WALLAGA UNIVERSITY

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ASSESSMENT OF GROUNDWATER POTENTIAL USING ELECTRICAL RESISTIVITY METHOD AND GEOSPATIAL TECHNIQUES: - A CASE OF WALIYE CATCHMENT, AROUND GEDO TOWN, ETHIOPIA

MSc Thesis

BY

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May, 2023

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ASSESSMENT OF GROUNDWATER POTENTIAL USING ELECTRICAL RESISTIVITY METHOD AND GEOSPATIAL TECHNIQUES: - A CASE OF WALIYE CATCHMENT, AROUND GEDO TOWN, ETHIOPIA

A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Earth Science.

(Exploration Geophysics)

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APPROVAL SHEET FOR SUBMITTING FINAL THESIS

As members of the boards of examining of the final MSc. Thesis open defense, we certify that we have read and evaluated the thesis prepared by **Shuma Banti** on the title "***Assessment Of Groundwater Potential Using Electrical Resistivity Method And Geospatial Techniques: A Case Of Waliye Catchment, Around Gedo Town, Ethiopia***" and recommended that thesis it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Exploration Geophysics.

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DECLARATION

Certification of the final thesis

I hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled "**Assessment of Groundwater Potential Using Geospatial and Electrical Resistivity Method**" prepared by **Shuma Banti.** I also adhered to academic integrity and honesty throughout my thesis. The thesis is being submitted as partial fulfillment of requirement for a master's degree from Wallaga University and has not been submitted to any other institution.

Name: Shuma Banti **signature**: ________________

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BIOGRAPHICAL SKETCH

Shuma Banti was born on January 5/1990 E.C from his father Banti Jando and from his mother Gexe Dugasa in Gedo 02 kebele, West Shoa Zone of Oromia regional state, Western Ethiopia. He started his school (1-8) at Gedo primary Dire Gudina in (1998-2005) E.C, High school (9-10) at the Gedo secondary high school in (2006-2007) E.C and preparatory school (11-12) at Gedo preparatory School in (2008-2009) E.c. After he completes his preparatory school, he joined Wallaga University by Natural and Computational science department of Earth science in 2010E.C and graduated in 2013 E.C. After graduation he joined his master's degree directly sponsored by Wallaga University. Finally he started master by Exploration Geophysics in 2014E.C and finished in 2016E.C.

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LIST OF ACRONYMS/ABBREVIATION

BMI…………………..body Mass Index

CSOWB………………..Civil service of wareda bureau

CWWRB……………….Chelia Wareda Water Resources Bureau

DEM: ……………… Digital elevation model

DTM....…………………Digital terrain modeling

ERT…….…………….…..Electrical Resistivity Tomography

ETM+…………………..Enhanced Thematic Mapper Plus

FAO……………………Food and Agricultural Organization

GIS: …………………,..Geo-Information system

GPM…………………...Groundwater Potential Map

GPS: …………………...Global position system

MOWR: ………………..Ministry of Water and Resource

MRI…………………..…..Moderate Resolution Imaging Spector-radiometer

NMA……………………National Metrological Agency

RMS……………………Root Mean Square

VES…………………..……Vertical electrical sounding

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Abstract

Groundwater under most conditions is safer and more reliable for use than surface water. Ethiopian societies have long prioritized the availability of water resources. The problem of obtaining adequate water supply is generally becoming a more difficult task. With over-increasing political displacement towards the city, lack of self-wells, *increasing population numbers, increasing urbanization and an increasing amount of drought in the country, demand for water is increasing rapidly. This study focused on identifying a potential groundwater zone in the Waliye watershed in west Shoa, Ethiopia, where Gedo town is located. The areas get water from different sources, but all the water supplies for this community were 739,600 liters per day. Even if the population consumes 50 lit/day, the average daily demand is 1,273,000L/day, as recommended at the time. The aim of this research is the assessment of groundwater potential using the geospatial method and the electrical resistivity method in the Waliye catchment. In this method, thematic layers were processed by using Arc-GIS and Google Earth to specify slope, drainage density, lineament density, topography, aspect value, lithology, and soil map of the study area to produce a groundwater potential map. Both qualitative and quantitative interpretations of the study's field results are available. The number of layers and pseudo-section are qualitatively described by observing the form of the field curve in the qualitative interpretation, but the true resistivity, thickness layer, and geoelectrical section display quantitative characteristics. The vertical electrical sounding was taken at twelve points by a 100-m gap distribution interoperated by ipi2win software with a resistivity value between 1.2 m and 105 m and a 105 m and an RMS error of 1.84–3.39. The vertical electrical sounding data is interpreted by pseudo-section to specify the low resistivity distribution area. Most of the VES data interpretation is in the (H) type format of the earth layer; those types of earth layers have high water-bearing zones. The electrical resistivity tomography was also imaged over five parallel profile lines with a specific 100-meter distance between each profiles study area to get fracture structures. Reverse forwarding interpretation was used to get the most clearly structured structure in this thesis. The inverted interpretation model for both uses effectively minimizes the difference between the observed and estimated values of identified data at the end point to get the high groundwater potential area zone that was mapped on the result.*

Key Words: Geo-electric section, pseudo section, aspect value and geospatial.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Water is an important resource necessary for all species on Earth to live, and it is also necessary to achieve significant socioeconomic growth. Groundwater is an exceptionally reliable and safe source of water for domestic, commercial, municipal, and irrigation needs. Water is becoming increasingly important and has many uses. In addition, it is necessary for a variety of developmental tasks in addition to drinking. Every activity we do in our daily lives needs water. Increasing population growth, urbanization, and industrialization are in parallel with an ever-increasing challenge to the use and sustainability of water (Mishra, 2023).

The provision of suitable water of acceptable quality is an important constraint in both local and regional planning for urban and rural areas. As the demand for water in developing countries continues to increase with the rapid growth populations, water supply decreases through drought, miss-management of water resources etc. In most cases, the demand for water exceeds the supply of water from various sources, such as surface and groundwater (Mikman, 2018). This is true in both urban and rural areas in particular. Water availability for drinking, washing, construction, for hospitals and clinics, for schools and colleges, for irrigation purpose and the other purpose depends on a variety of environmental and geological conditions.

The water source Ocean, Icecaps Glaciers, Groundwater, and other factors with volume percentage 97.24%, 2.14%, 0.61% and 0.1% respectively. Other factors Fresh Water Lakes (0.009), Inland Seas (0.008%), Soil Moisture (0.005%), and River (0.001%). Groundwater has only 3% of the world's water where two-thirds of it is frozen forming the polar ice caps, glaciers, and icebergs. The remaining 1% of the total world water supply is freshwater available as either surface water or groundwater. A groundwater resource is created when some of the precipitation in the atmosphere seeps into the ground. Some of this precipitation is converted to groundwater as it seeps into the ground. However, the importance of an aquifer as a source of groundwater depends on how permeable the geologic layer from which it was formed is important. (Driack, 2021).

