UNIVERSITY OF NAIROBI

Groundwater investigation using Vertical Electrical Sounding and GIS: A case study of five districts in Mogadishu, Banadir Region, Somalia.

BY

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I56/12746/2018

A DISSERTATION SUBMITTED TO THE DEPARTMENT OF GEOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN GEOLOGY (APPLIED GEOPHYSICS) OF THE UNIVERSITY OF NAIROBI

DEPARTMENT OF EARTH & CLIMATE SCIENCES

December, 2021

DECLARATION

This is to make an official declaration that all the work done in this dissertation is absolutely genuine and original one. No one has ever used this work elsewhere for the degree program of Master of Science in the geology or Applied Geophysics. This is all fresh and investigated content and work on other people has been used as referenced and this has been acknowledged in the end as per requirements of the Nairobi's university.

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DEDICATION

This Dissertation is lovingly sincerity to my dear Parents Mr. Ali Yusuf Nur and Mrs. Lul Muse Mohmoud and my siblings, who have been my constant source of inspiration.

ACKNOWLEDGEMENTS

For the First, my appreciation goes to the Almighty Allah for the gift of life to me, in particular, by enabling me to complete this dissertation.

I wish to express my gratitude to my supervisors; Dr. Z.N. Kuria and Dr. J.K. Mulwa for their continued assistance and guidance, which they have approbated me throughout the research. My sincere thanks go to Professor J.O. Barongo for the guidance he granted to me during my studies in the University of Nairobi. My gratitude also goes to the entire department staff for all the support and encouragement they provided during my studies.

I am grateful to Mr. Mohamed Abdulkadir for the provision of data used for this research.

In this dissertation, I get another opportunity to mention by deepest thanks and gratitude to MPMR (Ministry of Petroleum and Minerals Resources). The ministry offered me an ideal and most precious opportunity to me to continue my studies in University of Nairobi. His Excellency Abdirashid Ahmed, the Minister of MPMR deserves my deepest gratitude for my nominating me for the degree program and to study and complete my dissertation at University of Nairobi. Thanks for all the confidence and Trust you have given me.

I would also like my deepest thanks and gratitude to the Federal Institute for Geosciences and Natural Resources in Germany (BGR) for awarding mea scholarship and financial support to pursue a Master's degree at the University of Nairobi (UoN). In particularly, I would like to thank Mr. Johannez Danz and Mr. Nils Worthberg for the great part they played in the award and administration of this scholarship.

In the end, my special thanks to my class fellows and batch mates for their non-stop cooperation and help during the course of my investigative process.

ABSTRACT

Groundwater occurrence in the open spaces within unconsolidated sediments and rocks is highly influenced by the geological structures of an area. Five different districts are located in Banadir region in the southeast of Somalia which is herein referred to as study area. The study area is dominated by unconsolidated sedimentary deposits covered by red sand dunes. Unconsolidated sediments have high porosity and have made the study area to have high groundwater potential. The main aim of this research was to delineate the subsurface geo-characteristics with a view to determining groundwater condition and their geometric characteristics in the study area. A total of 18 Vertical Electrical Sounding (VES) were used to determine the subsurface structure through 1D inversion approach to interpret the geo-electrical data. VES curves were achieved by using a preliminary quantitative interpretation. The modeling results from IP12WIN program were used to construct a five geo-electric section. From the research discovers, noted that the area of study is confirmed by four to six geoelectric layers to a depth of about 230m.

The first topsoil covers all the study area consists of red sand dune which has resistivity value estimated from (25.5 – 460 Ω.m) and average thickness (0.75 – 3.83 m). The second layer is considered as fluvial sand that has resistivity values ranges from (10.4 - 569 Ω.m) and average thickness (0.72 – 14.9 m) considered as shallow aquifer layer. The third layer considered as a saturated aquifer and consists of fine marine sand has rated low resistivity values from (3 – 1351 Ω.m) and has a thick average thickness (3.88 – 133 m). The fourth layer is limestone has a resistivity value range from (1.54 – 766 Ω.m) considered a fractured layer and has the thickest average thickness from (11– 236 m) which indicates the possibility of groundwater potential is too high. The fifth layer resistivity ranges from (4.78 – 1828 Ω.m) the average thickness is infinity. The low resistivity layer considers as marine sand which is made of saline water.

In this study area: there are two main aquifers, the shallow aquifer and deep aquifer. The analysis and outcome of geophysics indicates that the type of aquifers known as shallow aquifers are occurring within from (15-35m) from the surface, contained in unconsolidated fluvial sands material. Deep aquifers occur at (60 m to 90 m) below the surface contained fractured limestone.

TABLE OF CONTENTS

CHAPTER THREE: ELECTRICAL RESISTIVITY METHOD

3. Electrical Resistivity Method

CHAPTER FOUR: MATERIALS AND METHODS

4. MATERIALS AND METHOD

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5. RESULTS AND DISCUSSIONS

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description	Abbreviation	Description
A	Area	m2	Squared meter
a.m.s.l	Above mean Sea level	m3	Cubic meter
D	Day	N	N North
DEM	Digital Elevation Models	NE	Northeast
E	E East	No.	Number
Eq.	Equation	NW	Northwest
ERT	Electrical Resistivity Tomography	R.M.S	Root Mean Square
ETM+	Enhanced Thematic Mapper plus	S	S South
FAO	Food Agriculture Organization	SE	Southeast
GPS	Global positioning system	SW	Southwest
Km	Kilometer	VES	Vertical Electrical Sounding
Km2	Squared kilometre	W	West
M	Meter	Ω.m	Ohm-meter

CHAPTER ONE: INTRODUCTION

1.1 Background

Groundwater potential is a decisive resource in a rural and urban community in the southeastern part of Somalia. Increasing interest in the past few years in the sources related to ground water has ended up in the more requirements for the geometrical and intensive studies for the system of aquifer. .In the Benadir region located in the Southeastern part of Somalia, In Southern Somalia, there are two main kind of sedimentary basins, the Mesozoic and tertiary ones are known as coastal basins while they develop in North East and South Western direction. The other one comprising of Mesozoic layer makes Luuq Mandera Basin and it moves forward to NNE and SSW direction. The Mogadishu basin is part of the depression along the Indian Ocean coast of Somalia, which extends about 250 Km NE of Mogadishu to 200 Km SW of Mogadishu. Mogadishu city is a fast-growing town and high population growth in Somalia and needs to be supplied with sufficient groundwater to fulfill the demands of the ever increasing population. Despite its importance, water is a scarce resource, yet an essential component for human survival. This groundwater desire has tremendously risen in the last two decades. Previous studies have shown that the water table recorded has no seasonal variation but maintains consistent level throughout the year due to its major recharge sources from Shabelle River (Gibb et al, 1985).

Different types of methods regarding to geology and physics are often applied on the studies conducted about the composition and kind of ground water. The rocks and their chemical as well as physical characteristics are determined in these studies, in the same way fractures and other kind of faults is discussed, the thickness variations are studied along with lithological changes. For the identification of aquifer presence, these studies are considered highly significant and ultimately these studies can lead to establish some main features and limitations of aquifer. The investigations conducted here along with geophysical studies are applied with the help of VES data (Vertical Electrical Sounding) to delineate the groundwater system and to develop a conceptual hydrogeological model. The VES method was chosen because it has better resolution at the shallow depth i.e. the first few meters below the subsurface (Thomas 2002). Loke (2001) suggested that the data sounding electrical, it is often more reliable in the location of aquifers. Hence, the interpretation of Vertical Electrical Sounding data together with other supplementary data such as geology of the study area, hydrogeology, geochemistry, etc. provides good information of the groundwater system of the study area.

1.2 Problem Statement

The continuous expansion of the Mogadishu city and surrounding towns requires adequate water supplies both in terms of quantity and quality. Therefore, appropriate sitting of water wells is needed to identify productive aquifer systems.

Various geological and geophysical surveys have been carried out in Southeastern part of Somalia. However, most of the other former studies focused on the through deep geological structures hosting petroleum resources with little attention in shallow to geological structures. Additionally, previous studies on groundwater (Gibb et al, 1985) used VES and borehole data only. The failure to integrate GIS into groundwater resources assessment, particularly at large surveys, in Somalia resulted into a huge gap in understanding regional aquifer system.

Geophysical investigation s for oil exploration has indicated that there are three main faults; the major Fault runs paral1e1 to the coast, divided the coastal Pliocene-Pleistocene sediments from Oligocene-Miocene sediments; and influences the groundwater movement of regional aquifers. However, an investigation aimed at ascertaining the hydrogeological importance of this fault, or fault system, has not yet been carried out. The second fault which runs approximately north to south and affects the Yasoomman Formation; A third important fault or fault system runs approximately 50 to 100 km parallel to the coast of Central Somalia. The hydrogeological importance of these faults is not well studied (Pozzi et al, 1983; Faillace & Faillace, 1986).

This research utilized the VES method in order to delineate groundwater aquifer system as well as the prevailing geological structures, which as controls for groundwater flow. These geological structures and their contribution to the groundwater occurrence and distribution have been evaluated.

1.3 Scope of the Research

The area of study is bounded by five different districts namely Dayniile, Yaakhshid, Hiliwaa, Kaxshiikhaal, and Dharkiinley around Banadir Region. The research implicated the existing secondary data, its analysis and interpretation. For the identification of 2D and 3D geoelectical structures in the region of Benadir the VES data is often used.

1.4 Aims and Objectives

The aim of this study area is to investigate the subsurface geological characteristics of the lithologies and determining their groundwater condition as well as and their geometric characteristic in the study area.

The Specific objectives are:

1. Delineating the vertical geoelectric variation of the earth's subsurface (2D) and defining aquifer zones.
2. Determining the geometry of the aquifer system (3D) in the study area.
3. Establishing geological controls on groundwater occurrence and distribution.

1.5 Research Questions

I. What are the geological the lithological units in the study area?

II. What are the major geological structures influencing groundwater occurrence and distribution in the study area?

III. Which are aquifer systems in the study i.e. deep or shallow aquifers?

1.6 Justification and Significance of the Research

The objective of this study area is to investigate the geology of the area and determine water-bearing zones and their characteristic, and establishing geometry of groundwater system in the select area.

There are a diverse suite of effective geo-scientific survey techniques that can be used to determine the physical and chemical characteristics of geological units necessary for interpreting their groundwater potential. Various surveys have been carried out in Banadir region and surrounding areas, the previously studied data as evident kept a focus on the earth related structures giving us valuable sources of petroleum and to other shallow geographical structures, a little attention was give. The vertical electrical sounding methods are applied with the help of this investigation for the right delineation of the system of ground water and other earth related structures, in the same way the ground water aquifers and their contributions are estimated as well. Additionally, GIS has been applied to determine regional aquifer systems and sources of recharge to these aquifers. The combination of the VES data and GIS therefore provide a unique opportunity to identify regional aquifer system. The data used was from previous field work, previous work and open data sources in different websites. The results accrue from this study were compared to the previous studies and areas of up scaling or complimenting knowledge noted.

1.7 Expected outcomes

The following is a summary of research outcomes and contribution to knowledge:-

- Drainage system and Contour maps identifying recharge sources.
- The geo-electric structures of the study area defining aquifer system with 2D and 3D images.
- A Piezometric surface map depicting groundwater flow directions
- A final results, discussions, conclusions and recommendation.

1.8. Study Area

1.8.1. Location

The Banadir Region is the area of study which is located in South-East Somalia. It is bounded by the longitudes 35°15´E - 36°20´E and latitudes: 17°20´N -17°55´N, at an elevation of about (520m at mean sea level). As shown in the Figure 1.1.

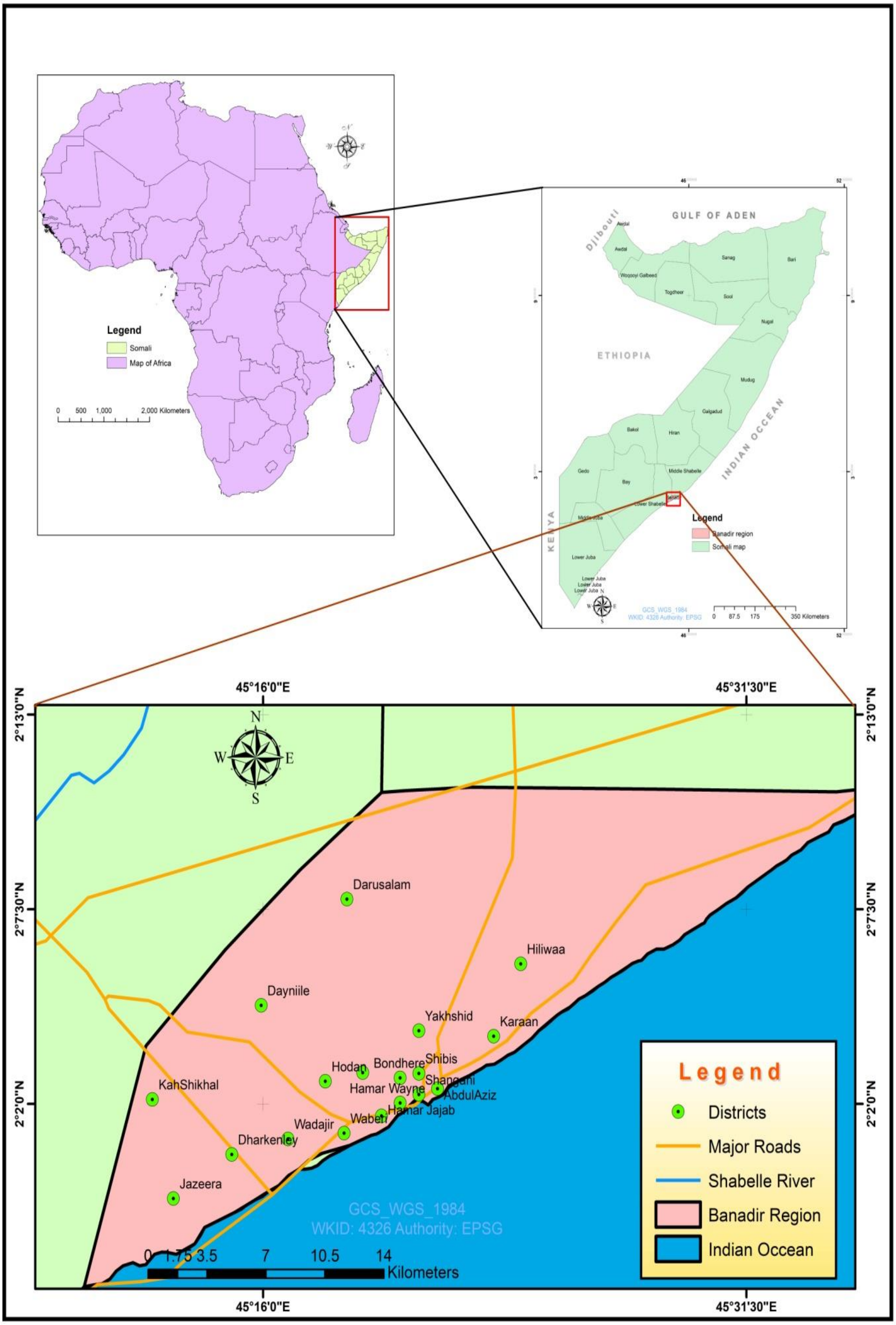

Figure 1.1. Shows the location map and its accesibility of the study area

1.8.2. Physiographic Features

Somalia is considered it's a land of a limited contrast. The study area is vast, and featureless with gently undulating landscape which stretches from the Ethiopian border and sloping gently towards the Indian Ocean (Figure 1.2). Outcropping along the coastal sites, the rocks from the area of investigation to the borders of Kenya represent the sequences such as Pliocene to Pleistocene and these are also called Marka formation according to investigative workers named (Piccoli et al,. 1986). The eolian and biogenic sedimentary processes are supposed to control the patterns of coral build up deposits, eolian stands and paleosols etc. With the fluctuations in the level of sea, these all structures along with various changes in climate and neotectonic movements end up in combine production of the modern coastal line. An ancient dune ridge complex is a notable feature of this area and known as Marka Red Dune. From 6°N extending beyond the Kenyan border it rims the Somalian coast and separates the narrow belt of coastal areas from Shebelle River alluvial plains as mentioned in the year 2000 by Federico and Giovanni.

1.8.3. Climate

The climate of the area is influenced by monsoon winds and can be defined as tropical and semi-arid. The temperatures are high and stable throughout the year. However, Months between March and May are considered to be of high temperatures while months between July and September are considered to be of low temperatures. The Humidity is high; while Mogadishu is estimated about the mean annual rainfall is 430mm. The rainfall is due to the zenith passages of the sun and occurs in two periods from March to late May and from October to early December. The rainfall records are quite high from May to November. The wet month is June; the average precipitation of whole year is 429 mm. The sun shines frequently throughout the year, but especially in the winter, June and July are the least sunny Months because the rains are more frequent.

1.8.4. Drainage system

The surface water of the area of study is drained by Shabelle River which is a 25 Km far away in West Mogadishu City and considered the longest river in Somalia as it flows towards the Indian Ocean. The dendritic drainage system from highlands sloping and merging into the plateaus of Ogaden in Ethiopia which in turn descends to the vast plain in the Coastal plain of Mogadishu Banadir Region as illustrated in figure 1.2.

1.8.5. Land Use and Land Resources

Generally, the Somali terrain consists mainly of highlands, plains and plateaus. The study area is considered plain dipping to the coast (Figure 1.3).In the western part of the study area of the Shabeelle River alluvial plain is largely used for regular cropping, while the alluvial areas away from the immediate vicinity of the Shabeelle River are less cultivated.

1.8.6. Soils

The types of soil found in Somalia are different and these are dependent generally on the climatic conditions and Parental rocks. The sandy soils make up the most prominent parts of Somalia and are in dominance along with the coastal lines and slightly deeper loamy soil containing gypsum and higher quantities of calcium carbonate in the inlands. For the study area, the southern parts are generally linked with Juba and Shabelle rivers and are low laying alluvial plains. The clay is present mainly in the soil of these plains and the main reason behind it is the poor system of drainage and higher salt contents. The flooding and likelihood of flooding are also higher in riverine.

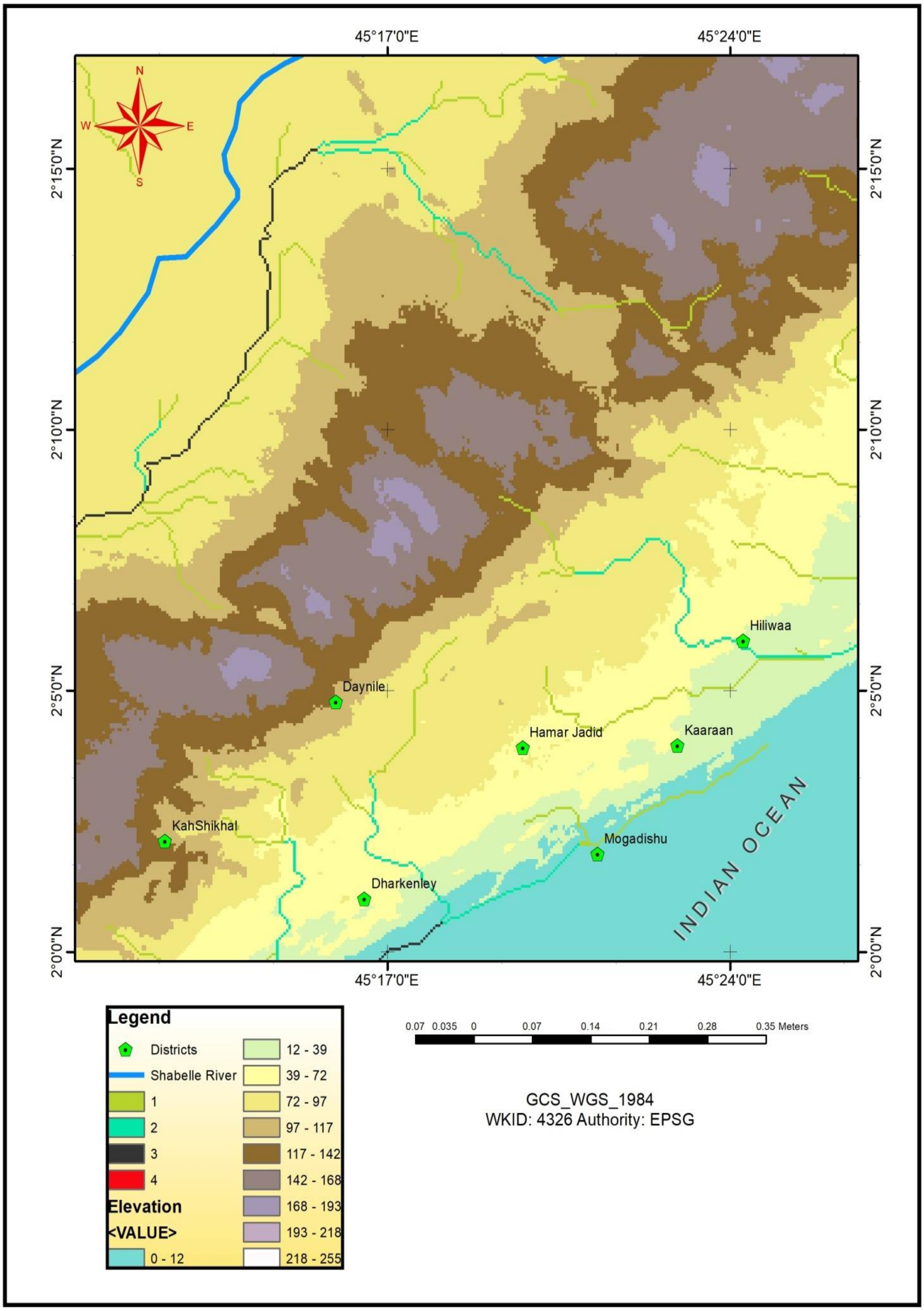

Figure 1.2. Topographic and Drainage System of the study area.

