	168.53
0	2	39.91	365	5	162.62
0	2.5	39.67	365	6.3	159.87
0	3.2	41.75	365	8	146.78
0	4	51.07	365	10	138.23
0	5	60.71	365	13	132.81
0	8	67.08	365	16	132.72
0	10	78.47	365	20	118.06
0	13	72.42	365	25	99.56
0	16	68	365	32	79
0	20	60.33	365	40	68.4
0	25	57.6	365	50	57.7
0	32	53.04	365	63	53
0	32	44.4	365	80	53
0	40	37.1	365	100	52.2
0	50	39	365	130	87
0	63	46.7	365	106	102
0	80	53.5	365	200	110
0	100	60.1			
0	130	77.8			
0	160	81.1			
0	200	81.9			
225	1.6	34.84			
225	2	30.25			
225	2.5	28.25			
225	3.2	30.01			
225	4	29.54			
225	5	29.66			
225	6.3	30.72			
225	8	36.49			
225	10	37.07			
225	13	46.96			
225	16	51.55			
225	20	54.14			
225	25	61.44			
225	32	72.5			
225	40	79.7			
225	50	86.4			
225	63	94.7			
225	80	99.3			
225	100	99.8			
225	130	91.6			
225	106	80.8			
225	200	80.6			
225	250	69			
365	1.6	157.51			
365	2	159.18			
365	2.5	156.82			
365	3.2	167.74			

Profile 9 Data

X	Y	Z	X	Y	Z
0	1.6	114.61	250	3.2	41.66
0	2	129.24	250	4	41.87
0	2.5	134.01	250	5	42.95
0	3.2	125.49	250	6.3	42.73
0	4	107.78	250	8	42.73
0	5	97.02	250	10	44.3
0	6.3	86.62	250	13	46.65
0	8	79.55	250	16	50.58
0	10	73.51	250	20	57.31
0	13	65.65	250	25	62.02
0	16	57.24	250	32	59.1
0	20	52.23	250	40	62.7
0	25	51.32	250	50	56.4
0	32	51.2	250	63	60.5
0	40	50.9	250	80	53.5
0	50	52.8	250	100	50.1
0	63	67.6	250	130	47.8
0	80	92.3	250	160	41.1
0	100	110.3	250	200	41.9
0	130	140	350	1.6	13.82
0	160	160	350	2	10.75
0	200	163.4	350	2.5	12.72
0	250	160.2	350	3.2	15.39
75	1.6	174.42	350	4	16.88
75	2	167.11	350	5	19.55
75	2.5	170.47	350	6.3	23.47
75	3.2	165.67	350	8	27
75	4	172.75	350	10	36.58
75	5	182.7	350	13	38.31
75	6.3	184.61	350	16	42.62
75	8	180.42	350	20	46
75	10	174.3	350	25	51.81
75	13	170.23	350	32	53.3
75	16	136.42	350	40	51
75	20	105.13	350	50	50.2
75	25	115.08	350	63	48.4
75	32	118.8	350	80	42.8
75	40	132.8	350	100	44
75	50	141	350	130	65.2
75	63	146.6	350	160	70.9
75	80	151	350	200	83.8
75	100	159.1			
75	130	162.3			
75	160	160.1			
75	200	153.3			
75	250	147.8			
250	1.6	40.3			
250	2	43.18			
250	2.5	43.87			