Groundwater can be investigated in a variety of ways. The basic methods for investigating groundwater are combination methods. Each of the groundwater exploration strategies has a number of sub-methods. For example, geospatial methods are surface methods, and geophysical survey is one of the sub-methods under the subsurface method of groundwater exploration (Neuman, 2018). The use of geophysical systems and related numerical modeling techniques for groundwater investigation has increased in recent years due to the rapid development of these technologies, which are relevant and usable methods. The study is mainly focused on the exploration of groundwater in the area of concern because of inadequate water supply.

Studies use geophysical electrical resistivity survey methods, geospatial tools, and Electrical resistivity data to investigate any relationships between geological features and groundwater occurrence in the studied area (Pajock, 2023). The geology, geomorphology, tectonics and climate of the country have a great influence on the presence of groundwater. Groundwater is an important source of drinking water in several parts of the country (Alamayo, 2022). Due to this, the importance of vertical electrical sounding (VES), a type of geophysical survey and geospatial tool is currently being increasingly used for groundwater potential mapping. This geophysical survey method determines the surface effects caused by the low electric current in the earth. It provides information on the depth, thickness, and relative water yield of the various layers of the subsurface.

The general study depends on the geospatial methods and geospatial tools that we used in the study are very goods and simple to get enough information from some tools like maps, Global Positioning Systems (Thakur, 2017). It also needs ability to read and interpreted by different Geo-Information System. Geospatial analysis of identifying and mapping groundwater potential zones significantly reduce the costs and time of exploration and proper allocation of dried boreholes that helps to avoid failure of groundwater withdrawal planning and development (Murmu, 2019).

1.1.1 Groundwater studies in Ethiopia

Ethiopia has large Amount of water resource but, water has become scarce in many areas of the country due to uneven distribution of rain, higher demand, and frequent droughts (kazman, 2016). In developing countries like Ethiopia, whose economy is highly dependent on agriculture, sustainable water is critical for social progress. According to the best available information on groundwater resources, Ethiopia's groundwater potential is estimated at 2.6 billion cubic meters, which can be replenished annually (ESWS, 2021). However, compared to surface water resources, groundwater potential in Ethiopia is lower (MOWR, 2009).

In our country, which is characterized by a great diversity of geological, geographical and ecological parameters, it is noteworthy that it has difficulties in finding rich aquifers. Recognizing the thickness of the aquifer helps in determining the drilling depth as well as the resources and water reserves (Shayaq, 2015). To characterize water circulation within recharge and Discharge, it is uses to study the variables that control freshwater (Kebede, 2012).

1.2 Statement of the Problem

The Gedo town total population is 25,460 and has water scarcity due to over-increasing political displacement towards the city, lack of self-wells, population numbers increase, increasing urbanization, the increasing amount of drought overseas, construction development, and other factors hospitals like lack of drinking water, lack of water self-safety and in common institutions like hospital, schools, health institutions, colleges etc. in a society. Those causes bring different challenges for the community, though our health problems, agricultural productivity and nutrition quality affect us etc.

The existing water for communities comes from one developed spring with electric power pressure. Its discharge is 3.5L/sec it's which is 302,400L/day (CWWRB, 2018). Again, there are two groundwater wells in the study area, but both wells are already un-functional. To maintain the community problem, there are three springs. Those three springs commonly pump 5.06L/sec. One pump 1.3L/sec is called center spring. The second one pumps 1.9L/sec, which is known as Bulo spring, and the third one pumps 1.86L/sec, known as Gulale spring. These also pump 345,584,000L/day. All the water resources supply 739,600L/day. According to the World Health Organization, water recommends between (50-100) liters of water for one person per day. Depending on the body mass index (BMI), water only for drinking is recommended 3.7lit/day for males and 2.7lit/day for females. (Adelana, 2015).

Depending on all-water supplies, this community gets 739,600L/day. Therefore, even if we take 50 community/day for each community needs the average L/day demand for water is 1,273,000L/day at that time. Almost 58.098% yield. The yield of this supply is not able to balance the gap between the demand of the town's community and the existing water supply. Because of this insufficient water supply, the community suffers from the scarcity of water to overcome this problem, sites of new potential well sites for an area with geophysical Electrical resistivity method and geospatial technique.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this study was assessment of groundwater potential using an electrical resistivity method and Geospatial method, moderating the town's community problem in waliye catchment.

1.3.2 Specific Objective

With the following particular goals in mind, the research is being done to acquire groundwater potential understanding of the study area's surface and subsurface geology:

1. Identify zones of low slope, high drainage density, lineament structures, and rain fall amount with lithological consideration for groundwater potential map.
2. Evaluate the influence of geologic formations, geomorphologic features, and surface configuration on groundwater potential.
3. Identify areas of low electrical resistivity of formation that host a high amount of groundwater potential for extraction.
4. To determine the depth and thickness of groundwater potential by VES interpretation.
5. Mapping the location of groundwater potentials that could serve as conduits or barriers to groundwater potentials for exploration.

1.4 Research Questions

A) Where is the potential waterfront site which can survive the community?

B) How can groundwater potential presence or absence be affected by geological formation like slope, topography, drainage density and aspect of features?

C) How geospatial methods use in groundwater investigation and aquifer indication in an area?

D) How geophysical methods determine the depth of groundwater exploration depending on resistivity value

1.5 Significance of study

This research uses enormous prospects we will anticipate. Immediate interventions need the availability and access to water for drinking, for household usage, and for other product applications. It is foreseen in the framework by other researchers of this study area and specifies that groundwater availability would increase and support local socioeconomic growth. It also provides coverage of research into prospective waterfront region and provides some data sets for the progress study of groundwater. It also confirms that integration of geospatial methods and electrical resistivity methods is appropriately used for groundwater potential investigations.

1.6 Limitation

While conducting this research, the researchers faced different problems. Some of the problems include lack of instruments and, in the case of seasonal rain, extension of appropriate time for resistivity data collection. Another is the challenges and effort made during ERT field survey measurement, the problem of financial resources and political problems. The other problem faced during this thesis work is the ability of software data interpretation.

CHAPTER TWO

LITERATURE REVIEW

Groundwater is the water found in a water-bearing geologic formation called an aquifer. This type of formation is porous, and the pores are interconnected. The degree of connectivity indicates that the formation is permeable, with various structures such as joints, faults, and fractures within the formation increasing permeability (Etter.s.w, 2017). Well-grown aquifers that can hold groundwater are gravelly sand, silt, fractured rocks such as weathered limestone and fractured basalt, and along lava tubes. Porosity refers to the voids that are found in the rock. These voids can be filled with water. Porosity is used to determine how much fluid or gas the formation can hold. Permeability indicates the extent to which these voids are connected. Permeability of formations, secondary structures, inclusion of secondary minerals, and various geological structures have great influence on groundwater potential.

Groundwater occurs in any type of rock when it finds or gets suitable conditions. This occurrence of groundwater is easily visible on the earth's surface. The geologists and engineers look for various indications of groundwater occurrences. Groundwater exploration is the search for water-bearing aquifers using surface and subsurface geological information. This includes 2-D aerial photographs, surface and bedrock geologic maps, agricultural soil survey maps, topographic maps, and surface drainage maps (Meneisy, 2021).