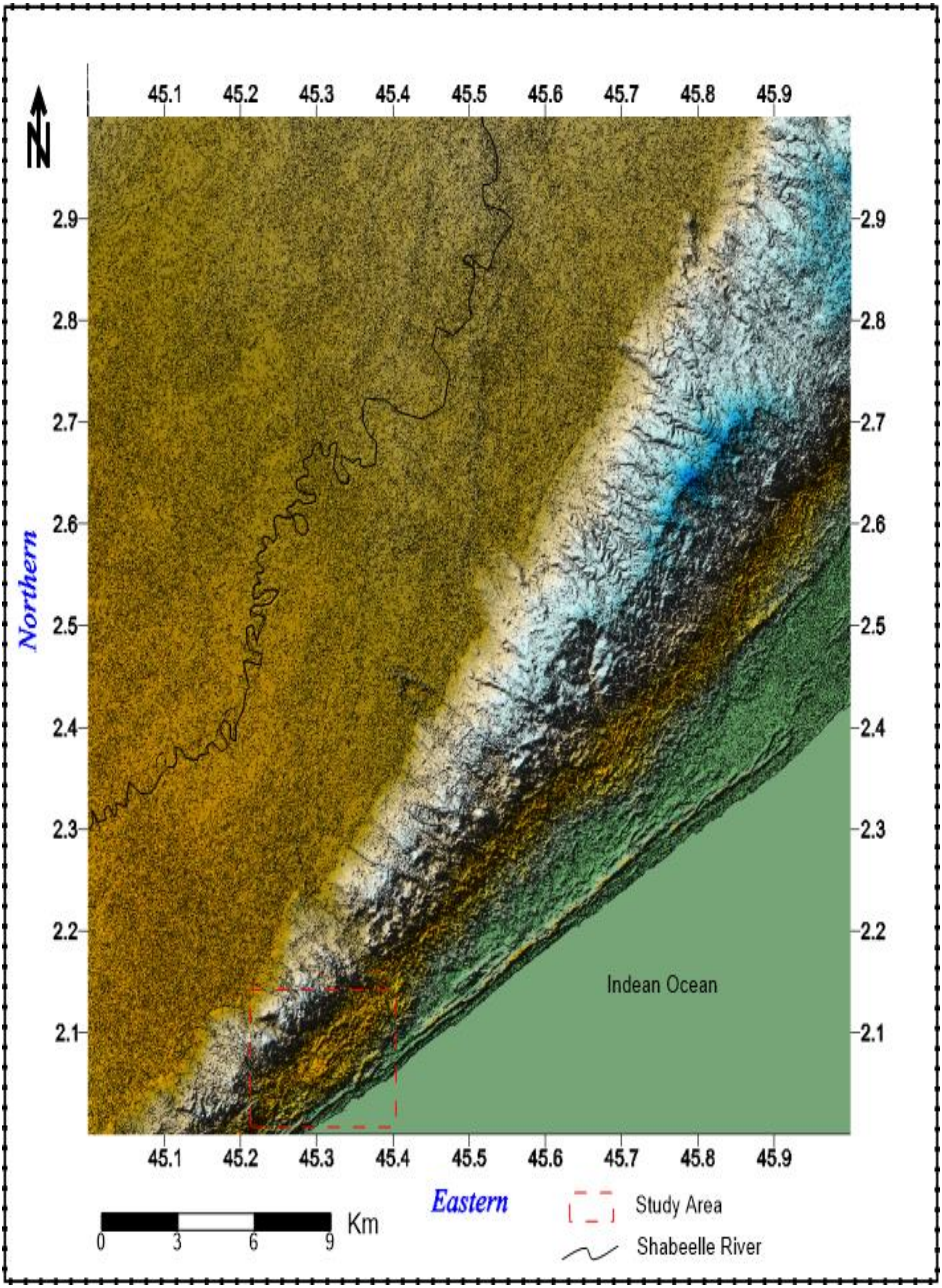

Figure 1.3. Satellite Image of the Study Area and Surroundings

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

During the civil war there was practically no information about the hydrogeology in Study area including central Somalia. Several studies have been carried out in the South central and Southeast of Somalia with a view to determining geological structures and hydrogeological conditions.

2.2 Previous study

The previous studies indicate that first Hydrogeological researches in Somalia were carried out by (Hunt, 1951), (MacFadyden, 1952) and (Wilson, 1958). Groundwater investigation was also carried out in 1963 by the Hydrotechnic Corporation, whose results were included in its "Feasibility report on Mogadishu water supply system". Its groundwater investigation consisted of the survey of the existing water sources, which were fully inventoried, and in the selection of future water wells for township water supply. In the year 1964 Faillace mentioned on the valley of Shabeelle and on the regions of Galgadud and Mudug, (Popov et al, 1973). According to (Pozzi et al, 1983), (Sommavilla et al, 1993), more papers deal with central part of Somalia. In the same way, (Dal Paro et al, 1986) studied the Mogadishu and the surrounding ground waters. (Sommavilla et al, 1993) studied and explained the hydrological system and its ancient features for the buried channels of Paleo. Water resources studies in Mogadishu and surrounding areas begun in the early 1960's, between 1977 and 1979 Sir Alexander Gibb and partners carried out the regional water resources with the institute of Hydrogeology (UK).The water table recorded that there was no seasonal variation but maintains consistent level throughout the year (Gibb et al, 1985), such response from its major recharge sources Shabeelle River.

A Groundwater investigation was carried out in 1963 by the Hydrotechnic Corporation which aimed at improving Mogadishu water supply system of the area for the construction of future water wells for the township water supply. The results of investigation confirmed that a large fresh groundwater body existed in the selected dunal area and that the town could receive sufficient water for its expansion. Detailed studies of the hydrogeological conditions of the major towns in central Somalia were carried out by GKW (Gesellschaft fur klaranlagen und wasserversorgung) from 1979 to 1983; these investigations were funded by the German government in its efforts to develop urban water supplies in Somalia.

A contribution was made by defining the stratigraphic and hydrogeological condition of central Somalia by (Pozzi et al, 1983). Pozzi's report is mainly an effort to interpret the sub-surface geology of the area and it includes information of the stratigraphy of water wells and defines the water quality of the shallow aquifers based on electrical conductivity of hand-dug wells. Lous Berger international Inc. produced several reports since 1983, providing information on water quality and on drilling results in central rangelands.

In the year, 1987, Faillace and Faillace made a remarkable achievement and they also suggested some parts of land with better and reasonable potential for the development of ground water nationwide. The water quality suitability, the use of hydro geological aspects of using water from wells which at that time was available was investigated.

2.3 Regional Geology

2.3.1 Geological settings

The study area is covered by sediment dating from Cretaceous to Quaternary unconsolidated sediments (Figure 2.1), the geology of the Somalia has been described by (Kozerenko, 1972), (Pozzi, et al, 1983) and geologists of University of Florence (1973). (Faillace and Faillace, 1986) described the hydrogeology and water quality which were constructed on the above mentioned works (Basnyat , 2007).

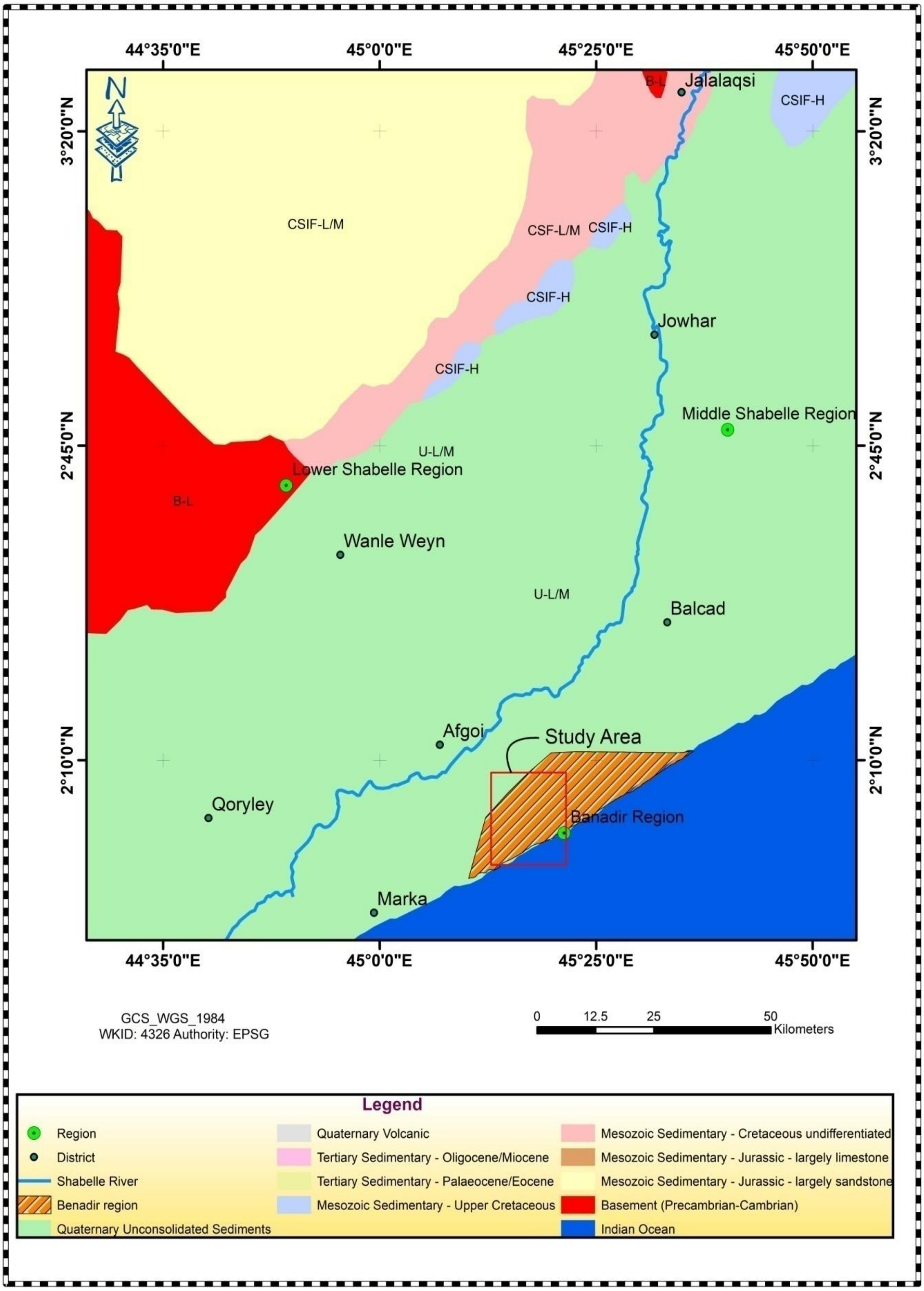

Figure 2.1. Geological Map of the Study area and surrounding (Modified from Abbate 1992)

2.3.2 Stratigraphy

The study area and surrounding area are considered Coastal zone covered by the sand dune and littoral and alluvial deposits of the Shabeelle River. Most of the central part of Somalia with study area is covered by the sediments dating from Cretaceous to Recent deposits (Table 2.1).

Table 2.1: Summarized the Stratigraphic of study area.

NO	LITHOLOGICAL CHARACTERISTICS	AGE
1	Superficial deposits consist of littoral, Alluvial, red sand-dunes and reef limestone.	Quaternary
2	Consists of Limestone, Evaporitic rocks and Thick of sedimentary rock. Auradu Formation Taleex Formation KarKar Formation Undifferentiated sediments	Tertiary
3	Consists of Limestone, Sandstone and Marls. Main Gypsum Formation Mustahil Formation Beled-Weyne Formation Fer Fer Formation Yasooman Formation	Cretaceous

2.3.2.1 Cretaceous Formation

Cretaceous rocks outcrop in the upper part of the Shebelle valley and includes the following formations: Main Gypsum, Mustahil, Fer Fer, Beledweyne, and Yasoomman formation.

2.3.2.2 Tertiary Formation

TheAuradu, Taleex, and Karkar formations.The Auradu and Taleex formationsdonot outcrop in the central part of Somalia according to the map of Kozerenko.The Auradu formation overlies the Yasoomman Formation a1onga narrow strip and in turn is covered by the Taleex Formation.Kozerenko assigned the limestone to the lower member of the Mudug-Marka formation, and the area previously mapped as Taleex Formation to the upper member of the same formation, which is dates as Miocene.

2.3.2.3 Recent sediments (Quaternary)

This generally comprises the superficial cover of sand, beach sand, red sand dunes, sandstone and limestone dating from Pliocene – Pleistocene to recent.

2.3.3 Tectonic Settings

A geophysical investigation for oil exploration has indicated that there are three main faults; the major Fault runs paral1e1 to the coast, divided the coastal Pliocene-Pleistocene sediments from Oligocene-Miocene sediments; and influences the groundwater movement of regional aquifers. However, an investigation aimed at ascertaining the hydrogeological importance of this fault, or fault system, has not yet been carried out. The second fault which runs approximately north to south and affects the Yasoomman Formation; A third important fault or fault system runs approximately 50 to 100 km parallel to the coast of Central Somalia.The hydrogeological point of view of these faults is not well studied (Pozzi et al, 1983; Faillace et al, 1986).

2.3.4 Geological structures

The geological structure in the study are not identified there are no rocks exposed. This is due to the sediments covering the entire surface.

2.3.5 Hydrogeology

The first study indicating the presence of a continuous water table below the alluvial and sand dune formations was conducted by C. Faillace (1964). In Benadir region the water table lies at few meters of depth and is mainly recharged by the Shabelle River, these is the major recharge to the shallow and deep aquifers. Groundwater flows away from North western to the coast or inland. The water table gradient is not symmetric on the two sides of the river and is steeper toward the coastline by Faillace and Faillace (1986).The condition of groundwater is mainly unconfined condition. The digital elevation model and Potentiometric surface shows that the groundwater movement has different flow directions. Groundwater flows away from North western to the coast or inland. The water table gradient is not symmetric on the two sides of the river and is steeper toward the coastline by Faillace and Faillace (1986).The condition of groundwater is mainly unconfined condition. The digital elevation model and Potentiometric surface shows that the groundwater movement has different flow directions.

CHAPTER THREE: THEORETICAL FRAMEWORK

3.1 Electrical resistivity method

The techniques for geo-electrical resistivity are among the most popular techniques and methods are used for the study comprising of geo physical methods and the condition of ground water is studied. There are many factors on which the material's resistivity depends and these factors include the porous structures, presence of salinity, saturation, aquifer and condition of ground water. The EC (abbreviation of electrical conductivity) is the main thing that is related to the resistivity of aquifer. At the time when there is an increase in the electrical conductivity of ground water, the resistivity of aquifer decreases and attains the similar range as the medium of clayey and to determine the aquifer, the parameter of resistivity is no more useful. (Vouillamoz et al., 2002; Lashkaripour and Nakhaei., 2005). For the purpose of proper exploration of the ground water, the method of resistivity has been carried out successfully. To determine the length, depth and nature of an alluvium it is used extensively and also it can be used to determine aquifer boundaries and nature along with aquifer parameters, thickness of the saturation zones, and water quality. The main objectives of this survey are to delineate water-bearing formation, depth to basement rocks and distinguish between different rock types.

3.2 The Current Flow into the Ground from a Single Electrode

Where current is injected into the ground from a point source, it forms equipotential surfaces that are perpendicular to electric field lines as shown in Figure 3.1.

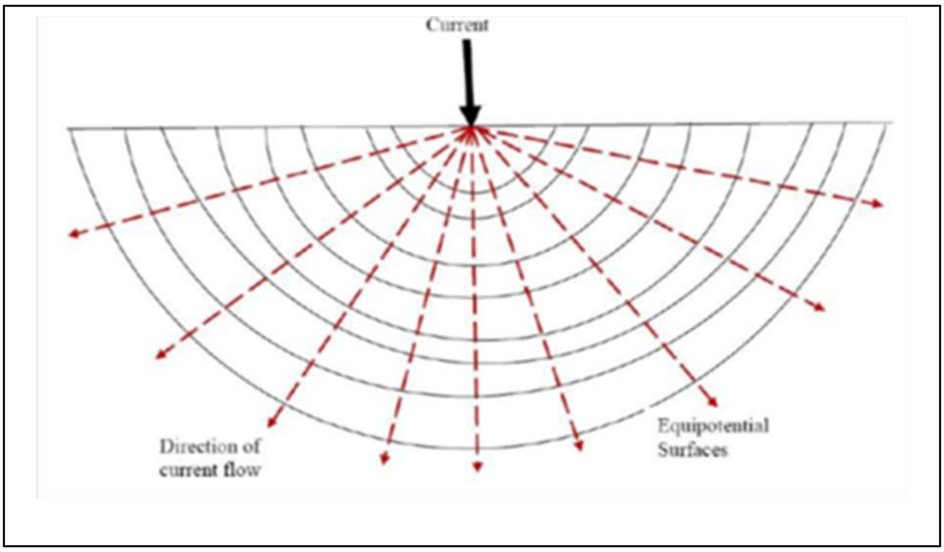

Figure 3.1. Current Flow Distribution (Aizebeokhai, 2010).

3.3 Theoretical Approach

The electrical resistivity measurements techniques are based on the penetration of low frequency electrical current with the help of electrodes into the sub surface of the ground and as a result the ΔV resultant potential is estimated in the ground making use of electrodes. Ohm's law suggests that via homogenous medium, when the current starts to flow, we can mention the resistance R by

$$R = \frac{\Delta V}{I} \quad (3\text{-}1)$$

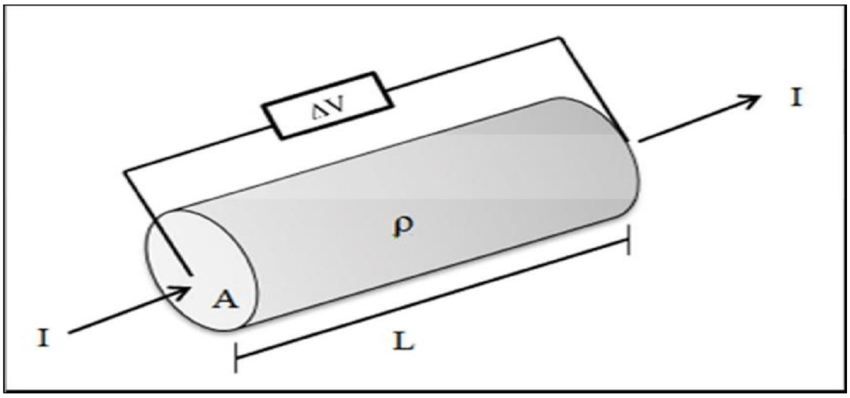

Figure 3.2. Illustrated relationship between the Resistance and Resistivity

The resistance in this case is mentioned as R, the potential difference is represented as ΔV and the current passing is represented as I. The resistance of the Rock is mentioned as R and it is proportional to L (length) of the resistivity substance and inversely proportional to A (area of cross section). The p is the true resistivity of the proportionality constant and it is mentioned in equation 3.3.

$$R\alpha \frac{L}{A} \quad (3\text{-}2)$$

$$R = \frac{\rho L}{A} \quad (3\text{-}3)$$

Equations (3.1) and (3.3) can be combined. This resulting expression can be written as follows;

$$R = \frac{\Delta V}{I}\frac{A}{L} \quad (3\text{-}4)$$

Where ρ is true resistivity (ohm-m).

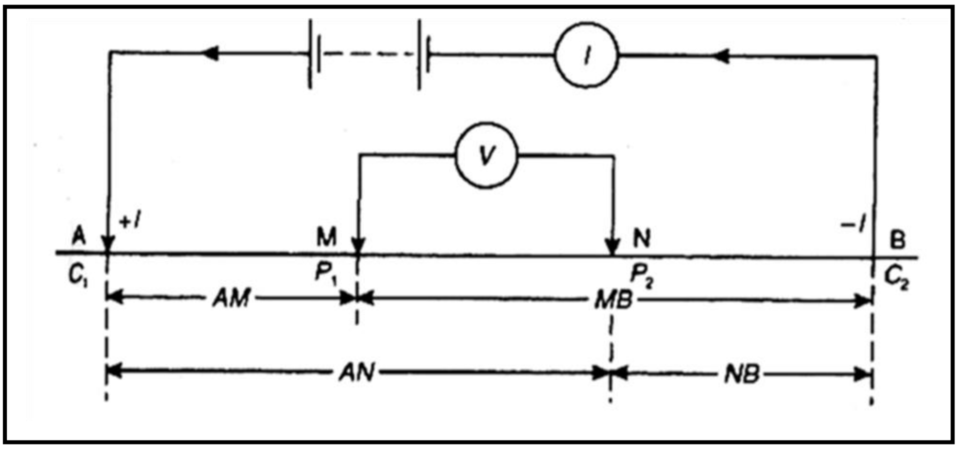

Figure 3.3. Show generalized from electrode configuration.

For given electrode configuration the apparent resistivity can be computed by the following equation;

$$\rho_a = K\frac{\Delta V}{I} \quad (3\text{-}5)$$

Where ρa is apparent resistivity, K is the geometric factor; the ratio (ΔV/I) is resistance in ohms. If the electrodes separation is in meters, the apparent resistivity (ρa) would be in ohm-meter.

From the (Figure 3.3.), TheGeneralized form of electrode configuration he potential $V_M$at the internal electrode M is the sum of potential contributions V_A and V_B from the current source at A and the sink at B.

$$V_M = V_A + V_B$$

At the electrode M and N are

$$V_M = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB}\right] \quad (3\text{-}6)$$

$$V_N = \frac{\rho I}{2\pi}\left[\frac{1}{AN} - \frac{1}{NB}\right] \quad (3\text{-}7)$$

The potential differences are measured

$$\Delta V_{MN} = V_M - V_N = \frac{\rho I}{2\pi}\left[\left(\frac{1}{AM} - \frac{1}{MB}\right) - \left(\frac{1}{AN} - \frac{1}{NB}\right)\right] \quad (3\text{-}8)$$

$$\rho = \frac{2\pi\, \Delta V_{MN}}{I} \frac{1}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-9)}$$

Where the Geometric factor;

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-10)}$$

$$\rho = \frac{\Delta V_{MN}\, K}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-11)}$$

3.3.1 Electrode Configurations

There are several methods by which four electrodes can be arranged resulting in different types of arrays such as Schlumberger, Wenner, dipole-dipole, and pole-dipole. However, we shall discuss only the Schlumberger and Wenner configuration, with their geometric factors Figure (3.3). These arrays are chosen because they are widely used for Groundwater investigations, Engineering and shallow surveys and the interpretation tools are well developed.

3.3.1.1 Schlumberger Array

A symmetrical configuration is used by the array of schlumberger in a condition whereby the electrodes for voltage are represented as M and N and are spaced closely to each other to the central part of an array and the current moves outwards in the electrodes named A and B as mentioned in the Fig. 3.4. The equation 3-12 represents the geometrical factors:

$$K = 2\pi \frac{1}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-12)}$$

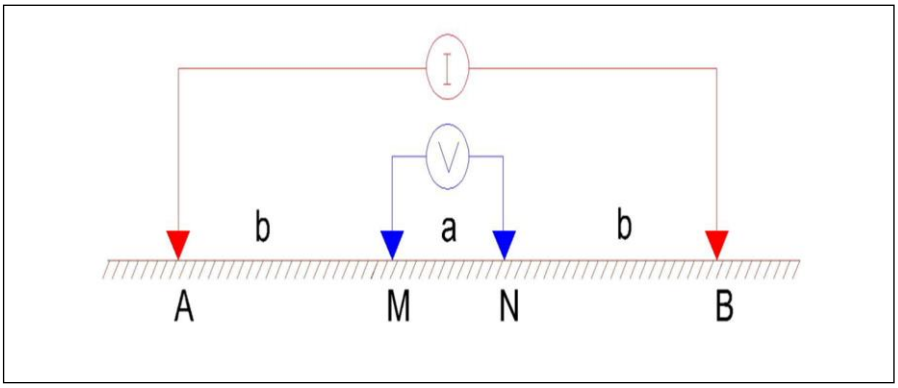

Figure 3.4. Schlumberger configuration.