2.1 Exploring Groundwater

The most abundant valuable resource on Earth and naturally renewable source of precipitation and snowfall that percolates through soil and other unsaturated materials is groundwater. The existence or lack of geologic features such as liniments (fractures) and geomorphologic landforms is directly associated with the occurrence of groundwater (Ksr, 2020). Groundwater cannot be utilized directly anywhere if its amount is minimal. Accurate assessment of aquifers for large-scale systems is still challenging due to the temporal unpredictability of hydrologic inputs and the spatial diversity of hydraulic features.

This study emphasizes the importance of combining geologic, Geospatial methods, and geophysical methods to define an aquifer and evaluate groundwater productivity assessment (Mathewos, 2024). Despite the widespread distribution of groundwater resources, nature does not deliver groundwater where we want it.

2.1.1 Surface and Geological Investigations

The optimal site for a subsurface study can be chosen using the general source and conducting an examination using surface techniques. Remote sensing and geographic information systems (GIS) integration is one of the oldest methods used for surface water research (Kabeto, 2022). Numerous scholars have created maps of groundwater resources using this technique all throughout the world. These are very inexpensive and crucial for showing locations that may contain groundwater using several indicators, such as slope, drainage density, lineament density, and precipitation.

2.1.1.1 Precambrian Geology of Ethiopia (PCM)

The Precambrian geology of Ethiopia doesn't clearly understand or poorly understands. But, the joining of the major structure of the lithology which one Arabian shield and Mozambic belt meets in Ethiopia (Johnson, 2021). The Precambrian rocks are exposed in small area central Ethiopia, in west and southwest direction and in south part. The comprised with variety of volcano-sedimentary and plutonic rocks. The most Ethiopian Precambrian rocks are basement rocks most of it is undivided or doesn't clearly understand.

2.1.1.2 Cretaceous Jurassic (KJ)

The lithology formation stage at this time is known as intra-continental rift stage and post rift stage. This lithology extended from the main Ethiopian rift toward central. It is dominantly characterized by sandstones rocks. Sandstones rocks are mostly associated with conglomerate rocks which have high amount of porosity and permeability. The presence of permeability and porosity shows the most presence of high amount of groundwater potential. Fine- to medium-grained gravels that are further separated into thick, massive sandstone and fining-upward sandstone comprise the sand stone group.

2.1.1.3 Tertiary Volcanic Rocks

Geomorphology description land surface control water percolation and runoff production this includes surface structural like upper geological unity, the soil cover, vegetation properties and agricultural area. These studies suggested a significant increase in infiltration among vegetation plants. Fractured rock outcrops, as well as an increase in the vegetation automatically related to groundwater potential occurrence, recharge and discharge in terms of altering hydrological cycle such as interception and transpiration. Geomorphology is the laterally form or shape of the earth it is principally related to the land feature of the earth`s surface. It`s also common principles of the land cover and land use, vegetation's land features. It also deals with classification, descriptive and form.

Understanding the processes, lithology related to groundwater occurrence and potentials is aided by the depiction of significant landscape, underlain geology, on geomorphological topology maps. Potential groundwater exploration zones are shown on these maps. Geomorphologic mapping has made extensive use of satellite imagery ever since the first Landsat data became accessible. Landform categorization, process characterization, and the connection between landform and processes have been the main uses of satellite images. On the other hand, data on landform distribution, location, surface-subsurface composition, and elevation may also be obtained using remote sensing (Smith, 2009).

2.1.2 Soil Data

A) Aerosols soil

Aerosols are a textural sandy soil that is formed at residual sand in situ where the weathering of old materials is removed. They contain an amount of rock fragments up to 35%. The soils form in arid to humid environments and from extremely hot to tropical as the world distribution. These soils contain mostly scattered vegetation and light forest.

B) Eutric Nitosols

Nitosol is the most available soil in the humid tropics. The soil is deep and porous, with stable soil structures that allow for deep rooting and help to retain water content. The high amount of drainage roots and water-holding properties make it favorable to other tropical soils.

When Nitosols are dry, they become extremely rigid; when they are wet, they become sticky and plastic. They're 50–60% pores that are retained by the long length of roots. The morphological depths are more than 150 cm, and their colors range from red to dark. Nitosols mostly occur on basic and ultra-basic rock types on the upper and middle slopes. As the world's 200 million hectares of Nitosol cover, more than half of all Nitosols are found in tropical Africa, like Ethiopia, Kenya, and Cameron, above 1000m elevation. They are mostly found in parent areas, high-erosion environments, and boreal Polar Regions (FAO, 1980).

C) Humic cambisol

Humic Cambisols is one of the categories that make up an organization's (FAO) categorization system. The properties lack abundant humus, clay, dissolve ability salts, and (**Fe $ Al_2O_3**) its properties that differ it from others. They may be distinguished from weathered material by their aggregate structure, color, and clay content, which all give some indication of the processes that lead to the development of soil.

D) Eutric cambisols

Eutric cambisol covers 1.5 million hectares of land worldwide. Its deposition and erosion cycles explain why it formed in a mountain area. These soils are less common in the tropical region, where there is high erosion. Cambisols occur in some geologic active areas where their soil type has an association with mature soil type. These types of soil occur I study area in small amounts around the south-west of the study area. The soil type is dominantly at the cool temperature of the alluvial deposit.

E) Chrome vertisol

Vertisol is a soil that contains a high amount of heavy clay and a high proportion of swelling clay. There are dominantly covered northwest parts of the study area. This soil contains sementic clay. For this reason, this soil doesn't contain enough groundwater potential. Vertisol is commonly redistributed with equal particle size throughout the solum.

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2.2 Geospatial Theory

The method used to determine the geomorphological features and geological structures is such as lineaments, tectonic structure joints, fractures, and dykes. For this investigation, surface data is obtained using elevation data from the Shuttle Radar Topographic Mission. (Abili, 2021).

The geospatial approach employs QGIS for watersheds and ArcGIS software to ascertain the research area's lithology, drainage density, aspect, slope, and lineament (Alikhanov, 2021). According to earlier research, groundwater potential zones expand with low topographic height and gentle slopes (shaban & subba, 2016). The eight spectral bands that make up the ETM+ imageries have three distinct resolutions: 12.5 m for the visible, near-, and mid-infrared (bands 1-6 and 7), panchromatic (band 8), and thermal infrared (band 6). Following their initial projection to the Universal Transverse Mercator Zone 37, the pictures were subsequently projected to the Transverse Mercator (JTM) (Demissie, 2017). The Landsat 7 satellite collected the Landsat data that was utilized in this investigation in Digital processing was used to digitize drainage networks, geomorphological features, and lineaments from the photos.

The research area's final groundwater potentiality map is created using theme maps of geology, geomorphology, drainage density, slope, rainfall, soil, lineament density, and elevation. (Boru, 2018). The groundwater potential model's drainage network, lineaments, and geomorphology are all prepared and determined using remote sensing data (Landsat Enhanced Thematic Mapper Plus, ETM+). Data collection, picture digitization, and image sub setting were the procedures involved in the production of remote sensing data (Ayele, 2018). The Landsat digital online database, accessed through the website http://www.landsat.org, is the source of the visible, near-infrared, and mid-infrared bands of the ETM+ imageries.

These features' maps will be created by visually interpreting the photographs. Software like Surfer, Google Earth, and ArcGIS 10.8 is used in the preparation and analysis of remote sensing data. A lithology will fit nicely with other geographical data by digitizing and spatially adjusting (rubber sheet approach in Surfer and ArcGIS 10.8).

The geological map is used to look into the characteristics and forms of rocks. The digital elevation model produced by using topographic maps (1:50,000 scale) with 20-meter contour lines will be used to produce a slope-specific theme map.

2.2.1 Principles of Geospatial Data

2.2.1.1 Spatial data

This type of data, sometimes referred to as geographic information or geospatial data, is used to pinpoint the precise position of borders and features on Earth, including seas, built or natural objects, and more. Coordinates and projections of map able data are typically used to store spatial data. Geographic Information Systems (GIS) are often used to access, alter, and analyze spatial data (Ayele, 2018).

2.2.1.2 Data Types

Geographic features' shapes and locations are contained in map data. Three fundamental forms are used in maps to depict elements seen in the actual world: areas (referred to as polygons), lines, and points. Characteristic data GIS connects descriptive data to map features using attribute (tabular) data. Typically, attribute data is bundled with map data and is gathered and assembled for certain regions, such as states, census tracts, cities, and so on. Image information Aerial photos, satellite pictures, and scanned maps are examples of image data (maps are printed data transferred to digital format) (Nyssen, 2016).

2.2.1.3 Data Models

According to Bailey (2011), data models are the guidelines that the GIS adheres to, such as "county lines do not overlap," and they are crucial for specifying what is included in the GIS and facilitating the usage of GIS software. There are two primary classifications for all spatial data models: Model for vector data: The vector model is typically used to describe discrete characteristics, such as customer locations and data that has been summarized by area. Raster data model: The raster model is used to describe continuous categories, such as plant kinds, and continuous numerical values, like elevation.

2.3 Dynamic geospatial factors

2.3.1 Slope factor

When determining the watershed's groundwater recharge zones, slope is crucial. Due to its effects on infiltration capacity, runoff speed, and runoff retention on the soil surface (Warku, 2022). Because they promote high infiltration rates and low surface runoff production, flat lands are excellent for groundwater recharge capacity. Moderate slopes provide the possibility of significant groundwater potential since more rainwater can seep into the earth underneath them (Abrar, 2023)

2.3.2 Topographic factor

Groundwater is present in the area due to its gently sloping topography, high peaks, and/or small stream systems. There is a good chance of finding groundwater because of the permeability and infiltration at the low altitude value (Duguma, 2022).

2.3.3 Lineament density factor

Various academics have suggested that the existence of lineaments might indicate permeability zones that indicate the location of groundwater ((Berhanu, 2020). This variable has a significant hydrogeological impact since it creates a pathway for groundwater expansion. Since the presence of a saturation zone is frequently indicated by the lineament's closeness, the thickness of the lineament in the zone may be used to calculate groundwater potential (Anteneh, 2022).

2.3.4 Drainage density factor

Drainage is one of the most delicate factors that makes a big difference in defining groundwater potential zones (Kindie, 2019). Though less water is supplied to the river than surface water, extremely permeable rocks in any research area have a high groundwater penetration rate. When it comes to plateaus and steep slopes, drainage densities are very high and relatively low, respectively (Fenta, 2017).

2.3.5 Precipitation factor

Given that precipitation is the primary source of groundwater, heavy rains can promote groundwater recharge, but insufficient precipitation can potentially have the opposite effect (Mechal, 2015). So, while mapping the groundwater potential zone, precipitation is a crucial aspect (Nigussie, 2019).

2.4 Geophysical methods and its application

Geophysical method is a applied branch of geophysics. Geophysical survey measures the physical properties of Earth as well as anomalies in their properties by using subsurface methods. This allows for the detection of minerals, groundwater reservoirs, hydrocarbons, and other geological structure. In earth science, such as engineering geology, hydrogeology, and environmental science, many other techniques and integration of all the above techniques have been used (Carruther, 2012). For the purpose of exploring groundwater the use of a geophysical survey requires a thorough understanding of it (Ezeth, 2012).

2.4.1 Theory of Electrical Resistivity Surveys

Electrical surveying is focused on measuring changes in the earth's underlying electrical conductivity. The main factors influencing resistivity variation are variations in the underlying rock's composition and the presence of water. Dry deposits exhibit extremely high resistance and little electrical conductivity. The resistivity of a formation decreases with increasing water saturation of its pores or cavities; the porosity largely regulates this resistivity reduction. (Xu, 2024). This happens as a result of water's inherent ability to transmit electricity through its linked cavities, which lowers the formation's total resistivity. Water quality influences resistivity in addition to aquifer composition. (Walkixe, 2021)**.**

Some resistivity value of different materials

Table 2-1: Resistivity of common different Rocks

Materials	Resistivity (ohm)	Materials	Resistivity (ohm)
Air	00	Gabbro	$1x10^3$-$1x10^6$
Pyrite	$3x10^{-1}$	Basalt	10-$1x10^7$
Galena	$2x10^{-3}$	Limestone	50-$1x10^8$
Quartz	$4x10^{10}$-$2x10^{14}$	Sand stone	1-$1x10^8$
Calcite	$1x10^{12}$-$1x10^{13}$	Shale	$20x10^3$
Rock salt	30-$1x10^{13}$	Dolomite	100-10,000
Mice	$9x10^{12}$-$1x10^{14}$	Clay	1-100
Granite	100-$1x10^6$	Ground water	0.5-200

Water in heavily mineralized formations has low resistivity. Rock resistivity is decreased when water enters fissures carrying ions (such as Na+, Ca2+, Mg2+, Cl-, and SO4-). Those soaked with fresh water, on the other hand, have comparatively higher resistance. (Discosal, 2019) The resistivity of distinct saturated formations varies. Very low resistivity is found in silt, clay, and shale; moderate to high resistivity is found in sand and gravel when combined with fresh water.

Resistivity is directly proportional to cross-sectional area and inversely promotional to lengths of wire (the thickness of the layer):

$$R = P\frac{A}{L}$$

Where

P - Resistivity **L** - Length of wire

A - Cross Sectional area **R** - Resistance

Most rock electrical current is produced by electrolytic processes as opposed to ohm operations. The concept of conductivity is defined as the reciprocal of resistivity, and conductivity and resistivity materials are inversely related. Using direct or low-frequency interchanging current and a sequence of electrodes inserted into the ground, electrical resistivity is a geophysical technique used to measure subsurface electrical resistivity structures.

2.4.2 Basic Principles of Resistivity for Groundwater

Groundwater has ionic conductivity due to the various dissolved salts it contains, it allows electric currents to flow into the ground; therefore, measuring ground and subsurface resistivity allows one to determine the conditions that must exist for water to be present or absent. In resistivity surveying, particularly in vertical electrical sounding (VES), conduction in rocks is primarily caused by pore fluids acting as electrolytes.(Dahlin, 2019). Although pure water is not a good conductor of electricity, most water contains dissolved salts that help with this process. The water content (porosity), water resistivity, clay content, and metallic mineral content are the main factors that determine a rock's resistivity. (Barner, 2015).