3.3.1.2 Wenner array

In a Wenner configuration all four electrodes are uniformly spaced in a line. All electrode spacing are equal (AM = MN = NB = a). Figure (3.5) and the geometrical factor (K) are computed from equation (3-13).

$$K = 2\pi.a \qquad \text{(3-13)}$$

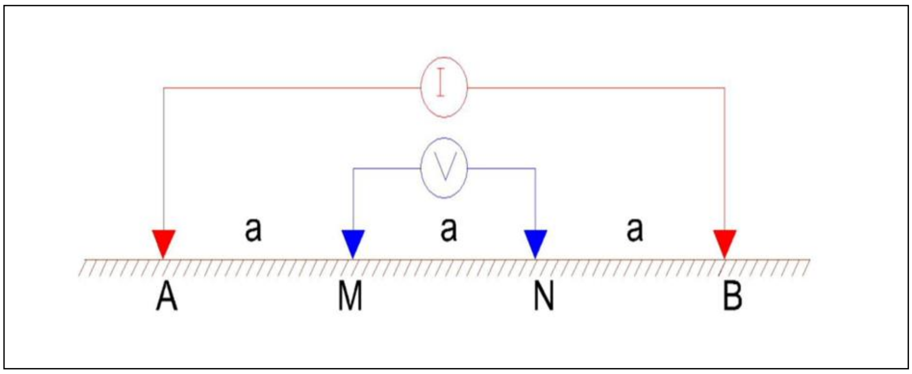

Figure 3.5. Winner configuration.

3.3.2 Data acquisition techniques

There are two main technique procedures are applied in electrical resistivity techniques and these are vertical electrical sounding (VES) and electrical profiling. The VES technique is used to detect the vertical variations in resistivity values while the profiling is used to detect lateral resistivity variations.

3.3.2.1 Vertical Electrical Sounding (VES)

A direct current method for the surveys to be conducted geophysically the method used is known as Vertical electrical sounding method. The methods of direct current are thought to originate from 1920 and it is due to the work of Schlumberger brothers and the way they used the quantitative methods of interpretation. (Koefoed and Mallick, 1979). It is always easier to deploy the vertical electrical sounding methods and these methods are generally simpler. In 2002, Thomas mentioned that higher resolution can be obtained by using the method of vertical electrical resistivity especially for the below surface in the first few meters. This is on the other hand, opposite to the method of TEM (TEM is an abbreviation of Transient Electromagnetic Methods). High signal to noise ratio is obtained by the array of Schlumberger along with the horizontal layers and good resolution, sensitivity and reasonable depth according to Ward in 1990. The current is led into the ground while carrying out the sounding resistivity and this is done by means of two electrodes named as electrode A and electrode B and other two electrodes are used as well and these are mentioned as electrode M and electrode N. In the array's central point, these electrodes are situated. By the flow of current the potential field is generated by the electrodes located at the inner sides. The potential difference and strength of the current are the parameters observed here and this can help to determine the resistivity of ground. When there is a sounding of resistivity, there is a step wise increase in the separation between electrodes and this is known as Schlumberger Array. This ends up in greater depths where the current can penetrate. On a double logarithmic paper, when a graph is plotted with the observed values of resistivity against the depth, we obtain a curve known as curve of resistivity and this curve indicates the depth wise variation of the resistivity. With the help of computerized program, this curve can be accurately interpreted and the layer of actual resistivity is obtained for the subsoil. The geophysics is given plenty of information by the depth and values of resistivity on the layering process geologically.

3.3.2.2 Electrical Profiling

The CST is another name for the constant electrode separation technique and another name of this technique is electrical resistivity profiling. This technique has been launched to find out the resistivity lateral variability. In the end, this methodology can help us to trace the dipping contacts, geological mapping and mapping various soil related faults and fractures. To trace the variations in resistivity, any of the different arrays can be used and for each electrode a constant spacing or separation is adopted. For searching the ores and ore bodies, faults and zones at which faults are located, sand evaluation, deposits of gravels the method of electrical profiling is used. It also helps to determine delineating boundaries and to find out the contacts dipping for all the under observation materials of Earth.

3.4 Interpretation of Field Data and Outcomes:

With the help of simpler curve shapes, the vertical sounding of electricity sounding curves is determined by simple quantitative ways and various programming software.

3.4.1 Qualitative Interpretation

In the interpretation of any sounding curve for resistivity, the first stage is to keep a record of the shape of curve. There is a simple way of classifying the curves and these are classified on the basis of three layered curves for electrify and more complicated curves are also obtained when some additional layers are added. (Reynolds, 1997).

3.4.1.1 Apparent Resistivity Curve Types

The resistivity curves are apparently four in kinds as mentioned in 2007 by Lowrie. He made this observation on the basis of slope shape as mentioned below in Fig 3.5,in this observation he added:

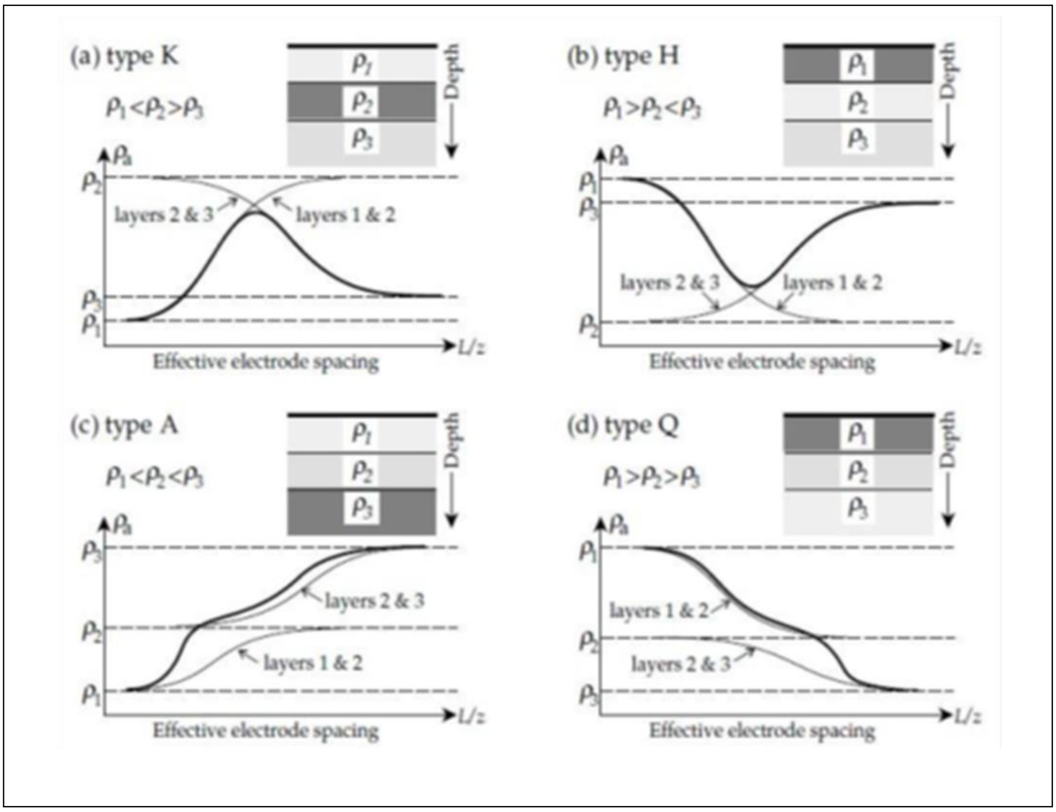

Figure 3.6. For a layered structure, a common curve of resistivity comprising of three horizontally lying strata (Lowrie,2007).

Curve type (K): -a rise is displayed by this curve and when there is a drop in the curve, it indicates higher resistivity layers and between two low layers of resistivity they are found embedded.

Curve type (H): - as compared to the K type curve, this curve is totally opposite since at the time when there is a decline followed by rise this indicates the middle layer is having lower resistivity as compared to the bottom and top layers in the model of three layers.

Curve type (A): - there is a rise in resistivity in this case when the depth increases. The slight slowdown is exhibited by the rising curve and this is due to the depth and the layers encountered with it. With the depth, there is an increase in resistivity.

Curve type (Q): - As compared to A type curve, this is totally opposite curve and the curve is seen to fall sharply with change in gradient moderately and this is an indication of successive changes taking place in the layers as there is an increase in depth.

3.4.2 Quantitative Interpretation

The field data are interpreted quantitatively using computer programs for the semi-automatic and automatic interpretation. This interpretation leads to layered geo-electrical models which in turn are transformed into layered geological models using the available geological information. Inversion of sounding curve data was achieved iteratively using inverse filters (O' Neil 1975). The match between computed resistivity model and field curves was obtained by continuous iteration with a root-mean-square (RMS) of less than 5% in most cases. The low (RMS) error values indicates good fits between field and computed resistivity model curves, however it may not indicate the best geological model.

3.5 Inversion

This is a special process used for the conversion of measurements observed into the property of physical materials. The initial model development takes place in the process of inversion a mentioned in 2007 by Lowrie. For findings connections between the model space and data, the process of inversion is important as mentioned in 2008 by Roy. It has been mentioned in figure 3.6, how the process of inversion takes place with the help of sample flow chart.

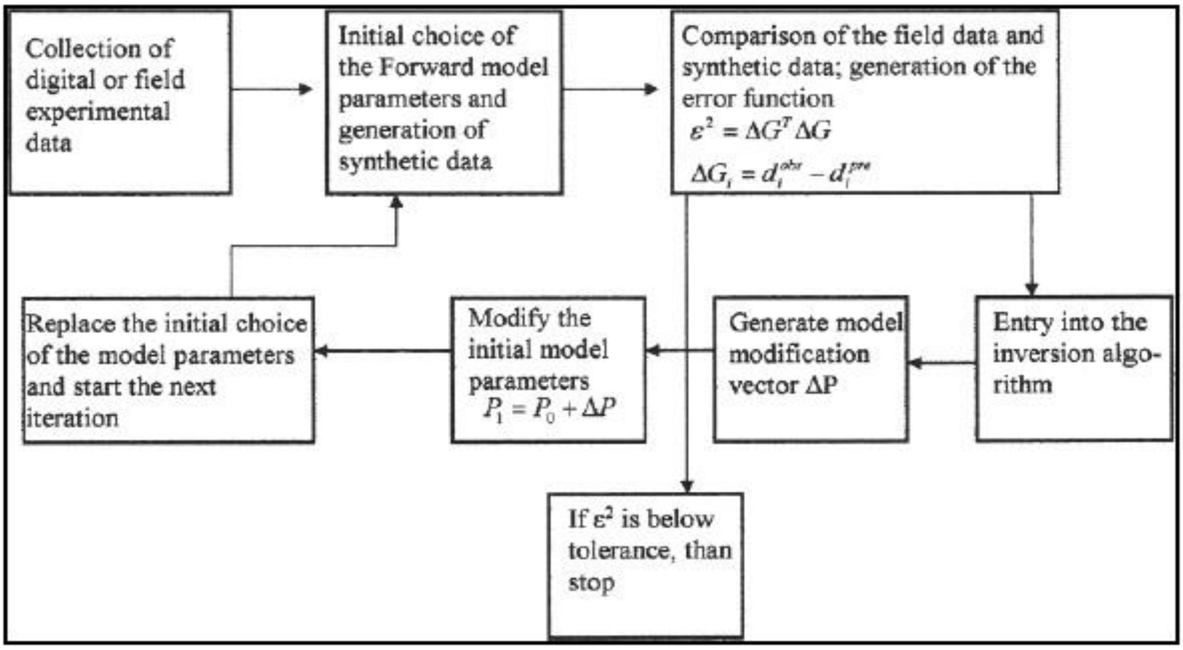

Figure 3.7. An Inverse problem flow chart sample (Roy, Roy,2008)

One of the most common routine used in the most inversion processes is the smoothness constrained method of least squares. On the equation 3-7 this method is based as mentioned in 2013 by Loke.

$$(J^{T}J + \lambda F)\, \Delta q_k = J^{T}g - \lambda F q_k \text{..(3-14)}$$

Where, $F = \alpha_X C_X{}^{T} C_X + \alpha C_y{}^{T} C_y + \alpha C_z{}^{T} C_z$

C_x, C_y= the filter for horizontal roughness

C_z= the filter for vertical roughness

J = partial derivatives' jacobian matrix

J^{T}= J and its transpose

λ = the moisture or damping factor

q = Model perturbation vector

g = Data misfit vector

The Gauss Newton method is used to solve the simultaneous system equations that involve the J and its partial derivatives. The subdivision of the subsurface into smaller blocks makes up the process of inversion and with the help of procedure of optimization and iterations in number the main aim of the process of inversion is to lower the differences existing between each block's calculated and observed resistivity. After the iteration number 5 or 6, there is a consistent RMS and it is expected to yield a true subsurface approximate model. In Jacobian matrix, there is a partial differential equation and is used to solve the matrix by making use of method of finite elements or finite differences.

3.6 Conductivity of Earth Materials and factors determining it:

3.6.1 Porosity

In the material of Earth, the function of amounts of voids is known as Porosity. The material's net percentage is the way it is expressed. A storage or conduits are provided by pore spaces for the flow of ground water and in this way, there is an increase in the pore spaces since more water is allowed to flow through these spaces and sometimes the spaces are held in such a way that at least one moment is given to allow the flow of electric current. There is a higher porosity in sediments and therefore, the porous surfaces are able to hold more water and these porous structures remain connected in most of the cases. There is a lower porosity in the crystalline rocks and there is an inhibition to the flow of current in the rock and hence the resistivity is higher.

The dissolved minerals are present in ground water and these are from wall rocks on the basis of contact duration as mentioned in 2007 by Lowrie. The current is transmitted easily when injected into the earth and a saturated medium is formed and hence the electrical resistivity is reduced.

When the temperature is higher, or we can say greater than 300 degree Celsius or about 500 bars there is an increase in the earth materials' resistivity and this is due to the loss of soil surface porosity. (Hersir and Arnason, 2009 and Ushher et al., 2000).

3.6.2 Water Content

The litho logical characteristics are different for different rocks for example, the characteristics of minerals, the weathering rates etc. There is lower resistivity in wet and moist layers due to uninhibited flow of electrical current. On the other hand, there is higher resistivity for the dry materials and hence they can resist the flow of current.

3.6.3 Temperature

The amount of water contained in the soil or rock material is directly proportional to the rock materials' conductivity and also it is directly proportional to the ions dissolved inside it. (Lowrie, 2007). The dissolving potential of the liquids is determined by temperature such. With the more dissolved ions the conductivity of rocks will increase.

CHAPTER FOUR: MATERIALS AND METHODS

4.1 MATERIALS

4.1.1 Software's

When the secondary information or data is acquired, to process and analyze the information the relevant software are used and also these software help to interpret the data set VES. This software comprise of:

ArcMap: - it is one of the essential parts of the suites such as Esri and ArcGIS for the programs of geospatial processes. To offer the relevant maps this is considered as an open source software which makes use of certain features like, the location map, geological map, contour maps, drainage and surface map, Piezometric maps and topography.

IPI2WIN:- the True resistivity values are generated by this commercial software

Global Mapper 13:- is a Geographic information system developed by Blue Marble Geographic used to convert a set of Digital elevation models into fully gridded data sets that can be used for contour generation.

Surfer13:- is powerful scientific software that is used for data mapping, Modeling, and Analysis features as well as preparing depth and thickness maps.

4.1.2 Hardware

To gather data from different sources, specific hardware were used such as personal Laptop, Scanning machines, Photocopying, and printing machine among others.

4.1.3 Data

This research data utilized from multiple different sources i.e. from open source databases in the internet, companies, and organization as well as previous studies.

4.2 METHODS

Methods that were used to succeed the objectives of this study include the upcoming three phases: Pre-field studies, Fieldwork, and Post-field work.

4.2.1 Pre-field studies

The pre-field stage comprises a literature review, collection of previous data in the literature review of previous reports in the study area such as geological structures, hydrogeology, geophysics, etc., and to get a general idea about the study area. This phase is mainly focus on preliminary aerial photograph interpretation and TM Image Processing to define the geology and structures of the study area.

4.2.2 Data Acquisition

For this study, vertical electrical sounding were carried out. The Schlumberger configuration was used in the collection of VES data. As shown in figure (4.1) about a total 18 VES were achieved for this study. ABEM Terrameter SAS 1000 was used for data acquisition, the geo-electric section comprised of 18 depths sounding into five traverses I, II, III, IV, V. Geo-electric layers were used to determine the subsurface, Aquifer depth and thickness and to detect the fractured structure in the study area.

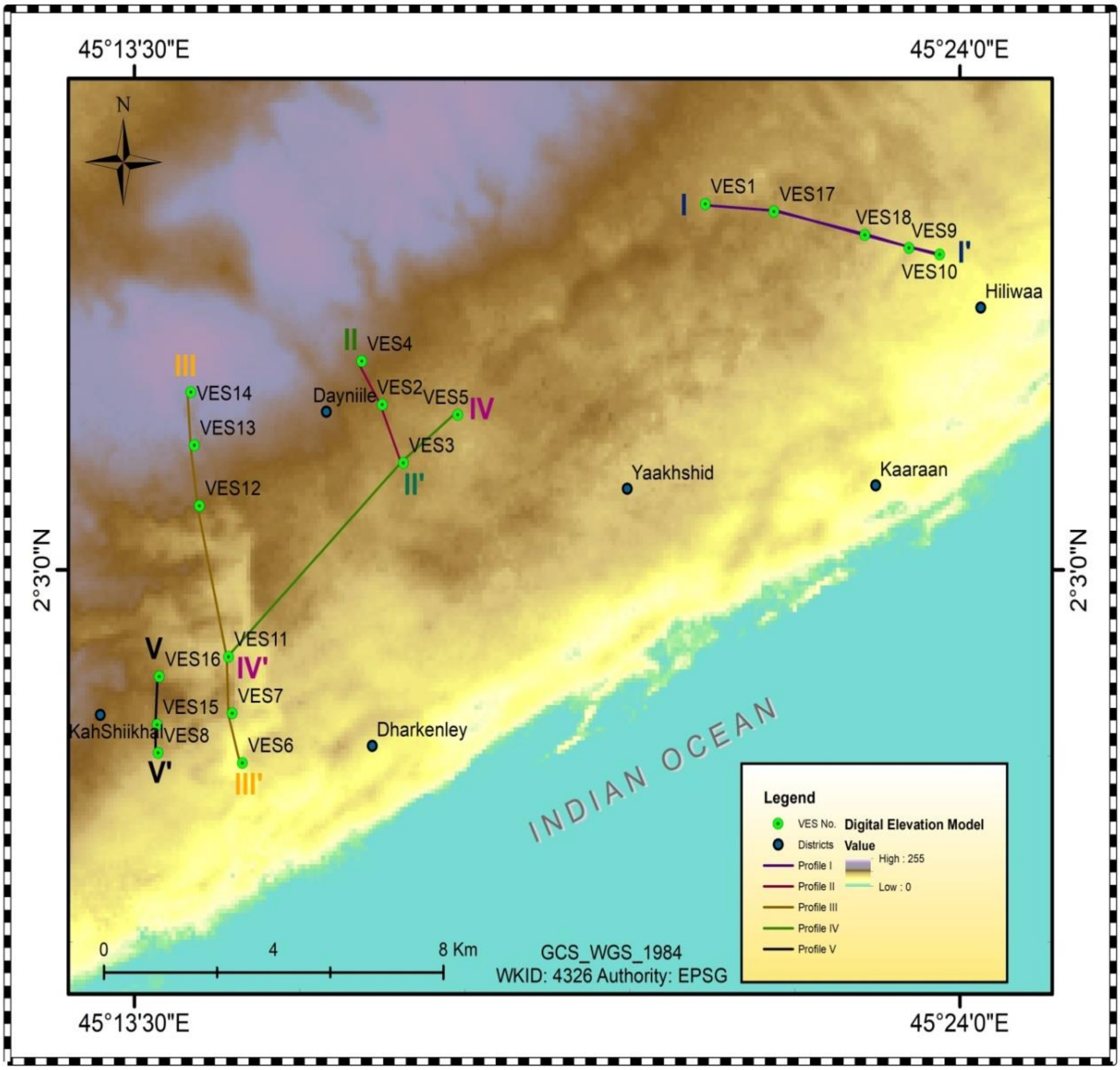

Figure 4.1: Acquisition survey lines with Traverse and Sounding stations.

4.2.3 Data processing and Analysis

The following four steps were done for the analysis and processing data as explained in the following section.

4.2.3.1 Inversion

The computer program is set to put the data from field for the data quality check was performed to determine the outliers, which were cleaned. The quantitative interpretation of VES data was done by creating a 1D model which first estimated electrical conductivity, depth, thickness and number of layers then followed by the model of forward. The inverse process was executed using the estimated parameter and the program calculated resultant parameters value, the program calculated thickness of layers except the last layer which is assumed to have infinite, and calculated electrical resistivity depth of each layers (Figures 4.2, 4.3, 4.4).

The software program is interactive which enables to input data and modify the graphics and sections and that the process is continued until the data become fit the program, the and computation and adjustment of models are continued until a reasonable fit is obtained, in this work, the quantitative interpretation is checked by standardization of VES data with help the previous studies in the study area.

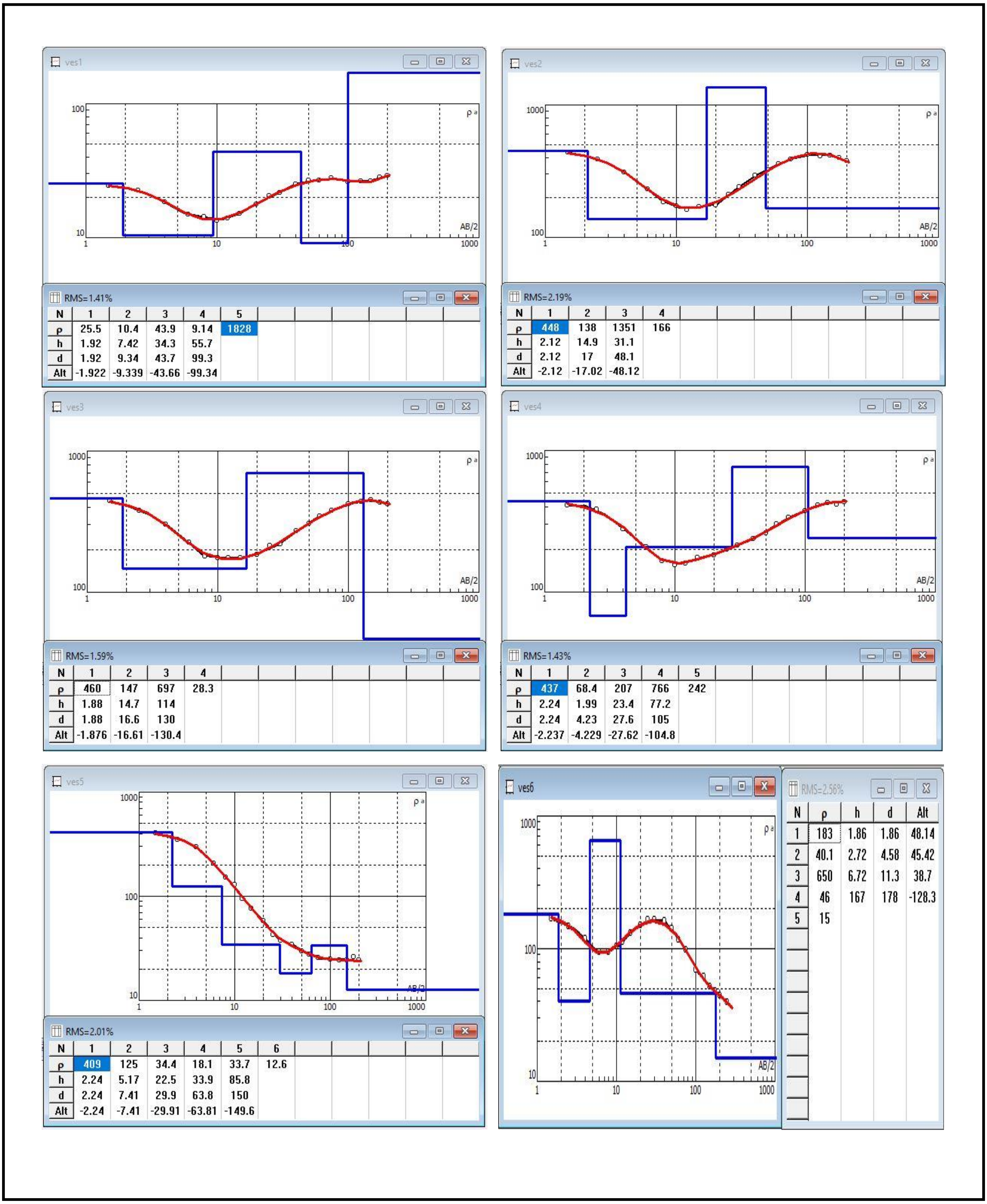

Figure 4.2: An Inverted VES data from VES 1 to VES 6.

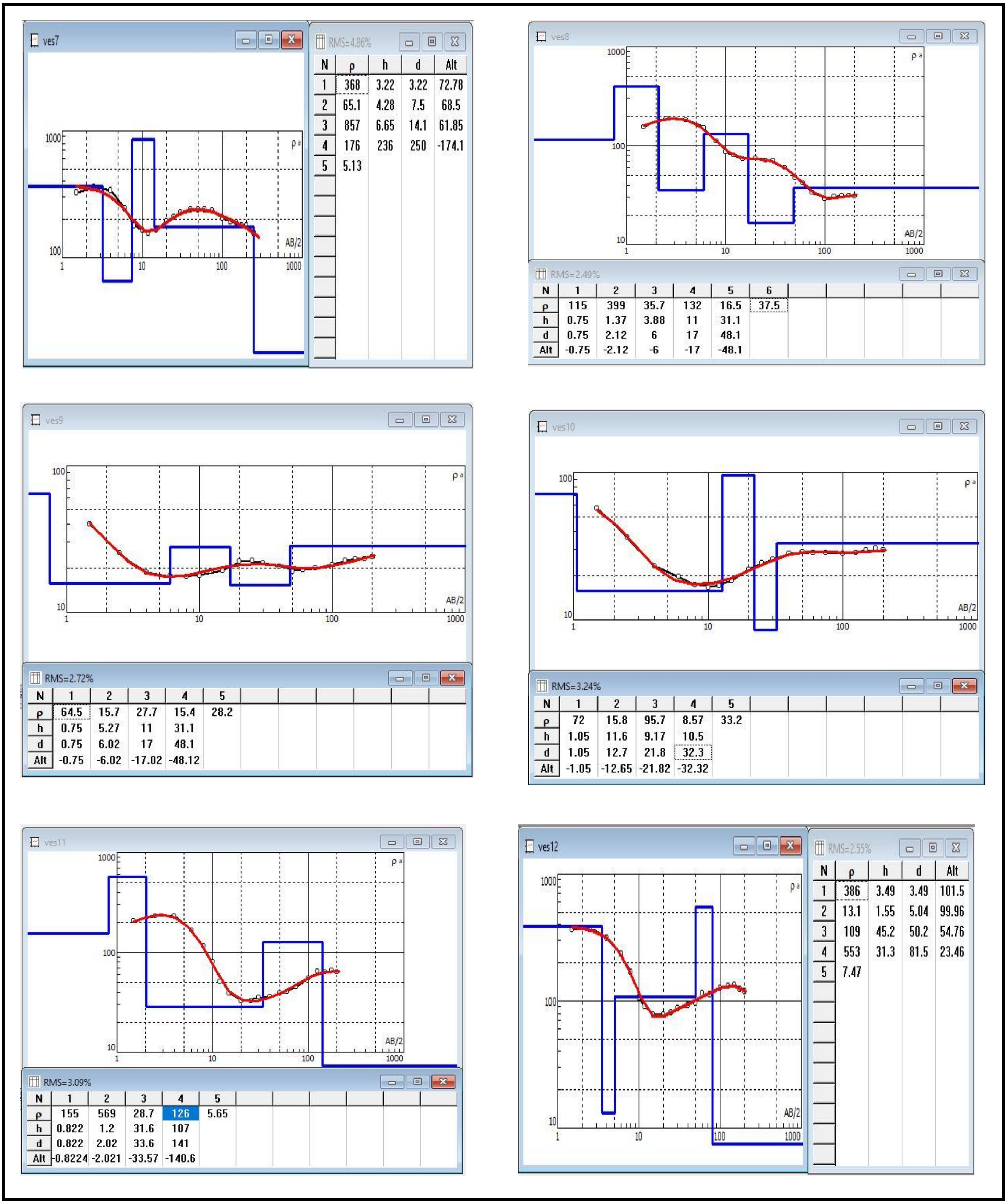

Figure 4.3: An Inverted VES data from VES 7 to VES 12.

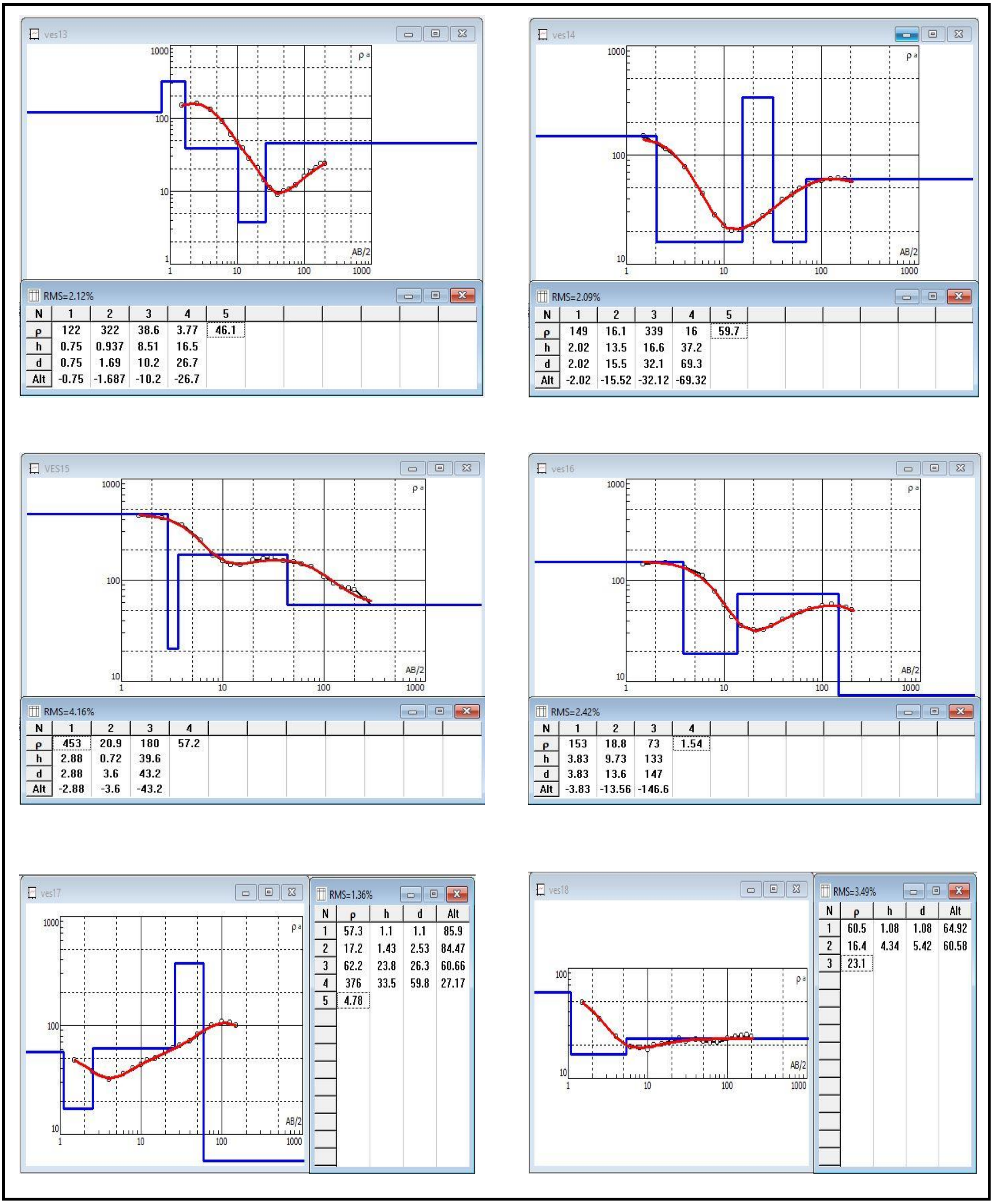

Figure 4.4: An Inverted VES data from VES 13 to VES 18.

4.2.3.2 Relationship between Geology and Resistivity

The contrasts in the resistivity of subsurface materials are generally a function of lithology. Information about resistivity contrasts within subsurface can be related with different materials. Some values of resistivity are given in Table 4.1.

Table 4.1 Resistivity of common geologic and subsurface materials (Source: Reynolds, 1977)

Materials	Normal Resistivity (Ωm)
Granite	$3 \times 10^2 - 10^6$
Syenite	$10^2 - 10^6$
Diorite	$10^4 - 10^5$
Gabbro	$10^3 - 10^6$
Basalt	$10 - 1.3 \times 10^7$
Schist(graphite)	$10 - 10^2$
Slates	$6 \times 10^2 - 4 \times 10^7$
Marble	$10^2 - 2.5 \times 10^8$
Quartzite	$10 - 2 \times 10^8$
Consolidated Shales	$20 - 2 \times 10^3$
Conglomerates	$2 \times 10^3 - 10^4$
Sandstones	$1 - 7.4 \times 10^8$
Limestones	$50 - 10^7$
Dolomite	$3.5 \times 10^2 - 5 \times 10^3$
Marls	3-70
Clays	$1 - 10^2$
Alluvium and sand	$10 - 8 \times 10^2$
Morine	$10 - 5 \times 10^3$
Gravel(Dry)	1400
Gravel(Saturated)	100
Quatenary/Recent sands	50-100
Ash	4
Laterite	8000-1500
Lateritic soil	120-750
Dry sandy soil	80-1050
Sandy clay/Clayey sand	30-215
Sand and gravel	30-225
Unsturated landfill	30-100
Saturated landfill	15-30
Glacier ice(temperate)	$2 \times 10^6 - 1.2 \times 10^8$
Glacier ice(polar)	$5 \times 10^4 - 3 \times 10^5$
Permafrost	$10^3 - >10^4$

From Table 4.1, it can be shown that most materials are characterized by resistivity values that differ by several orders of magnitude. The conductivity mostly affected by porosity, saturation, clay content, salinity, lithology and temperature.

4.2.3.3 2D Geo-electric Sections

For this phase, a 1D model was constructed for use in the IPI2 win+ IP in order to produce a 2D view section. The resulting 2D images were prepared by inserting and using the surfer13 program.

4.2.3.4 Iso-Resistivity Maps

Iso-Resistivity maps were plotted from the true resistivity values on irregular elevation of surface and subsurface with different layer depth delineating about the lateral variation of the study area.

4.2.3.5 D Visualization

In this stage, using 2D Geoelectric sections, 3D geo-electric maps were constructed using by using the Voxler program.

4.2.4 Piezometric Surface Map

By the subtraction of elevation of static level of water from the surface level elevation, the piezometric map for the study area was constructed and the main purpose was to get the water resting level elevation. In reference to the level of sea, the water level adjusted was plotted on the horizontal surface and in this way the piezometric surface map was generated. When the level of piezometric level is higher, it indicates that there is a greater hydraulic head and vice versa. On the other hand, the recharge area is indicated by the higher hydraulic head, while the discharge areas are represented by lower hydraulic heads.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

A total 18 Vertical ES data were analyzed and interpreted based on the selected locations of the study area as illustrated in Figure 5.1.

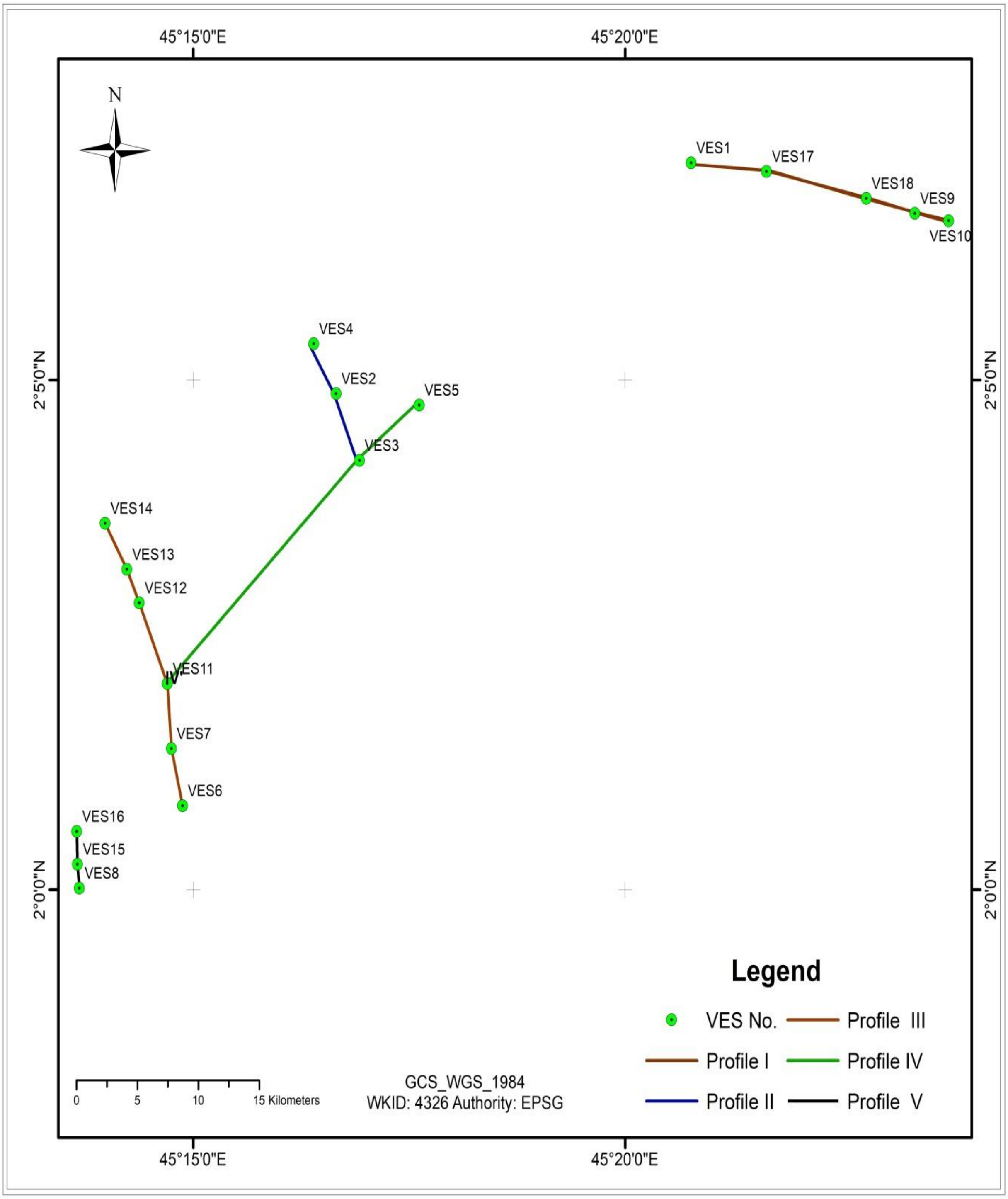

Figure 5.1. VES point locations and Geo-Electric sections applied in this study.

5.2. RESULTS

5.2.1. Procedure of data Presentation

The 2D geoelectric sections were presented from the results of data analysis in the study area, Iso-resistivity at different depth layer maps and 3D images for better information of the subsurface geo-electric structure. 2D geoelectric-sections' images were constructed using IP2WIN, Surfer13 and Global mapper software. Iso-resistivity and Isopach maps were set for the different layers, in order to realize lateral variation changes within the geo-electric layers. 3D images were built by Voxler 3D modeling software. The interpreted layer parameters are listed in (Table 5.1) in the form of resistivity, thicknesses, root mean square and curve type.

Table 5.1. Summary of Interpreted results of all 18 VES survey carried out in different districts.

VES No.	Resistivity's layers (ρ)						Thickness (h)					Curve Type	RMS%
	1	2	3	4	5	6	1	2	3	4	5		
1	25.5	10.4	43.9	9.14	1828	-	1.92	7.42	34.3	55.7	-	HH	1.41
2	448	138	1351	166	-	-	2.12	14.9	31.1	-	-	H	2.19
3	460	147	697	28.3	-	-	1.88	14.7	114	-	-	H	1.59
4	437	68.4	207	766	242	-	2.24	1.99	23.4	77.2	-	HK	1.43
5	409	125	34.4	18.1	33.7	12.6	2.24	5.17	22.5	33.9	85.8	QH	2.01
6	183	40.1	650	46	15	-	1.86	2.72	6.72	167	-	HQ	2.56
7	368	65.1	857	176	5.13	-	3.22	4.28	6.65	236	-	HQ	4.86
8	115	399	35.7	132	16.5	37.5	0.75	1.37	3.88	11	31.1	KK	2.49
9	64.5	15.7	27.7	15.4	28.2	-	0.75	5.27	11	31.1	-	HH	2.72
10	72	15.8	95.7	8.57	33.2	-	1.05	11.6	9.17	10.5	-	HH	3.24
11	155	569	28.7	126	5.65	-	0.822	1.2	31.6	107	-	KK	3
12	386	13.1	109	553	7.47	-	3.49	1.55	45.2	31.3	-	HK	2.55
13	166	32.8	3	131	5.93	-	2.76	9.08	14.7	59.5	-	QK	3.54
14	149	16.1	339	16	59.7	-	2	13.5	16.6	37.2	-	HH	2.09
15	453	20.9	180	57.2		-	2.88	0.72	39.6		-	H	4.19
16	153	18.8	73	1.54	-	-	3.83	9.73	133	-	-	H	2.42
17	57.3	17.2	62	376	4.78	-	1.1	1.43	23.8	33.5	-	HK	1.36
18	60.5	16.4	23.1	-	-	-	1.08	4.34	-	-	-	H	3.49

Note: the values of layers resistivity's (ρ) and its thickness (h) in the table represent the values getting from IPI2WIN program.

5.2.2. 2D Geo-electric sections

Based on quantitative interpretation of the apparent resistivity (Table 5.1) and correlation of resistivity values with lithology (Table 5.2), five Geo-electric sections were constructed (Figure 5.1) were used and described below.

5.2.2.1. Geo-electrical Section I – I'

The geo-electric profile (I-I') is located in Hiliwa district in Banadir Region, It comprises five vertical electrical sounding VES 1, 17, 18, 9, and 10 respectively, in the direction that approximately W-E. These VES results were used to construct a Geo-electric section image along traverse I-I’ as illustrated in Figure 5.2. The section has five layers at all VES points with except VES 18 which have three layers. The first layer is the topsoil which is consists of a red sand dune, this layer it characterized by resistivity values from 25.5 Ω.m to 72 Ω.m and thickness 0.75m to 1.92m. The second layer is the fluvial sand that is wet or moist, and this layer it characterized by low electrical resistivity ranges from 10.4 to 17.2 Ω.m (VES 1, 17) and thickness ranges from 1.43 to 7.42 m. The third layer is characterized by marine sand and has resistivity values from 27.7 to 95.7 Ω.m and a thickness of 9.17 to 34.3 m. It is generally reliable for groundwater accumulation at VES locations (1, 17, 9, 10), and an indication of the aquiferous layer. The Fourth layer is a fractured limestone layer and the resistivity values range from 376 to 1830 Ω.m (VES 1, 17) and the thickness ranges 74 m (VES 1) and unknown (VES 17). The fifth layer is a saturated layer and characterized by marine sand layer has resistivity values from 4 to 34 Ω.m and the thickness ranges to infinity (VES 17, 9, 10). This layer indicates low resistivity values.