The following factors are taken into account when determining the resistivity of rock: Electric current flows very slowly through a hard rock that has no holes or cracks in it. Hard, fresh Precambrian rocks are often where this is seen. Sand that isn't wet and dry is particularly resistant. The resistivity of porous or cracked rock that contains free water is influenced by both the porosity of the rock and the resistivity of the water. Wet impermeable clay layer with low resistivity; yet, yields may be insufficient for groundwater extraction to be profitable. The electrical conduction of mineral ore bodies (iron, sulfides) results in extremely low resistivity, often considerably lower than 1 ohm/m (Barbar, 2016).

The Resistivity values of earth materials cover a wide range. In resistivity measurements, the highest resistivity is associated with igneous rocks. Sedimentary rocks tend to be most conductive due to their high fluid content. Metamorphic rocks have intermediate resistivity. Granites and quartzite have high resistivity ranges; sandstone and shale have intermediate resistivity ranges. Earth materials have a wide variety of resistivity values. Igneous rocks have the highest resistance when measured for resistivity. Because sedimentary rocks have a high fluid content, they are typically the most conductive. Rocks undergoing metamorphism have moderate resistivity.

The resistivity ranges of sandstone and shale are moderate, whereas those of granite and quartzite are high. This form of geophysical surveying involves the identification of surface effects brought about by low levels of electric current within the ground. It lists the various subterranean strata depths, (Shishaye & Abdi, 2016)

Table 2.2 Resistivity Value for some common geologic formations

Material	Nominal Resistivity(ohm/m)
Sandstone	200-5000
Sandstone (Weathered)	50-200
Clays	1-102
Gravel(Saturated)	100
Basalt	10-1.3/107
Top Soil	250-1700
Sandclay/Clayed Sand	30-215
Sand And Gravel (Saturated)	30-225

The absolute value of the ground resistivity must be taken into account in order to determine the prerequisites for the presence of groundwater from resistivity measurements. Aquifer resistivity typically has a target range of 50–200 Ohm–m (Barner, 2015). The goal of groundwater in a hard rock environment is a low-resistivity anomaly because these rocks are thought to be extremely resistive to the flow of electric current.

Table 2-2: Numerical resistivity value for various types of water

Type of water	Resistivity (ohm-m)	Conductivity (micro/cm)	Salinity (mg/l)
Very Fresh	200	50	35
Fresh	20	500	150
Salted	10	1000	700
Sea Water	0.3	30000	35000

2.4.3 Apparent resistivity

We can observe that the resistivity, as calculated by the equation, is not a constant but rather depends on the electrical characteristics of the subsoil and the electrode placement geometry. A resistance measured in ohms, ρa, is perceived to exist. In order to compare the two methods' applications and notice similarities in their usage and handling in the field, the Wenner and Schlumberger method's apparent resistivity utilizing four probe electrode configurations is conducted at the same chosen locations. Schlumberger and Wenner techniques were used to conduct the VES. Wenner calculates values once the data are plotted on the appropriate graphs. IP2Win software was utilized for Schlumberger.

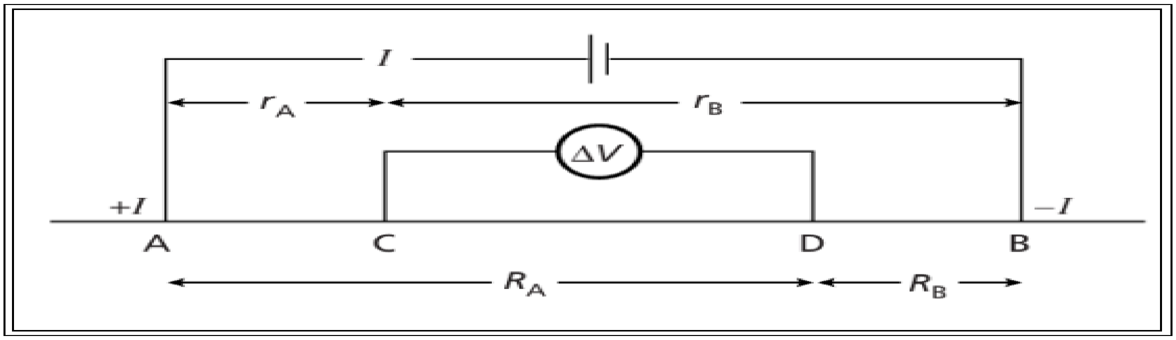
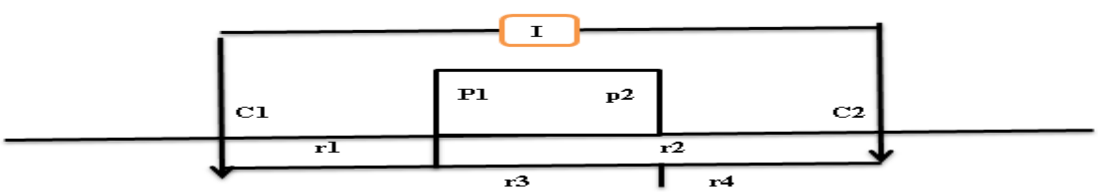


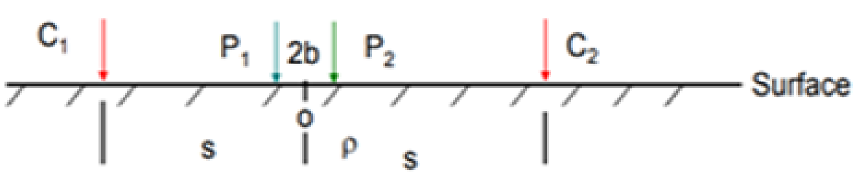
Figure 2 1: Schlumberger array system

When two current electrodes are placed one on top of the other, the amount of current that penetrates below the surface is 1:13. Its foundation is the inverse slope approach, which uses four probe techniques spaced equally apart. To infer the depths and resistivity of the layers that are present, VES is used to record the changes in resistivity with depth and connect it with the geological data that is already accessible.

In The Schlumberger array system, in order to identify locations that are appropriate for groundwater development, vertical electrical sounding (VES), a method used during the current survey, provides subsurface information about the composition of rocks and their degree of weathering and/or fracture. According to (Maurya, 2024) subsurface vertical variations in resistivity can be found using vertical electrical sounding (VES).

Using the maximum current electrode parting range, the Schlumberger electrode arrangement was utilized for VES reading at every spot that was tested. A surface electrode is used to conduct an electric current in order to measure the resistivity of the stratum. The depth of penetration rises in proportion to the distance between the electrodes. In this system, the electrodes are symmetrically placed around a point at the center of the array





Here r_1=s-b; r_2=s+b; r_3=s+b; r_4=s-b and therefore from this

$$\Delta V = I\rho \left[\left({}^{1}/_{s\,-\,b} - \frac{1}{s+b}\right) - \left(\frac{1}{s+b} - \frac{1}{s-b}\right)\right]$$

$$\Delta V = \frac{I\rho}{2\pi}\frac{2b}{(s^2 - b^2)}$$

$$\rho_{as} = \pi\left(\frac{s^2 - b^2}{2b}\right)\left(\frac{\Delta V}{I}\right)$$

The polarizing electrodes needed for measuring the potential differences are placed at predetermined distances on either side of the chosen center, near the measuring equipment. This method assumes considerable importance in the field of groundwater exploration because of its ease of operation, low cost, and capability. The VES curves are interpreted by using the IPI2WIN Geoscientific Software (Olatunji, 2024).