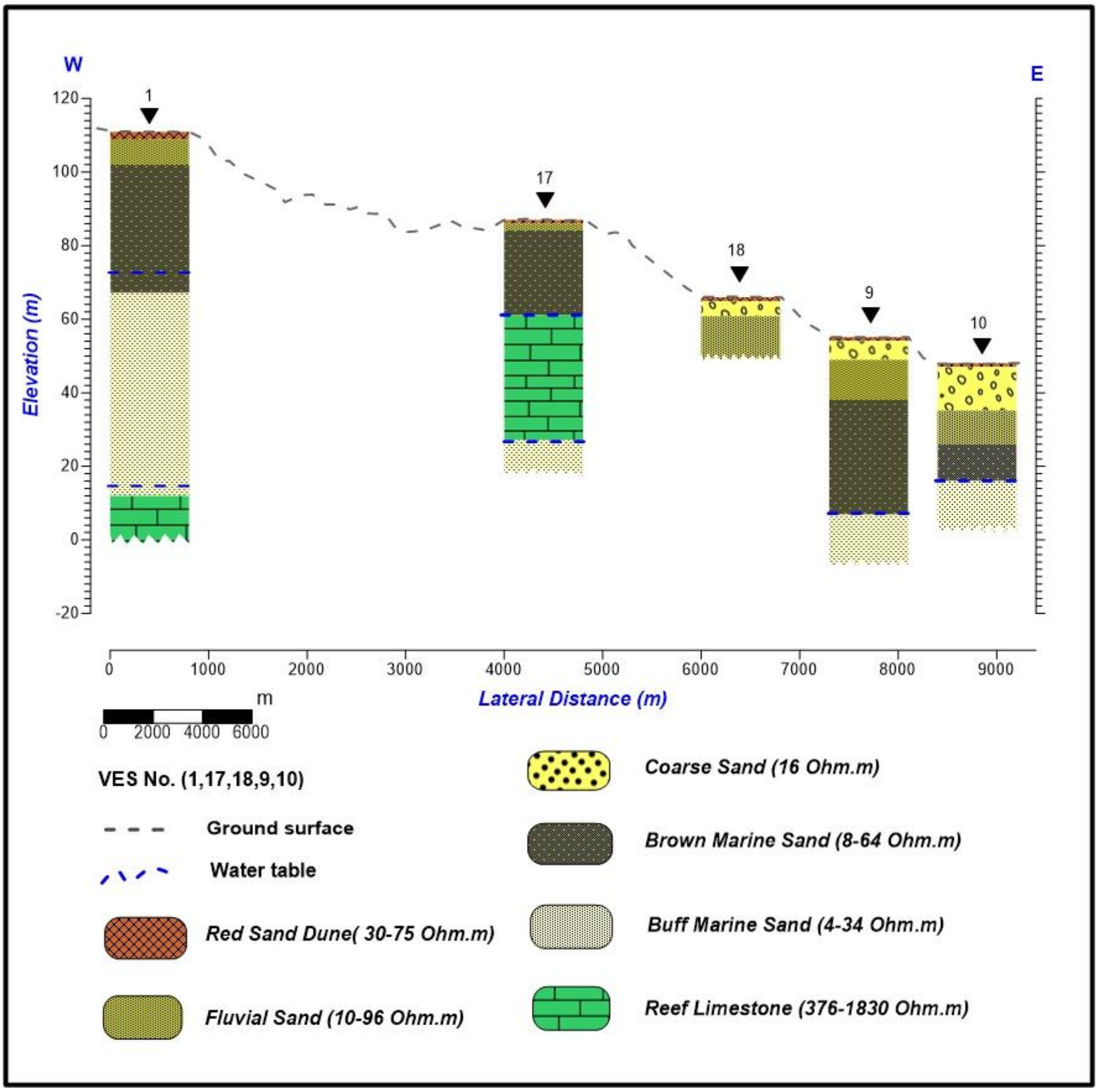

Figure 5.2: Geoelectric section along Traverse (I-I') in W-E direction

5.2.2.2. Geo-electrical Section II – II'

The geo-electric profile (II-II') is located in Dayniile district in Banadir Region, It comprises of three vertical electrical sounding VES 4, 2, and 3 respectively, in the direction that approximately N-S. These VES results were used to construct Geo-electric section image along traverse II-II' as illustrated in Figure 5.3. The section has four to five layers with different thickness and apparent resistivity values. The first layer is the topsoil which is very thin with high apparent resistivity values (437 to 460 Ω.m) mostly dominant by top soil (red sand dune) and fine sand with thickness (1.88 m to 2.24 m). The second layer is the fluvial sand has resistivity values ranging between (68.4 Ω.m to 147 Ω.m) with thickness ranging from 1.99m to 14.9m likely suggesting the layer is porous and reliable for groundwater accumulation for the VES 2 and 3. The third layer is very thick extending from the depth of 48 to 130 m with apparent resistivity values between 697 to 1351 Ω.m, which could be interpreted as mainly composed of reef Limestone at VES's 2 and 3. However, this layer has thicknessranging from 31 to 114 m. The Fourth layer has the low resistivity values ranges from 28 to 170 Ω.m and the thickness value ranges to infinity. This could be interpreted as mainly composed of marine sand.

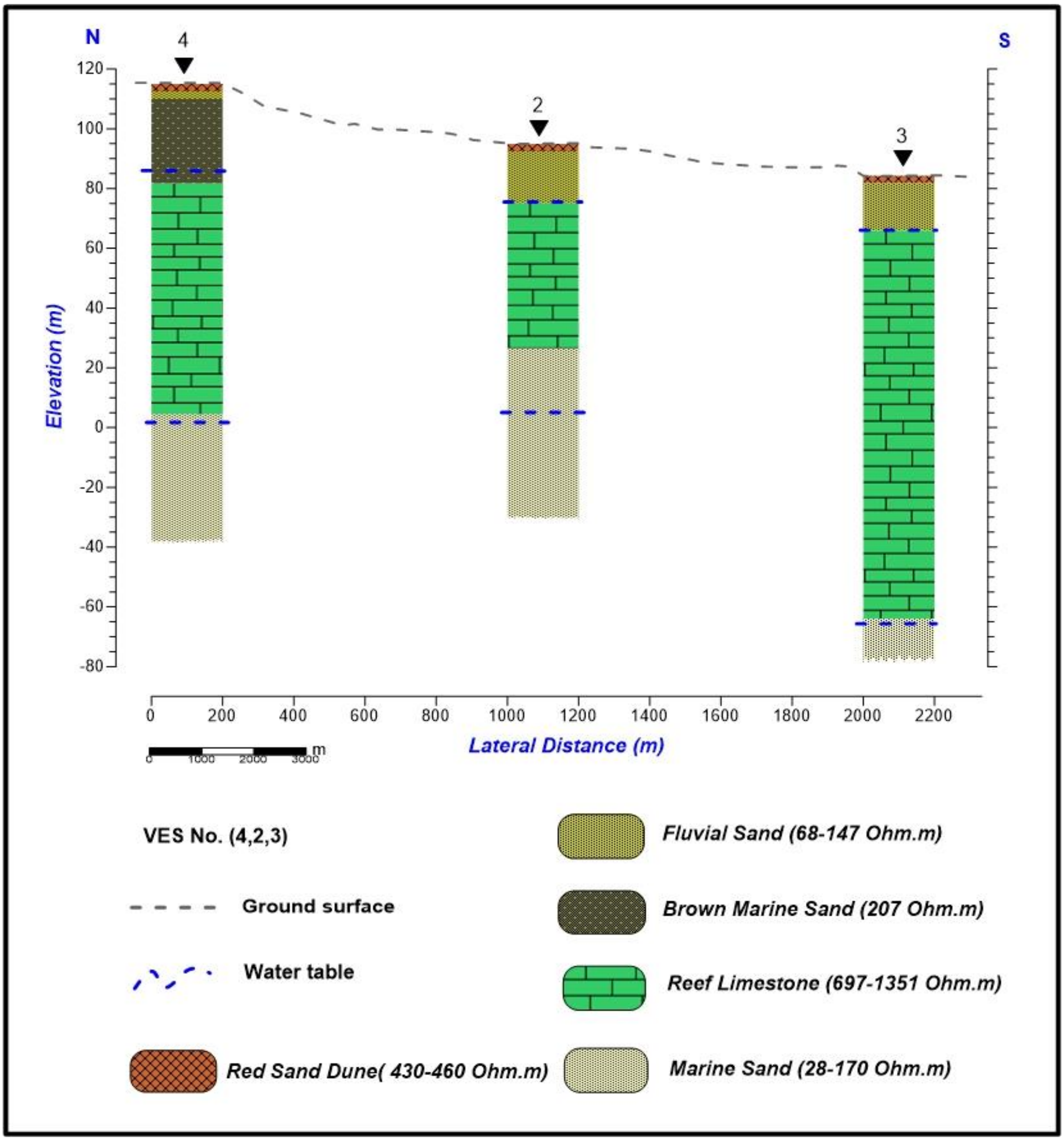

Figure 5.3: Geoelectric section along Traverse (II-II) in N-S direction

5.2.2.3. Geo-electrical Section III – III'

The geo-electric section (III-III') is located in Kax-Shikhaal district in Banadir Region. A total of six vertical electrical sounding VES 14, 13, 12, 11, 7 and 6, data points were used to construct 2D image along traverse III-III' in the direction that approximately N-S as illustrated in Figure 5.4. The section has five layers at the all VES points.

The first layer is the topsoil which is very thin with apparent resistivity values (155 to 460 Ω.m) mostly dominant by top red sand dune and fine sand with thickness (1.5m to 4m).The second layer is the fluvial sand has low resistivity values ranging between (14 to 65 Ω.m) with thickness ranging from 2m to 9 m, and Coarse sand (VES's 11, 7, 6) have thickness ranging between 1.5 to 7 m.The Brown marine sand layer has resistivity values between 95 to 207 Ω.m and a thickness >45m. The limestone layer has resistivity values ranges from 135 to 555 Ω.m and has thick thickness ranges from 16 to 236m. The fifth layer is and Buff marine sand layer is characterized by saturated layer has low resistivity values from 5 to 57 Ω.m and the thickness ranges to infinity.

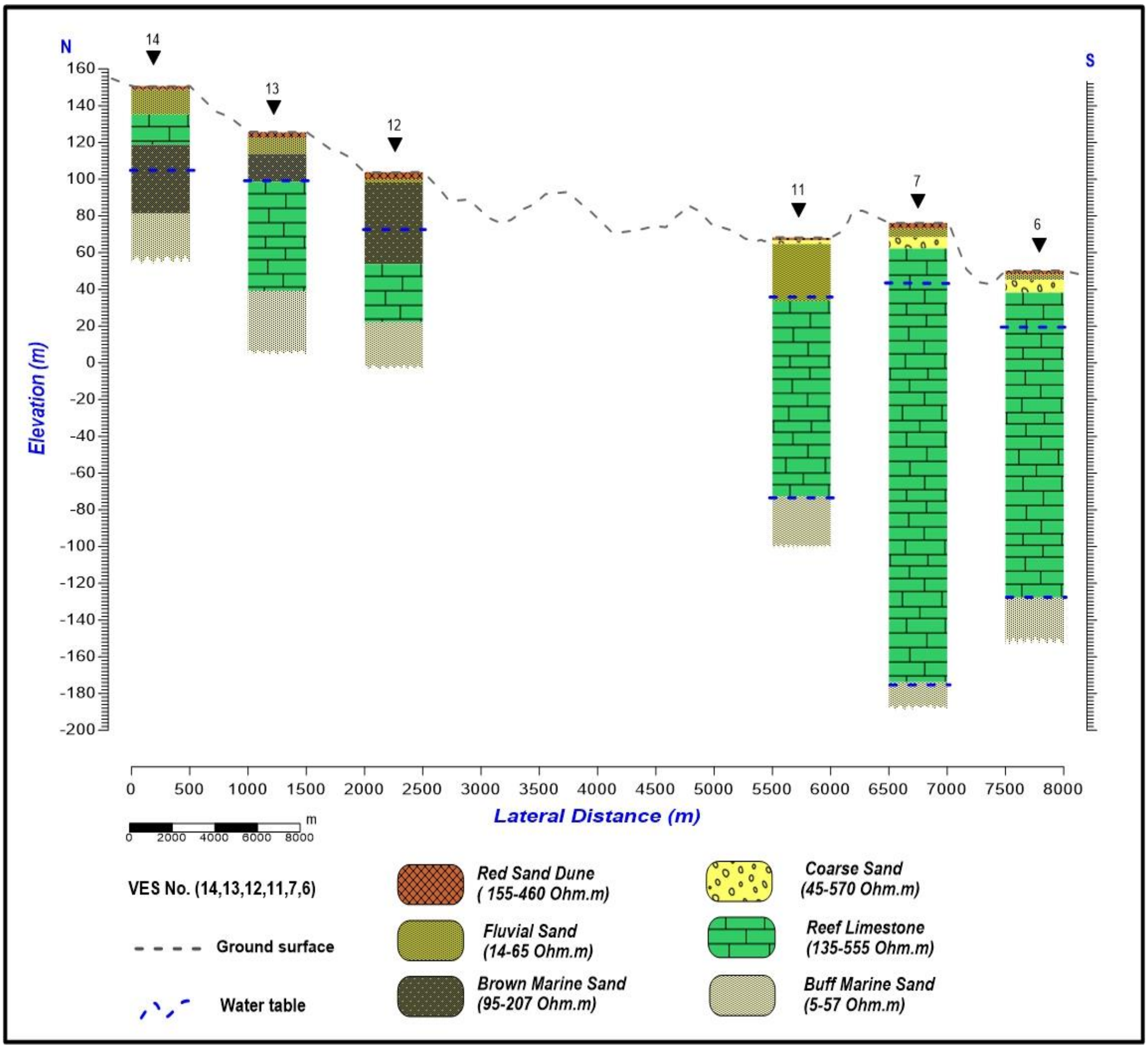

Figure 5.4: Geoelectric section along Traverse (III-III') in N-S direction

5.2.2.4. Geo-electrical Section IV – IV'

The geo-electric section (IV-IV') is located in Dayniile district in Banadir region (VES 5, 3) and in KahShiikhaal district (VES 11) in Benadir Region. A total of three vertical electrical sounding VES 5, 3, and 11, data points were used to set up in 2D image along traverse IV-IV' in the direction that approximately NE-SW as illustrated in Figure 5.5. The section has four to five layers at the VES points 3, 11, and 5.

The first layer is the topsoilwith moderate apparent resistivity values (155 to 460 Ω.m) mostly dominant by top soil (red sand dune) and very thin thickness 1 to 2.5 m.The fluvial sand layer has resistivity values ranging between (28 to 147Ω.m) with thickness ranging from 14 to 32m likely suggesting the layer is porous and reliable for groundwater accumulation.The limestone layer has high resistivity values 697 Ω.m and enormous thickness ranges from >114 m (VES 3, 11). The brown marine sand has very tiny resistivity value 18Ω.m, and thick thickness 34m (VES 5). The fine sand layer which is considered as marine sand has low resistivity values between5 to 28 Ω.m and the thickness ranges to infinity.

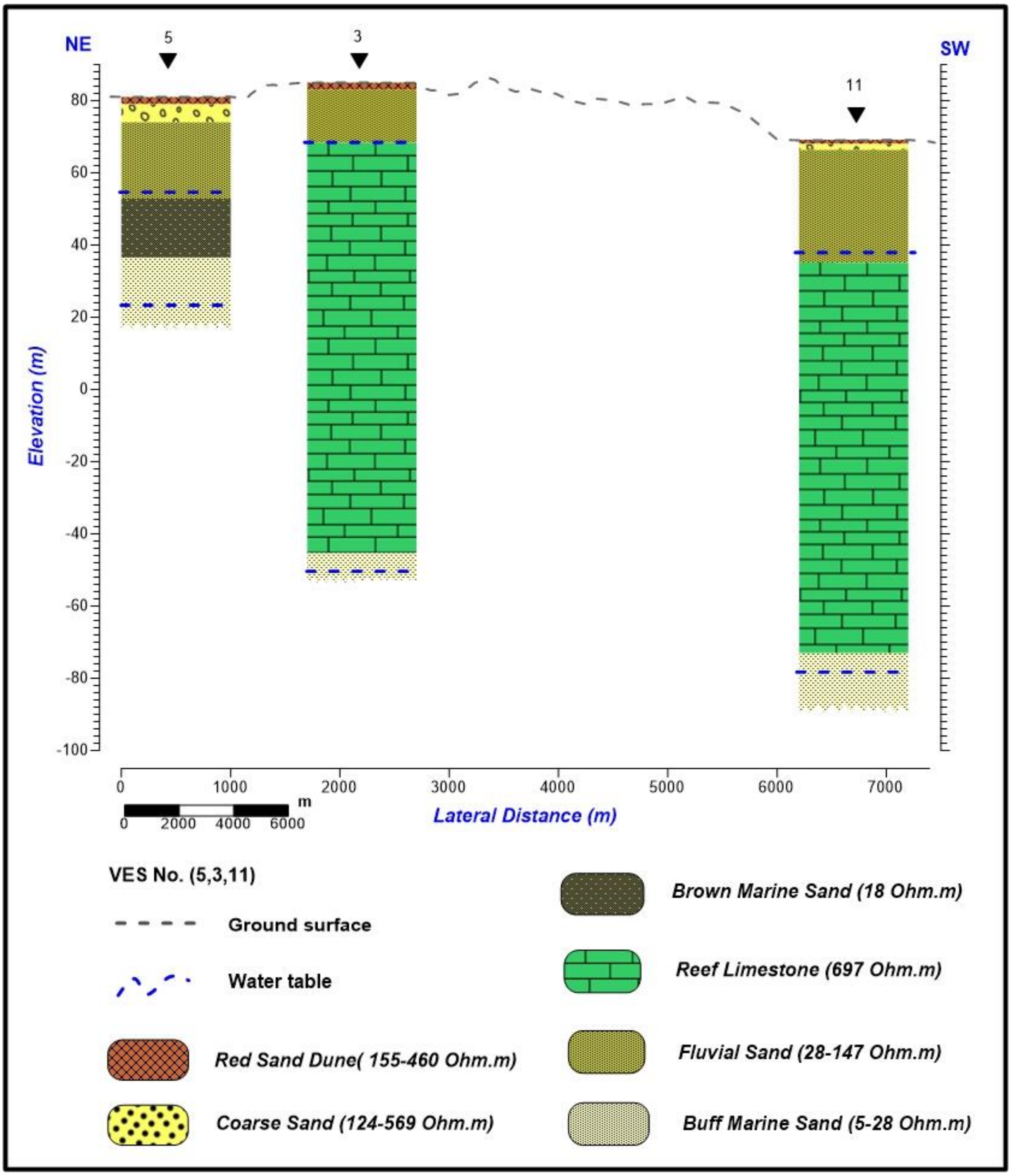

Figure 5.5. Geoelectric section (IV-IV') in NE-SE direction

5.2.2.5. Geoelectrical Section V – V'

The geo-electric section (V-V') is located in Jazeera village in Southeast Banadir Region, It comprises of three vertical electrical sounding VES 16, 15, and 8 respectively, in the direction that approximately NE-SE. The geo-electric section were used to set up 2D image along profile V-V' as shown in Figure 5.6. The section has four to six layers. `

The first layer is the topsoil which consist of red sand dune, this layer it characterized by medium resistivity values ranging from 115 to 454 Ω.m and thickness 1 to 4m. The fluvial sand layer it’s characterized by low resistivity values extent to between 18 to 36 Ω.m and thickness extend from 1m to 10mThe Coarse sand layer is a second layer for the VES point (8) has a resistivity values 399 Ω.m and thickness 1.5 m. The Brown marine sand layer has low resistivity values ranges from 73to 132 Ω.m and a thickness of 11 to133 m. It is generally reliable for groundwater accumulation in the VES’s (16, 15). The limestone layer has a resistivity 697 Ω.m and the thickness 31 m. The last fine marine sandy considered has low resistivity values ranging between 5 to 28 Ω.m (VES 16,15,8) and the thickness ranges to infinity. This layer indicates low resistivity values and possibility of groundwater potential is high, it consider as being deep groundwater.

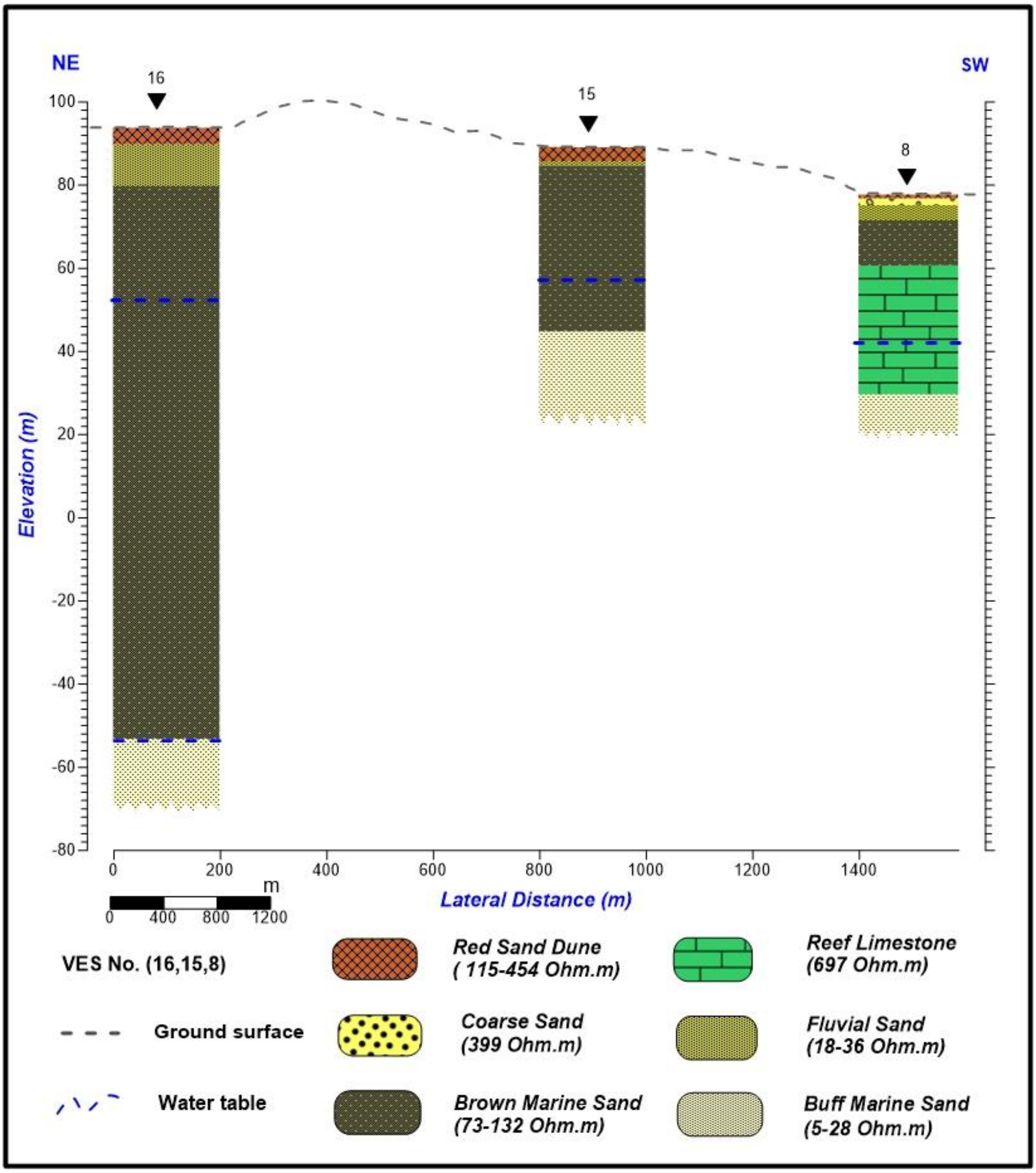

Figure 5.6. Geoelectric section along Traverse (V-V') in NE-SE direction

5.2.3. Geo-electric structure beneath the study area

Geo-electric structure under study area is presented to as many maps to understand the structure and groundwater potential. This was done using iso-resistivity and thickness maps,iso-apparent resistivity contour maps, aquifer resistivity map, aquifer thickness maps and 3D image.

5.2.3.1. Iso-resistivity contour maps at different depth layers

The interpreted VES's result, The Iso- contour maps are set by the five geoelectrical layers. The first layer (Figure5.7) resistivity extends from 25.5 Ω.m to 460 Ω.m. The low resistivity less than 25Ω.m occur in the parts of NE of the study area. The high resistivity more than 400 Ω.m are occurring in southern and central part of the study area. The resistivity range from 100 to 310 Ω.m which occurs in most part of the study area may be due to the red sand formation. The second layer (Figure 5.8) resistivity value range between 10Ω.m to 570 Ω.m,the high resistivity (>480Ω.m) eoccurs in Kax-Shikhal district in the eastern part of the study area (VES 11), the low resistivity (<180Ω.m) which exists in most parts of the study area may be due to fluvial sand with fresh water. The third layer (Figure 5.9) resistivity ranges from 3Ω.m to 1350 Ω.m. The low resistivity (less than 300Ω.m) mostly exists in the study area may be due to sand formation. This low resistivity indicates there is possibility of potential groundwater is existing.The moderate resistivity value range from700Ω.m to 900Ω.m (VES 3 and 6) occur towards southern and central side of the study area which is occupied by medium to coarse sand. The high resistivity (more than 900 Ω.m) exists of the map (VES 2 and 7), this high value of resistivity considered as limestone formation due to interpretation. The fourth layer (Figure 5.10) mostly dominant by low to moderate resistivity value, the high resistivity value (more than 600Ω.m) is occurring towards northern side of map (VES 4). While the low and moderate resistivity values occurs all sides around the map in the area. The fifth layer (Figure 5.11) resistivity ranges (less than 250 Ω.m) exists all around the sides of the map in the study area with except the (VES 1) which has highest resistivity value more than 1400 Ω.m. The low to moderate resistivity value in this layer of the study area shows possibility of good ground water potential.

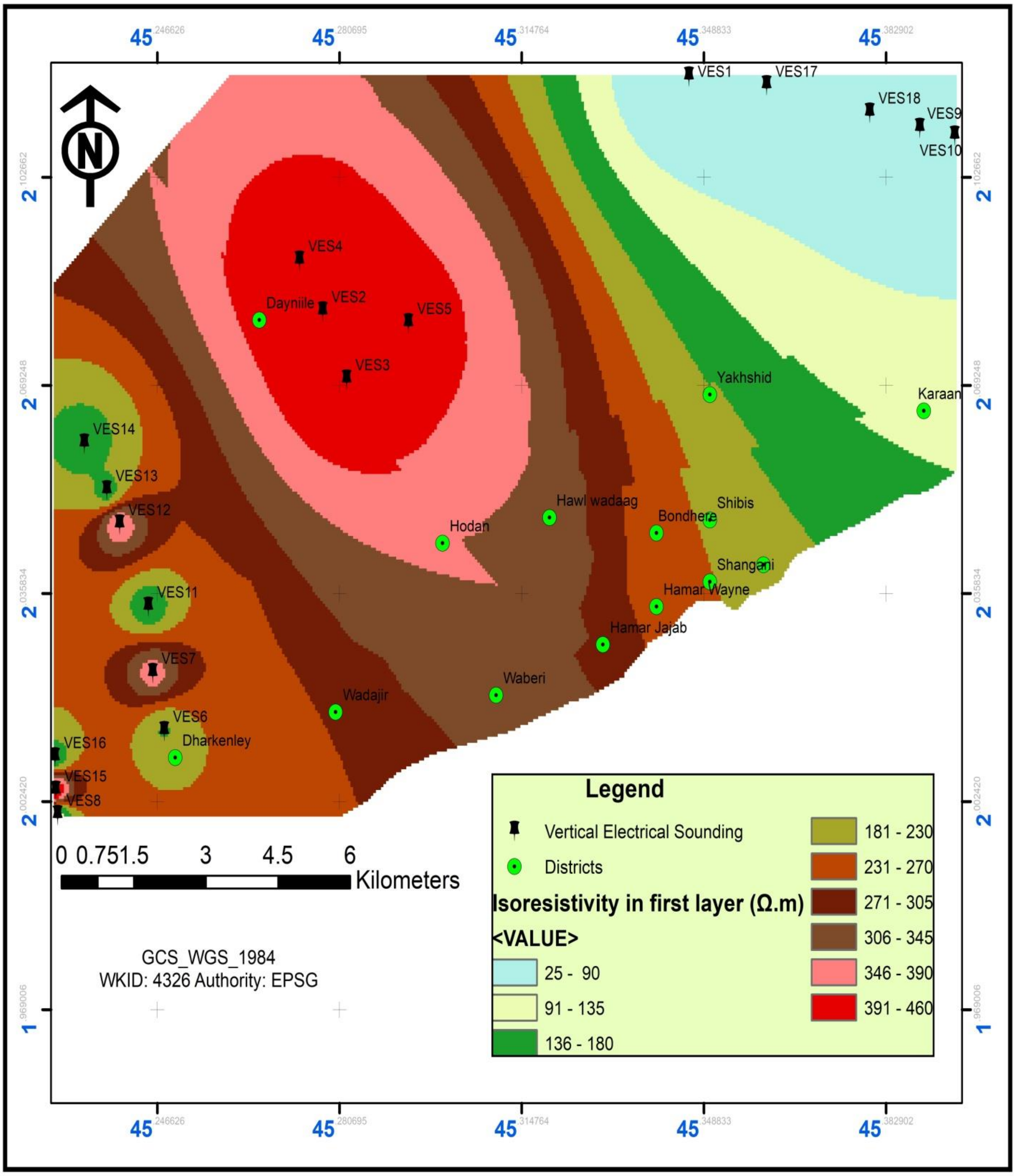

Figure 5.7. First layer Isoresistivity Map

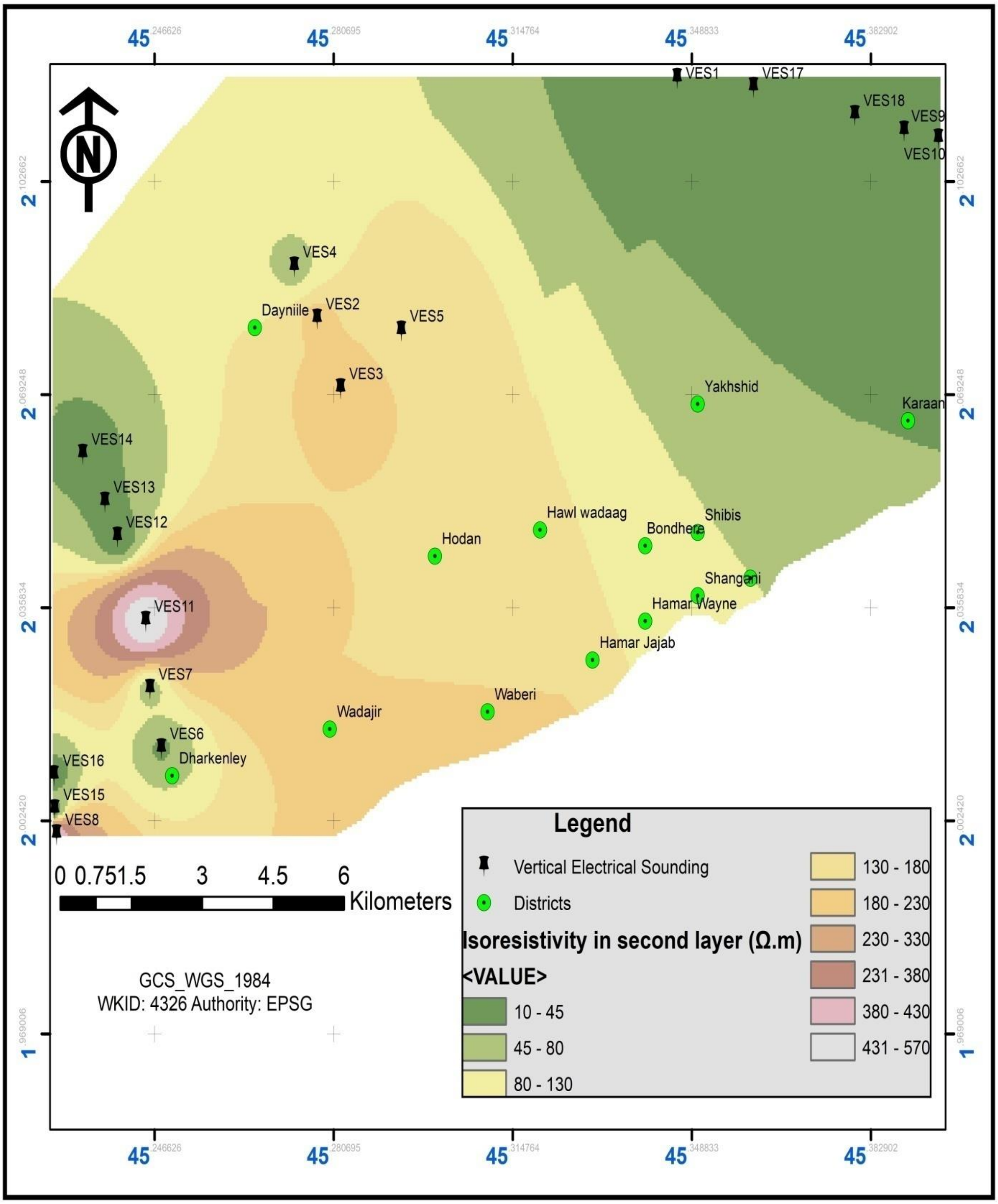

Figure 5.8. Second layer Isoresistivity Map

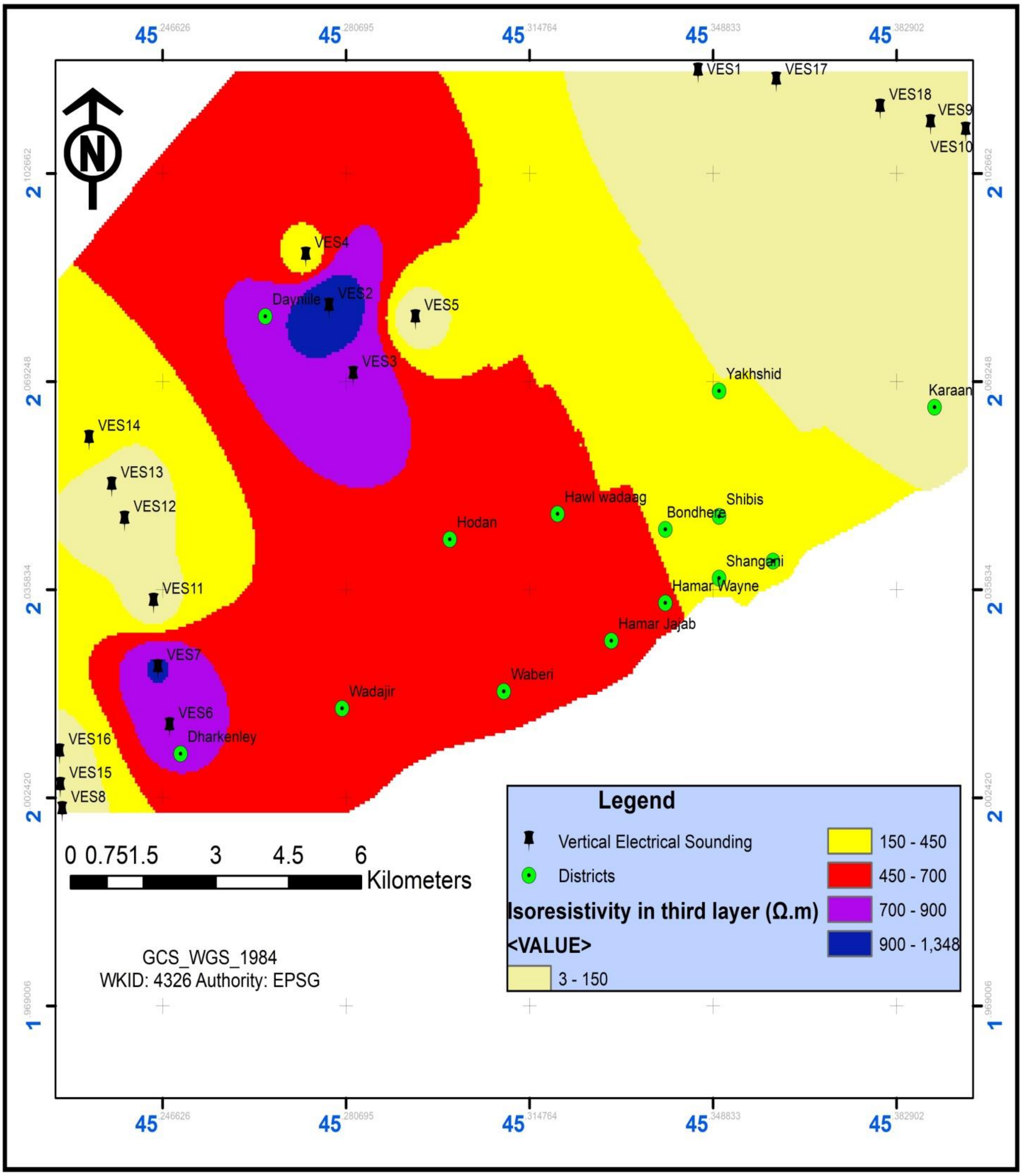

Figure 5.9. Third layer Isoresistivity Map

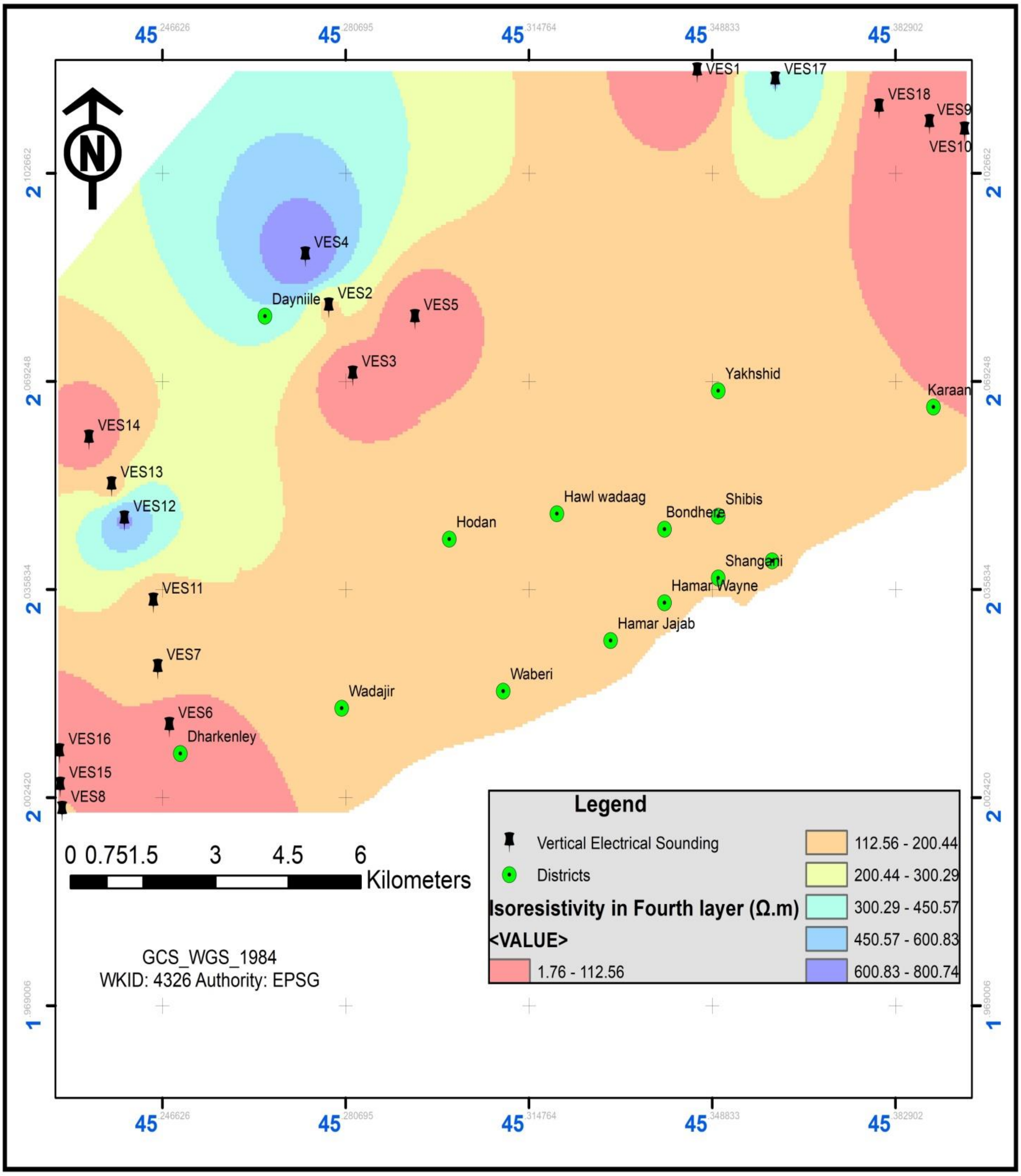

Figure 5.10. Fourth layer Isoresistivity Map

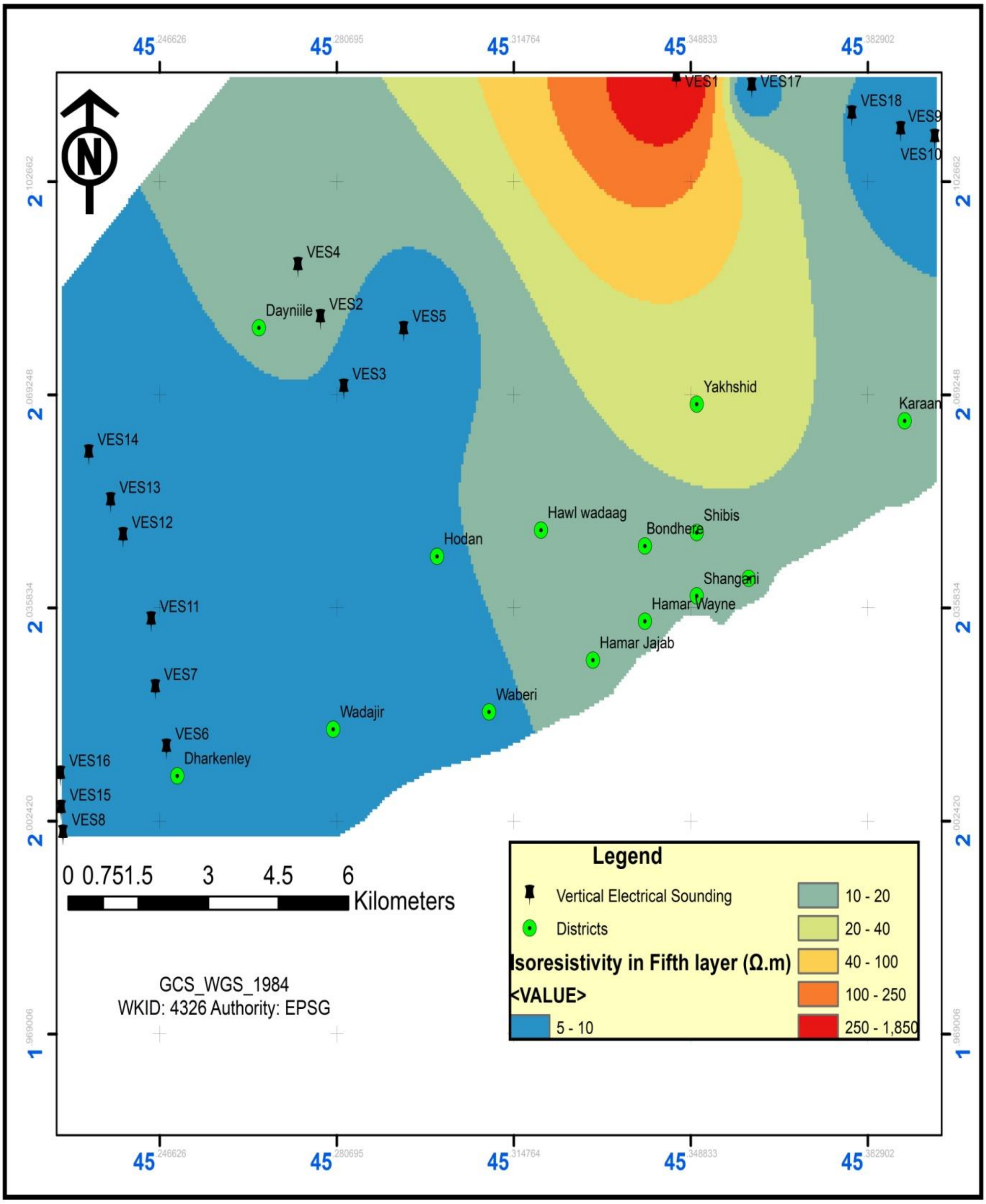

Figure 5.11. Fifth layer Iso-resistivity Map

5.2.3.2. Iso-resistivity thickness contour maps

The first layer thickness (Figure 5.12) extent from 1 m at Hiliwa district in approximately Northern east at the map and to 4.5 m occurred at the western side of the map. The second layer (Figure 5.13) ranges from low thickness 0.5 m to high thickness 14.5 m (VES 3, 2,10 and 14). The third layer (Figure 5.14) has a thick thickness extent from 5 m to 132 m (VES 3 and 16) and most considerable for the zone of potential groundwater. The fourth layer (Figure 5.15) has thick thickness ranges from 10 m to 235 m and some area not predictable as well as considered occurrence of groundwater potential zone.