CHAPTER THREE

METHODOLOGY AND MATERIAL USES

3.1. Descriptive Of Study Area

3.1.1 Location of Study Area

The study area is located along the Ambo-Nekemte main road in the Chelia woreda, west Shoa zone of Oromia regional state, Ethiopia. It is astronomically bound between UTM coordinates (**325690** to **323500)** Easting and (**997500** to **999870)** Northing. The elevation range of the study area is between 1084.87m and 3037.29m above sea level.

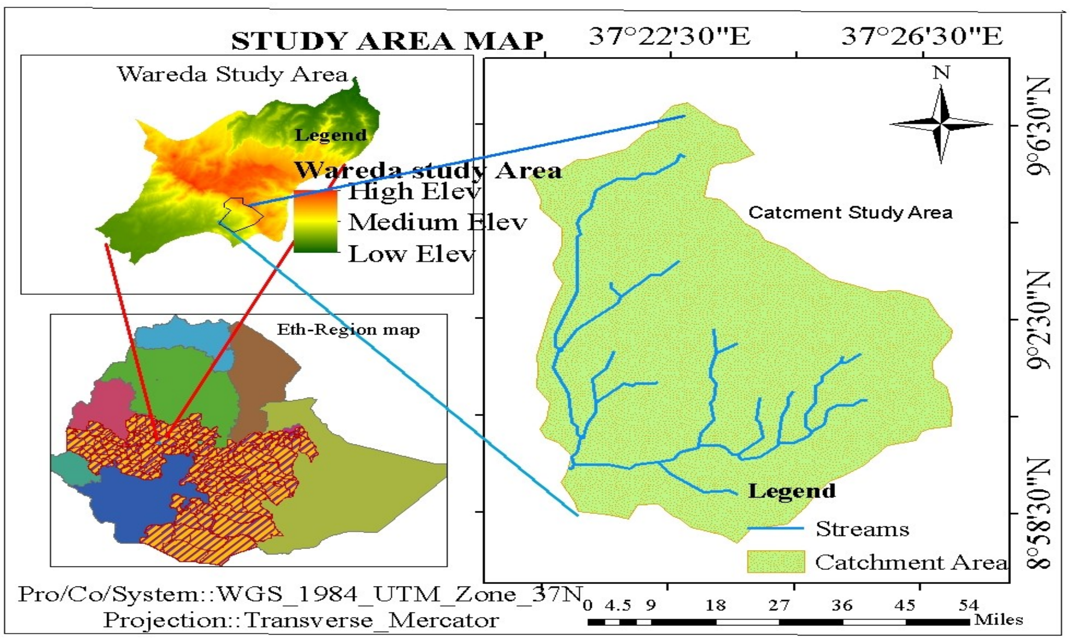


Figure 3-2: Study area map

3.1.2 Physiographic study area

Physiographic features of the study area generally include a cold climate during the summer and smooth heat during the winter in case forest is present there. The area is characterized by the mountains high rugged features, landslides (mass movement) of soils and sediments, and erosional sediments. The study area has gentle slopes and a small area of high range forest. Local landmarks A survey of the land in Chelia shows that 87.4% is cultivable, 7.2% is posture, and 2.98% is forest, 2.41% is grassland.

3.1.3 Accessibility study area

Geological features like lineaments and fractures that are visible along the road have an impact on the research area. Internal roads are primarily made of cobblestones, although major routes, like those connecting Addis Ababa to Nekemte, are mostly asphalt. The majority of morphological changes have an impact on roads and land features, particularly on distinct land formations.

3.2 Methodological Approach

The study procedures consider combinations of integrated geophysical and geospatial methods. Geophysical methods can provide information on the exact position of groundwater aquifers in the subsurface. Generally, the methods applied for groundwater exploration involve two different techniques and combination of methods.

1. Geospatial Methods
2. Geophysical Electrical Resistivity Method.

3.2.1 Geospatial Methods

In groundwater investigations, the idea of geospatial approaches has proven to be a useful tool, enabling improved data processing and interpretation (Murthy, 2017). A number of theme layers will be used in geographic methodologies to extract and design the groundwater potential. An essential initial step in any examination of groundwater is the surface geological approach. The ability to quickly extract information on groundwater occurrences, save money and time, and identify interesting regions for more groundwater research are the key benefits of adopting remote sensing and GIS tools for groundwater exploration. (Hammouri, 2012) As well as its capacity to provide data in the temporal and geographical domains, this is essential for groundwater investigation.

3.2.1.1 Material and Data used for geospatial method

The Global Positioning System topographic map, among other geospatial resources, is utilized in this work. Earth Explorer (www.earthexplorer.usgs.gov.com) is the website where the digital elevation model (DEM) data was obtained. Data on land cover in the information will be clipped to the research region and processed further in GIS. GIS will analyze and compute the slope layer based on the DEM. The DEM in GIS is used to process the research area's slope, drainage density layer, and river network. In kilometers per unit area, or km/m2, the drainage density layer is measured. Digital Elevation Model (DEM) digitization combined with the use of GIS methods to locate faults from geological data will result in the creation of the lineament density layer (Solomon, 2018).

3.2.1.2 Data Processing procedures

Multi-criteria decision analysis using the Analytical Hierarchical Process (AHP) is the most common and well-known GIS-based method for delineating groundwater potential zones. This method involves the interpretation of existing map data, topographic map data, aerial photograph data, and satellite image identification of overlying spatial factors to estimate the depth of the study to be made. After the site selection specified depends on the geospatial description, the geospatial method follows the following steps to indicate groundwater potential indication: The methods of analysis follow the bottom steps and are displayed under the result.