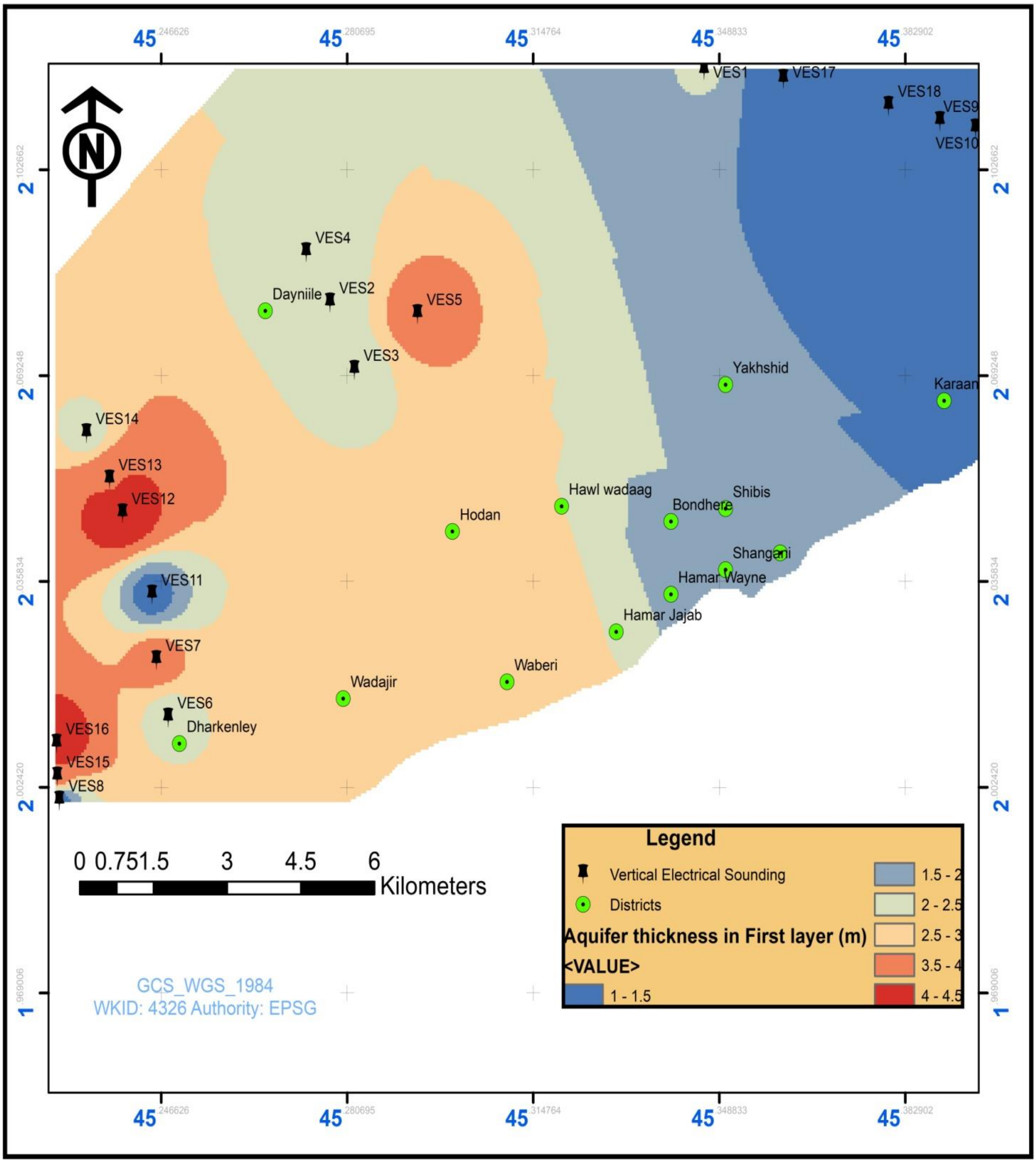

Figure 5.12. First layer thickness map

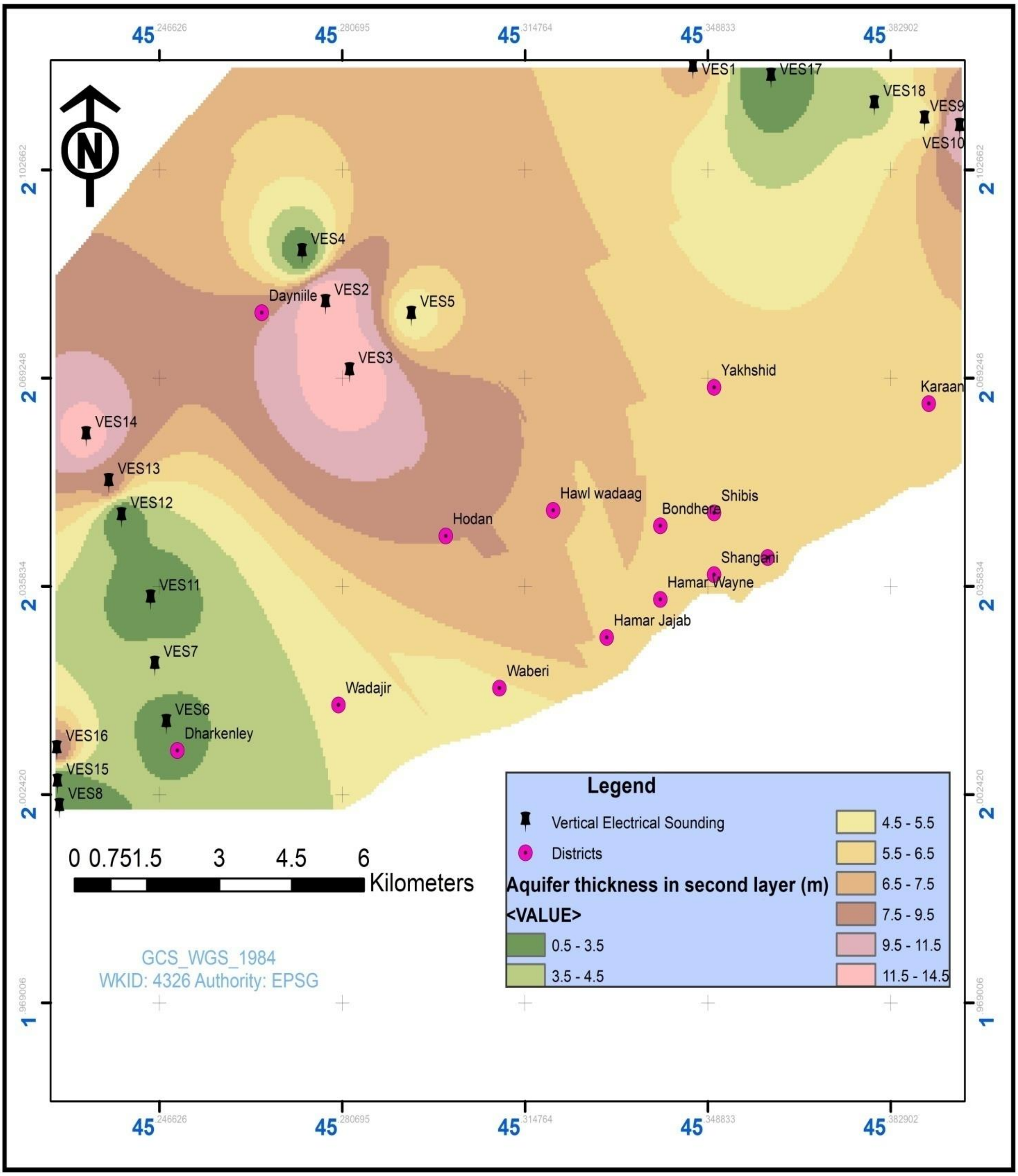

Figure 5.13. Second layer thickness map

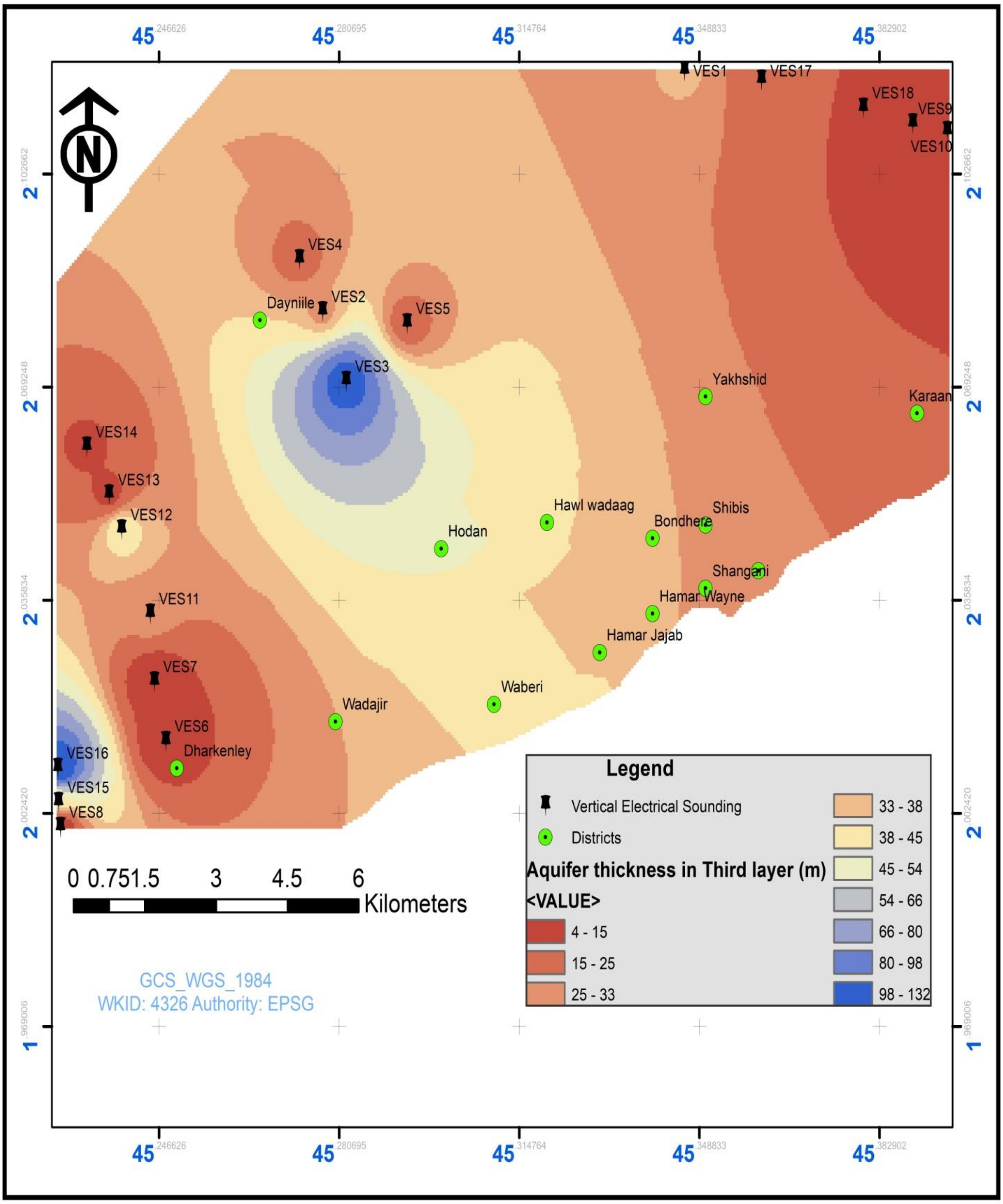

Figure 5.14. Third layer thickness map

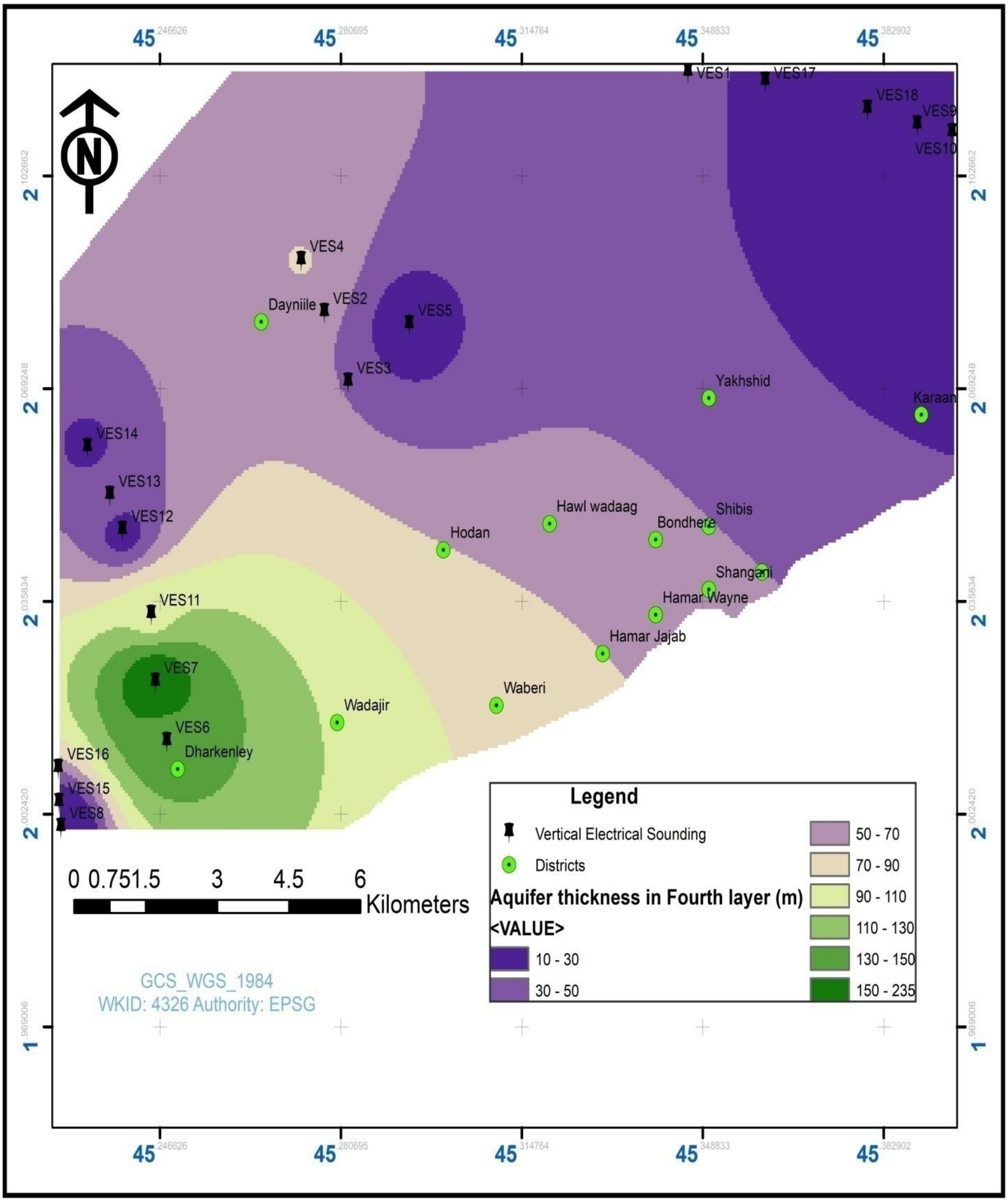

Figure 5.15. Fourth layer thickness map

5.2.3.3. Iso-Apparent Resistivity contour map

The Iso-Apparent resistivity layer contour maps at difference depth level at ground surface, depths of 30 and 60 m were prepared to show lateral variations resistivity of the study area Figure 5.16 (a-b-c). A resistivity contour map at the ground surface indicates zones of high resistivity value (>610 Ω.m) occur at the direction approximately NW and S as shown on Figure 5.16(a). A low resistivity value (<550 Ω.m) oriented approximately at the N and NE and SW. The small lateral variations in resistivity at a depth 30 m, shows that the layer is likely to be homogeneous, the high resistivity (550 Ω.m) occur at direction approximately West Figure 5.16. (b).at a depth of 60 m below the ground surface, the high resistivity values (>730 Ω.m) occur at the direction N and SW and the low resistivity values occur at the direction of SW as shown on Figure 5.16(c).

However, the lateral variation resistivity is mostly homogeneous in term of lithological characteristics. The overall resistivity contour maps show that the study area at a depth of 30 m and 60 m has low resistivity values between 10 to 190 Ω.m. This indicates that study area have highly saturated groundwater potential.

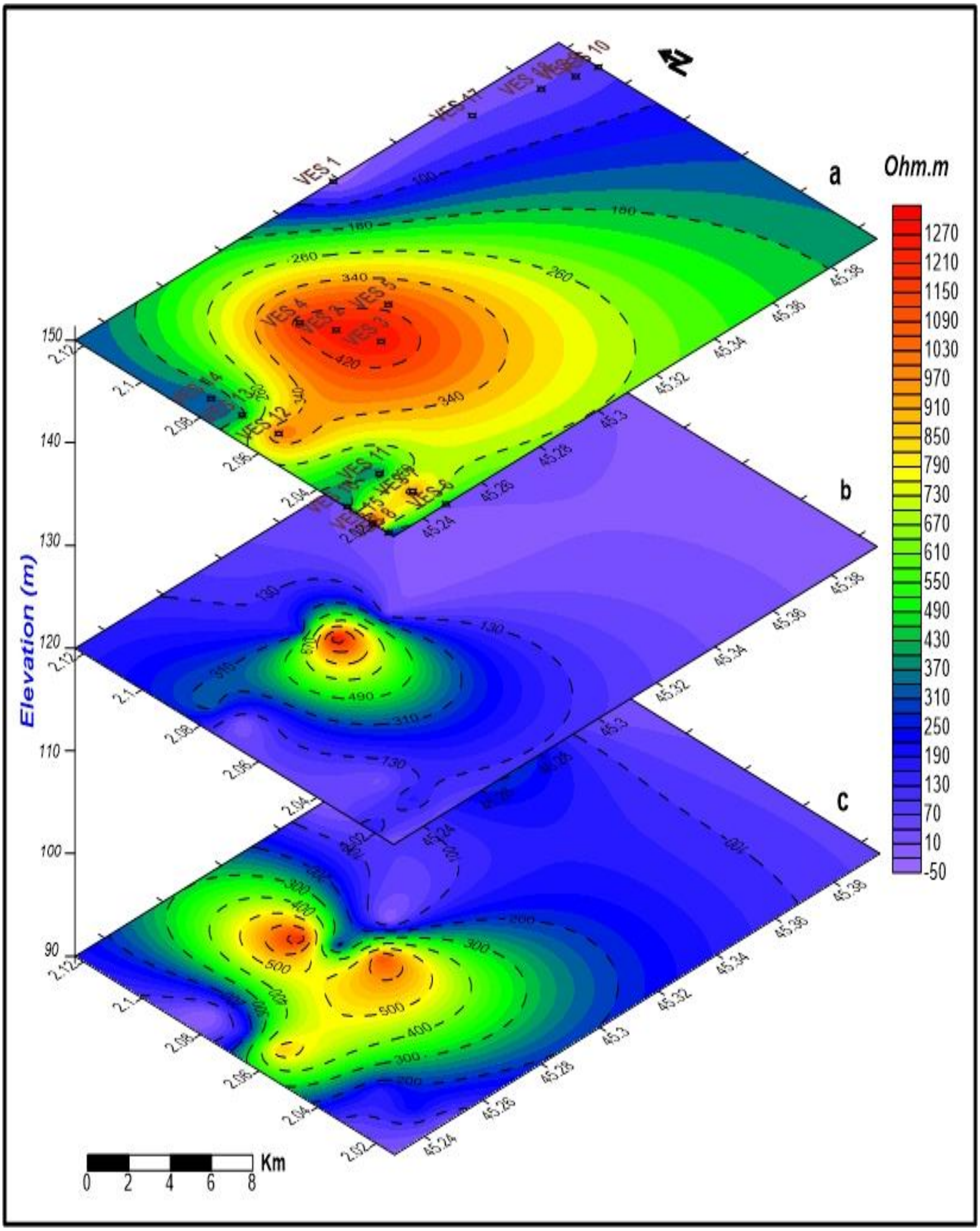

Figure 5.16. Iso-Apparent resistivity map showing lateral variation at surface (a) = 0 m, (b) = 30 m, (c) = 60 m.

5.2.3.4. Aquifer and Thickness resistivity layer map

The aquifer resistivity contour map of the study area shows laterally variation in resistivity values. The aquifer resistivity contour layer as illustrated in the (Figure 5.17) zones, where resistivity value ranges more than 120Ω.m are considered as high potential groundwater, and the zones with resistivity value ranges less than 120 Ω.mare considered as low groundwater potential.

The thickness of aquifer is important for hydrogeological consideration in groundwater investigation. Figure (5.18) shows the saturated aquifer thickness layer in the investigated area is from 1.5 m to 80 m.