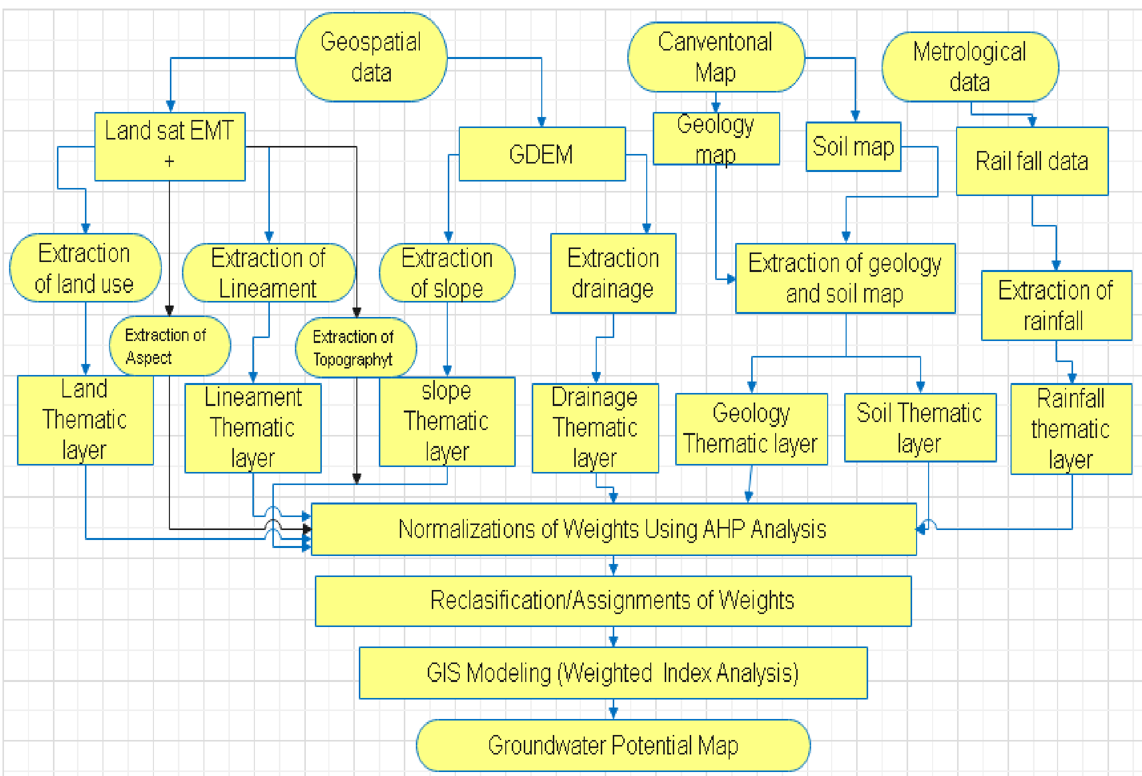


Figure.3-3: Methodological Flow of the Geospatial Analysis

3.2.2 Geophysical method

In Modern times, there is the emergence of a relatively new academic topic known as "geophysical techniques," which focuses on the geophysical examination of resource regions and defines the subsurface (Nikos, 2019). The conductivity of earth materials depends on porosity. When identifying differences in the various physical characteristics of materials, geophysical approaches might be helpful. Surface geophysical techniques don't require any invasiveness or intrusion. Consequently, the disturbance brought about by invasive research techniques like drilling and pitting is avoided. Electrical techniques use low-frequency alternating currents or direct currents to explore the subsurface electrical characteristic.

3.2.2.1 Electrical Resistivity Methods

The resistivity property of the ground, structural features in the area reported using this approach, and factors governing the presence of groundwater are detailed. On our study area we collected five Imaging data in parallel of each other. Each data points are interpreted under the result for common their objectives. It provides high-resolution, two-dimensional subterranean pictures that are appropriate for fracture detection. One kind of geophysical technique called electrical resistivity is used to measure the ground's electrical resistivity in order to create a two- or three-dimensional geoelectrical profile with a limited geological formation. (Reynolds, 1997).

In the Wenner arrangement, where the electrode spacing was fixed, the horizontal profiling approach was frequently used for operational simplicity. Appearance resistivity readings are measured at discrete intervals along 100m a profile after the complete array has been moved along it. A linear graph representing the apparent resistivity values as a function of profile distances is presented. Anomalies are highlighted during the journey by variations in the apparent resistivity magnitude. For the collinear array technique of electrical resistivity to function, the internal resistance of the potential measurement circuit needs to be significantly greater than the ground resistance between the potential electrodes.

3.2.2.2 Vertical Electrical Sounding (VES) Method

Vertical Electrical Sounding (VES) Method was injecting steel electrodes into the soil through two electrodes; one may measure the resistivity voltage between the two electrodes using direct current electrical resistivity. The collected data points are 12 point on my field study to specify objectives. The points re arranged by 100m gap distance and 300m to 500m extension to cover the study area. The collected data are interpreted under the result to specify depth and layer. With software analysis, the geoelectrical profile may be converted into an interpretive geological cross-section. Using data from geological maps, vertical electrical sounding (VES), and many field hydrogeological investigations, a comprehensive examination of the aquifer system is conducted. (El Makrini, 2022). Records were kept of the apparent resistivity at various electrode spacing and VES point locations. Plotting and analyzing the VES data in the field concurrently allowed for the management of data quality. The distance between the electrodes determines the depth of investigation (layer) as the distance increases.

3.3 Materials use

The materials and steps involved in the acquisition of the geophysical data used on the field trip are discussed in this portion.

3.3.1 Instrumentation and Field Procedures

Resistivity meter: The Omega resistivity meter has an external power source and also an internal or external battery. It has sockets through which electrodes and the external power source are connected to the resistivity box. The potential difference across the electrodes will be measured by a direct current voltmeter, while the resistivity meter measures the current that a direct current source transmits into the ground.

Metal Electrodes: They are usually steel metal rods about 90cm long, so that they can deeply penetrate into the ground for good electrical contact. In order to conduct the survey, four electrodes are needed: two are used to send currents into the ground, and the other two are used to measure the potential difference between them in order to conduct vertical electrical sounding (VES).

Connecting Cables: They are used for connecting electrodes (current and potential) to their respective meter units.

Measuring Tapes: They are uses for measuring the separation distances of the pegs.

Global Positioning System: This is uses to take the coordinate of data station on the field. **Compass Clinometer**: This is uses to determine the orientation of the traverses, angle of dip and strike directions of fractures on rocks and also to determine the bearing of a given location on the field with respect to one another.

Hammers weighing up to 6.9kg is uses. These hammer use for driving the electrodes firmly into the ground.

Cutlass: This is uses in clearing paths and location for where pegs are fixes for easy access when electrode are moves.

3.4 Survey Design/Procedure

The general survey for geospatial and geophysical approaches, including vertical electrical sounding and electrical resistivity, is provided below. The resistivity meter deployed for this project is a fully automatic resistivity meter. The measurement is made fill automatic though the control of a microprocessor and highly accurate by way of; Noise monitoring before injection, Standard deviation computation, Automatic spontaneous polarization (SP) correction, Automatic ranging, Digital stacking for signal enhancement, Error display in case of procedure troubles. It has a maximum output voltage of 600 V With a reading a current at 10pA. A serial link permits to transfer the data to a PC for data processing and interpretation. The instrument used for the logging was powered by a rechargeable l2 V batteries accompanied by a high resolution registry entity Figure **44**.

3.4.1 Geophysical Survey Electrical resistivity

Stainless steel stakes with the ability to transmit current and measure voltage are called electrodes. Select a distance between the electrodes. When selecting electrode spacing, it is crucial to take into account the mathematical relationship between the sensors and the site's depth in order to perform an electrical resistivity survey over the area that has to be measured accurately. There is virtually minimal electrical resistance at a depth of 100 meters below the surface. To identify a target, vertical electrical sounding is necessary since the area's electrical resistivity is less than half the electrode spacing.

3.4.1.1 Lay out the tape measure

Stakes, electrode cable, switch box, and Super Sting must all be connected. While the apparatus is scanning the subsurface, more accurate electrode placements can be measured using a complete field station or differential GPS, if necessary. Depending on how many electrode sensors are planted, a scan may take a few seconds or considerably more.

3.4.1.2 Run a contact resistance test to check that all is connected right

Start the contact resistance test to confirm proper electrode connection across the board. If the electrodes are not properly connected or are not securely placed in the ground, the instrument will emit; therefore, verify before the real survey begins.