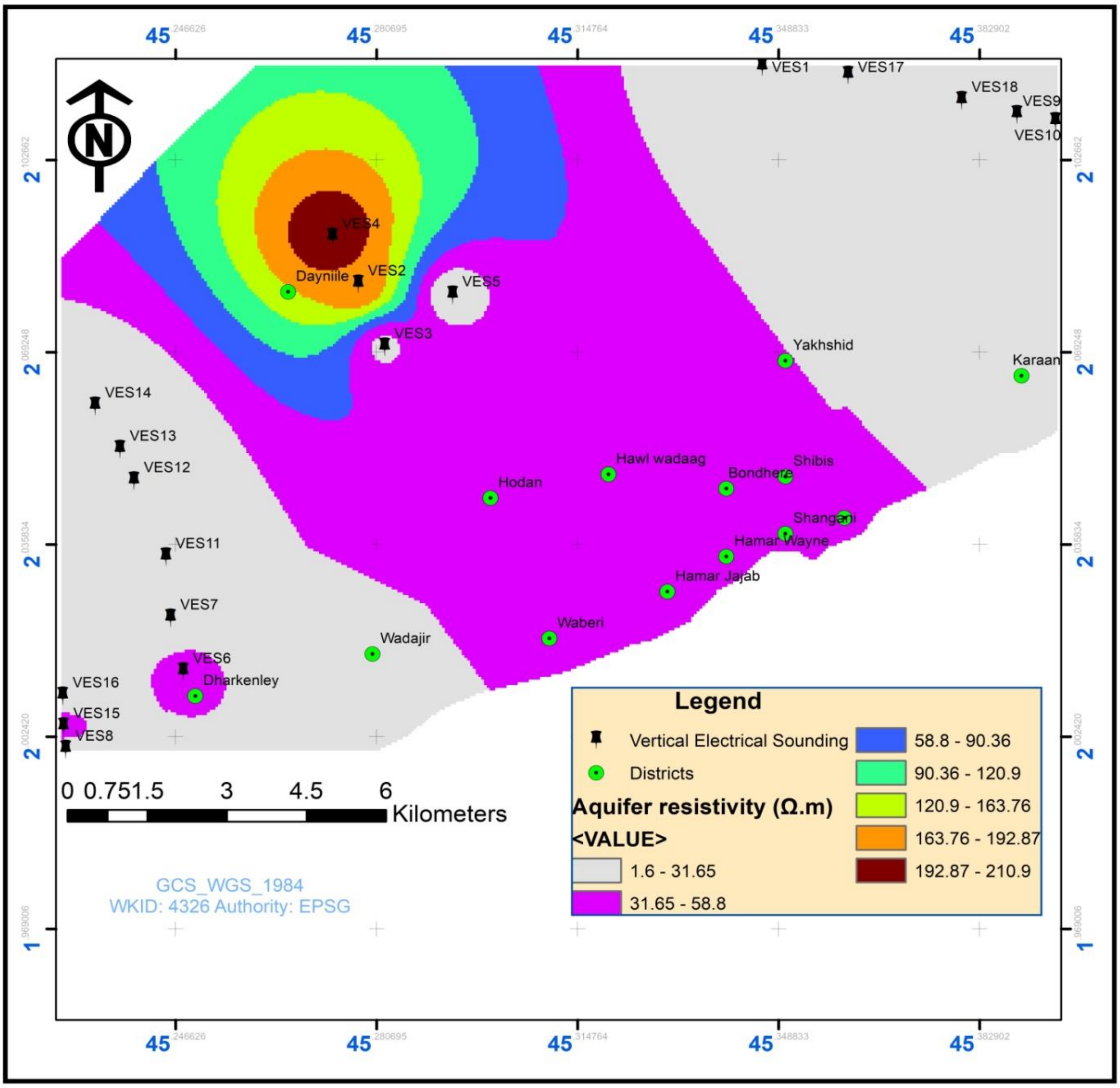

Figure 5.17. Aquifer resistivity map

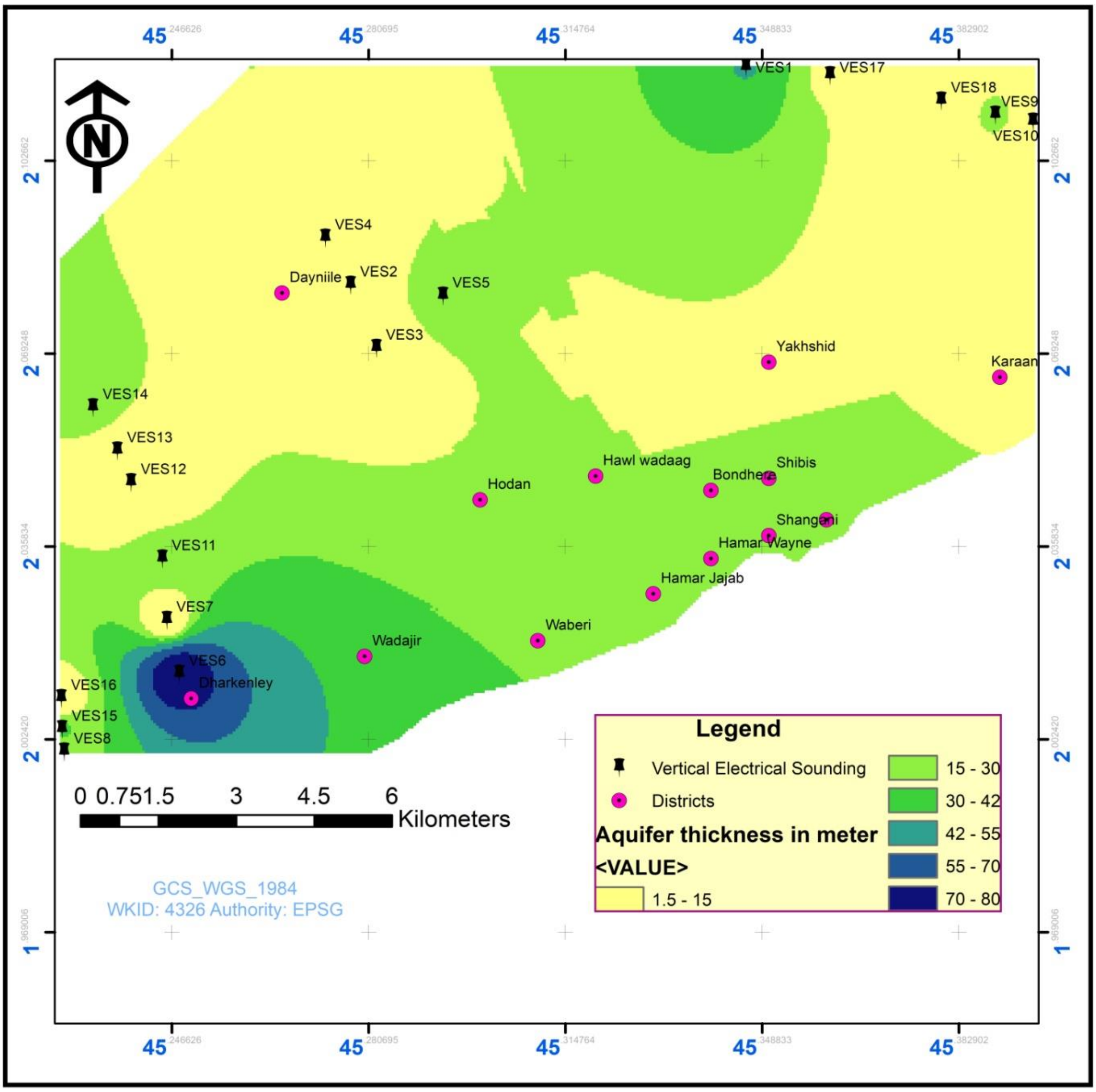

Figure 5.18. Aquifer thickness map

5.2.3.5. 3D visualization in the study area

Five 2D geo-electric section lines were collocated to create a distribution resistivity in 3D visualization (Figure 5.19, 5.20 and 5.21) in the study area. The 3D visualization indicates that there is small variation resistivity at the surface where both occur low to moderate resistivity zones. A low resistivity zone (<45 Ωm, shaded blue) occurs at the SE and SW direction in the map. A high resistivity zone (>225 Ωm, shaded red) occur at the S to N direction. The most dominant distribution resistivity of horizontal geo-electric feature countered in the 3D image is from low resistivity to moderate resistivity which indicates of saturated zone.

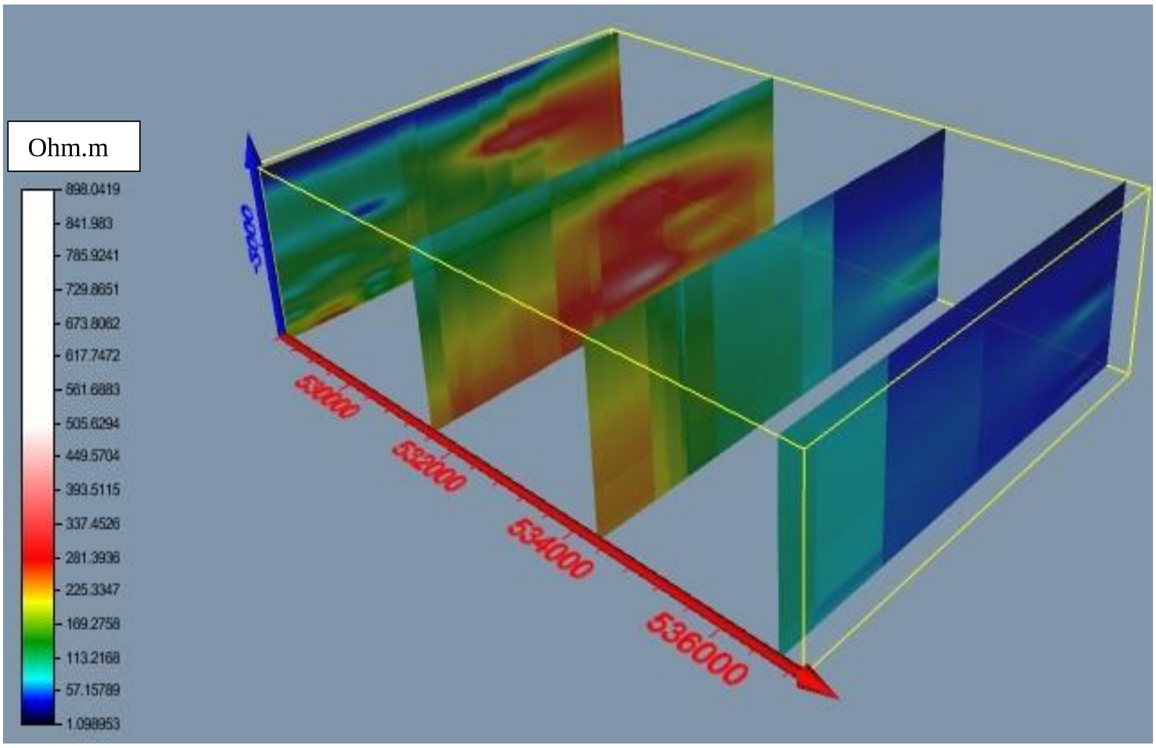

Figure 5.19. Shows the resistivity zones (section) in the study area W-E direction.

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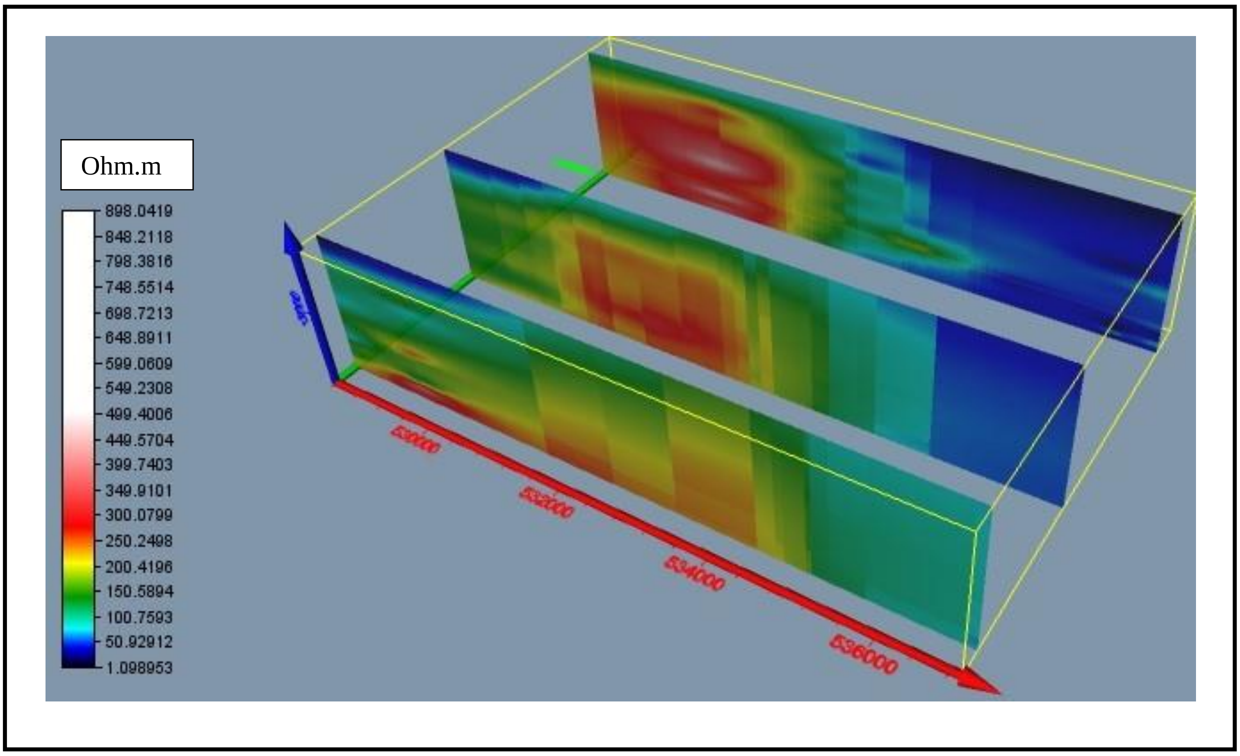

Figure 5.20. Shows cross section of resestivity zone in the study area N-S direction

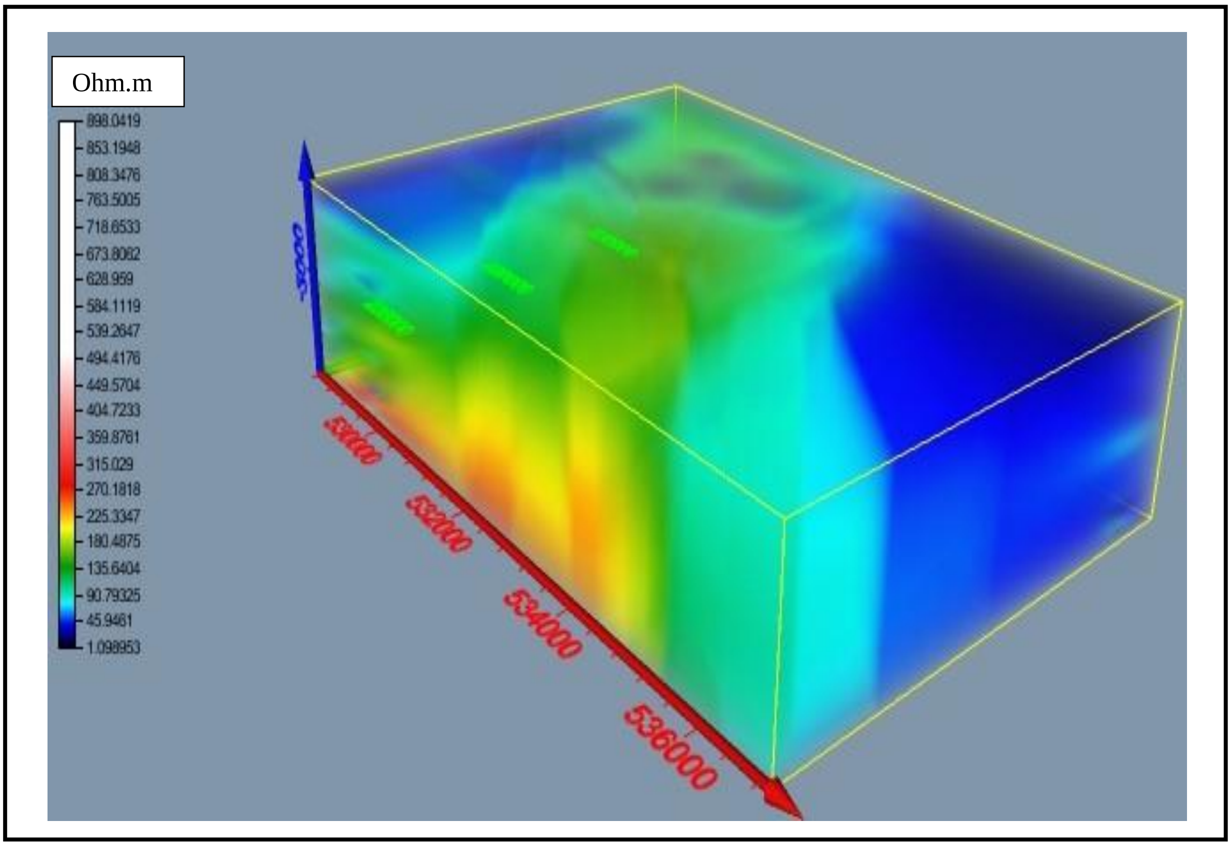

Figure 5.21. 3D Distribution of resistivity map.

5.3 DISCUSSIONS

The hydrogeology of Banadir region has been investigated using 18 VES points. The resistivity and the thickness of geo-electric section lines presented in table 5.1. VES data were acquired and analyzed using computer software IPI2WIN and geo-electric section built by Surfer v13 program. In the study area, four to five-layer models are discovered.
From geo-electric sections, resistivity and thickness map of the aquifer and groundwater potentiality noted as follow: The geo-electrical sections show the presence of four to Six-layer in the study area, the first topsoil covers all the area and consist of red sand dune resistivity value ranges from (25 – 460 Ω.m) and average thickness (1 – 4.5 m). The second are considered as fluvial sand that has resistivity values ranges from (10 - 570 Ω.m) and average thickness (0.5 – 14.5 m) considered as shallow aquifer layer. The third layer considered as a saturated aquifer and consists of fine marine sand has rated low resistivity values from (3 – 1350 Ω.m) and has a thick average thickness (4 – 132m). The fourth layer is limestone has a resistivity value range from (2 – 800 Ω.m) considered a fractured layer and has the thickest average thickness from (10– 235 m) which indicates the possibility of groundwater potential is too high. The fifth layer resistivity ranges from (5 – 1850 Ω.m) the average thickness is infinity. The low resistivity layer considers as marine sand which is made of saline water.

Iso-resistivity contour maps clearly clarified the aquifer in the area is structurally controlled by the recent deposits (Quaternary formation) from the whole study area. The depth in the investigated area ranged from (25 – 235 m). The aquifer resistivity (Figure 5.17) values are ranged from between (1.6 to 211 Ω.m), from map (Figure 5.18) the thickness of aquifer ranged from (1.5m to 80m). Aquifer layer and thickness enhance gives for efficient groundwater potential, it is favorable and productive in sufficient quantity and economic in use. From maps (Figure 5.16) Iso-resistivity contour map at different depth level shows that the study area has two aquifer system , shallow and deep aquifer zone and estimated at the depth of shallow aquifer about 15m to 30m and the depth of deep aquifer about 60 m to 90m below the surface. The 3D image (Figure 5.21) shows most dominant distribution resistivity of horizontal geo-electric feature countered in the study area is from low resistivity to moderate resistivity which indicates of saturated zone.

5.3.1 Piezometric surface Map

Piezometric surface map of the study area and surrounds regions (Figure 5.22), the direction of groundwater flow follows a curved path through an aquifer from areas of high hydraulic head to areas with low hydraulic head. The direction of flow is indicated by the slope of the water table which is called the hydraulic gradient (Charles 2002). However,the general recharge pattern of the study area (Red - Orange) in Figure 5.22.Shows zone High elevation, while the (Blue color) indicates zones of low elevation. In the study area of the map the flow direction is decreasing from the NW to SE approximately indicates that the entire recharge goes through to the sea.

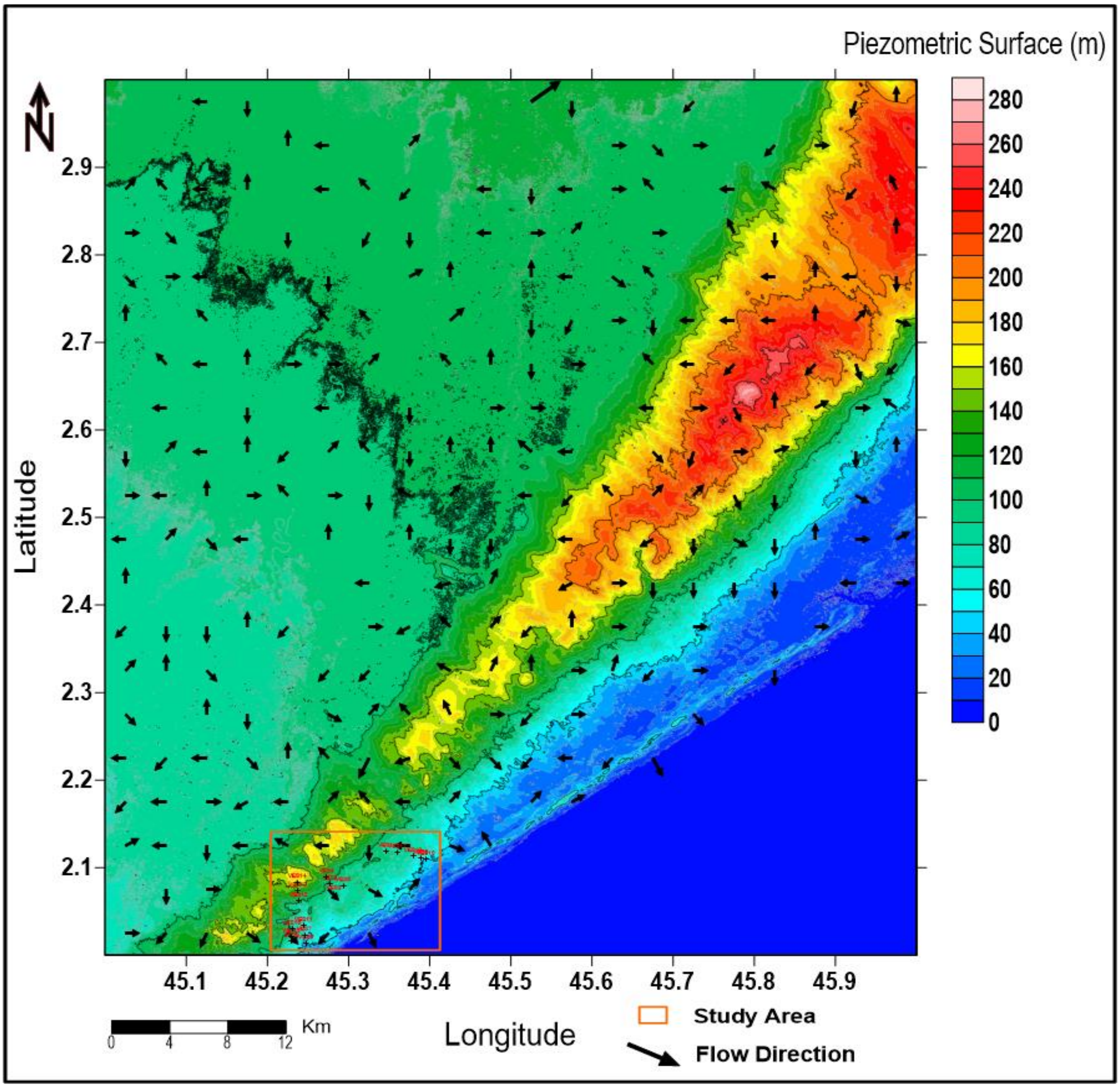

Figure 5.22. A Piezometric Surface map in the study and surround area.

5.3.2 Aquifer occurrence

The result of geophysical and hydrogeological analysis revealed that the study area have two main aquifer systems, deep and shallow aquifers. The shallow aquifers are occurring within from (15-35m) from the surface, contained in unconsolidated fluvial sands material, while deep aquifers occur at (60 m to 90 m) below the surface contained fractured limestone.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

An application of 1D VES to determine the influence of geology and geological structures on groundwater occurrence and groundwater potential was achieved this study area. 2D, 3D geo-electrical sections were used as an effective technique.A general understanding of the effect of geological structures on groundwater occurrence is achieved. This was necessary to develop and expand productive groundwater potential of the study area.

The VES data was used to determine a groundwateroccurrence in different litholgies. The geophysical characteristics of study area showing high and low resistivity zone in different parts of study area. VES 4, VES 5(Dayniile), VES 15 (Jazeera), VES 12 (KaxShiikhal) have high resistivity zone at shallow depth. It shows presence unconsolidated alluvial sand. Districts Dayniile, Kaxshiikhaal and Hiliwaa show a low resistivity zone with average thickness (5 – 22m) it may be a good groundwater potential zone. The fluvial, fractured and weathered limestone is the main yielding groundwater sources.

The depth to water table of the study area is different from place to place and varied from (15m – 25m) for shallow water, while the deep aquifer depth water is estimated between (60 – 120m). The groundwater flow direction is generally to the seaward direction approximately SE.The main recharge of the study area is ShebelleRiver about a distance15-20 km far awayfrom study area. TheGeoelectrical structure of the study area revealed four to five layers in Coastal province at the age of Tertiary to Quaternary Formation (recent sediments).

It concluded the vertical electrical sounding method revealed two groundwater system are exist in the study area; upper aquifer and lower aquifer, the upper aquifer mainly composed fluvial sand sediments at depth ranging from between 15m to 30m, with medium to low resistivity, while the lower aquifer is predominantly Tertiary and Cretaceous Limestone and marine sand at depth ranging from 60m to 90m below the subsurface.

It is also noted that the groundwater quality on basis of electrical conductivity there is interactionbetween fresh water and saline water, as goes to decrease the sea mean level through the ocean the salinity increase.

6.2 RECOMMENDATIONS

The present study area provided good knowledge about groundwater. Therefore, the following recommendations are suggested and consider in future investigations: Establishing drilling test boreholes at the areas of proposed high groundwater potentiality and should be consider more geophysical and hydrogeological investigation in the area in order to determine depth, thickness, and extension of highly potential groundwater aquifer and the interface between saline and fresh water. Increasing the population and expanding the city and surrounding areas demanding more water it necessary to make regular monitoring of subsurface water resources and its quality in the area for effective management. 2D and 3D electrical resistivity tomography will be more widely used in the future studies.

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