3.4.1.3 Begin the resistivity survey scan

Once the system is operational, input the survey filename, the electrode spacing, and the command file into the resistivity material before pressing the start button to start the survey. Depending on how many electrodes and what kind of electrode array is utilized, this might take anything from a few minutes to a few hours.

3.4.1.4 Visualize the data scan in real time

Employing a software programmer on a computer device, you can instantly see the measured data on a graphical color plot known as a pseudo-section. The pseudo-section is used in the field for data quality assurance and control.

3.4.1.5 Turn data into a model representing the subsurface

The data on the resistivity material is instantly accessible when the scan is finished. While still in the field, upload the data to a laptop via a Bluetooth connection or wires, and then utilize inversion software like Earth Imager 2D or 3D to acquire a comprehensive 'X-ray' of the ground.

3.4.2 Vertical Electrical Sounding survey

For almost horizontal formation layers, the electrical sounding suggests changes in resistivity with depth from a certain location on the ground. Hard rock, loose horizontal overburden thickness in river valleys, and groundwater projects may be determined with this approach. Just four electrodes and an appropriate connection for each electrode to connect to the equipment are needed for VES surveys. Typically, a logarithmic sequence is used to increase the spacing AB for a Schlumberger array VES. Around a given center point, vertical electrical sounding maintains current and potential electrodes in a straight line at the same relative spacing. As the distance between the current electrodes increases, it exerts pressure on the current to constantly penetrate deeper. {Sound} descends to higher depths as the electrode array size grows.

Commonly employed for VES, the Schlumberger array moves the current electrode dipole (A and B) while maintaining the potential electrode dipole (M and N) stationary. This is a well-liked option because of the constant potential electrode dipole, which makes the measurements less susceptible to resistivity variations on the lateral side.

3.4.3 Summary of field precautions

Surface disturbance distorts the current flow pattern, which introduces false findings and potential readings. Consequently, Measurements near power lines can be problematic since they can inject high voltages into the ground. This is especially true if the power lines are next to earth wires. It's not realistic to expect well-maintained equipment to operate. Because of this, routine examinations are essential, as is the repair of deteriorated accessories like batteries. It is important to emphasize that maintaining accurate records of field data and measurement point locations is crucial.

3.5 Data Acquisition

3.5.1 Geospatial Data Acquisition

Ensure that all data is appropriately put in space before beginning any data processing (various techniques of gathering require different procedures of geo-referencing). But collection and processing alone are insufficient; therefore, we also include various quality controls in our work processes. Spatial data precision is crucial information that is essential to assessing the caliber of data processing. Because of this, the research was held to appropriate standards that guarantee sufficient understanding of the thematic correctness, placement, and completeness of geographical data, all necessary for the effective execution of any spatial analysis. Geographical data is obtained from the distributor's satellite picture by giving exact instructions about the data's position, processing intensity, and quality.

3.5.2 Resistivity Data Acquision

3.5.2.1 Electrical Resistivity (Imaging) Tomography

During the electric field survey, the equipment syscal switch is connected to cables, each of which has a length of 720m and 72 electrodes are injected into the ground within a fixed separation of 10m in the field survey.

For the purposes of this study, it was determined that an interval spacing of 10m would adequately provide for the shallow area as well as the surficial materials. In the electrical resistivity tomography survey, five profiles were measured. At interval spacing of 10m, it penetrates a depth of about 120m for three profiles and two profiles are t the range of 5m in interval cables. After the Syscal switch instrument finished recording electrical resistivity data, the data was transferred to the pc computer by SD cable through Prosys II software.

3.5.2.2 Vertical electrical sounding

It is difficult for cover all study area surface survey. A resistivity survey will be taken over four parallel profiles at 12 along the specific distance between the profiles studied. A Schlumberger array arrangement across the catchment is generally used with electrode spacing (AB/2) ranging from 1.5 to 500m for maximum depth. The research region will be surveyed using a total of all VES distributions on four distinct profile lines, separated by 100 meters between each profile line. The position of VES points and the apparent resistivity for various electrode spacing were noted. By simultaneously charting and analyzing the VES data in the field, the quality of the data will be controlled.

3.5.3 Electrical Resistivity Data Reduction and Processing

Data processing of electrical resistivity tomography data collected from the field edited and modified by Res2dinv 2D software format to interpret and get the true resistivity sections. Geological formations, groundwater potential zones, and the physical characteristics of underlying rocks are all used in ERT studies. On logarithmic translucent paper, the apparent resistivity values are shown. During the data collection procedure, the ordinates' apparent resistivity value and the abscissa's electrode separation (AB/2) are processed. With a comparatively significant rise in the current electrode distance (AB/2) in the resistivity measurements, the potential electrode distance (MN) would gradually increase.

CHAPTER FOUR

RESULT AND DISCUSSION

GEOPHYICAL INVESTIGATION

The groundwater geophysical investigations designed to detect potential aquifers by indicating buried moisture as bright areas on processed imagery. This system integrates remote sensing and geophysical convectional hydrologic assessment technique. It has been used to map and assess potential alluvial aquifers, conductive fractures, and deep aquifers in a wide range of situations, including drought zones, emergencies, and early recovery problems like water scarcity situations. The methods have been applied successfully in several parts of the world since 2004 for groundwater exploration (Omosuyi, 2021). The hydrogeology has been assessed in terms of precise location, potential point, potential depth, and layer thickness by geophysical methods.

4.1 Geospatial Data Processing and Interpretations

Mapping groundwater potential may be accomplished by looking at storage sites, or aquifer sites, which rely on rainfall sources, geological structures, and geomorphological conditions that control their occurrence. Thus, the elements influencing groundwater transport, storage, and occurrences were investigated, and the creation of a groundwater potential map was aided by thematically mapped digital mapping. The layers include slope (Error! Reference source not found.) lineament density (**Error! Reference source not found.**), drainage density (Error! Reference source not found.), land use/land cover (**Figure 4-9**), topography contour (Error! Reference source not found.), aspect value (Error! Reference source not found.) rainfall (**Figure 4-12**), lithology (**Figure 4-10**), and soil type (**Figure 4-11**).

With the help of Arc-GIS 10.8 Version, these parameters were merged using a GIS environment. Groundwater infiltration and percolation are determined by the earth's surficial geology, which is implied by this component. Water is obtained by rainfall; lineament (rock fissures), which greatly improve water recharging; slope, which regulates the energy of water flow; drainage density, which is very influential in runoff distribution and infiltration level; and geomorphology, which regulates surface runoff and infiltration.

4.1.1 Digital Elevation Model (DEM) Data Interpretations

4.1.1.1 Slope Factor

Slant is vital in distinguishing the groundwater re-energize zones of a watershed or catchment since it influences the overflow speed, spillover maintenance, and penetration limit on the surface. Low-slope-level regions are excellent for groundwater capacity since they have high penetration rates and a slower runoff surface. Nonetheless, regions with steep slants have less groundwater potential in less time and are therefore more likely to invade. In this way, precipitation is exerted, transformed into spillover, and quickly streams down the slant. For the most part, level slant areas have a high possibility of having a having a large amount of groundwater potential.

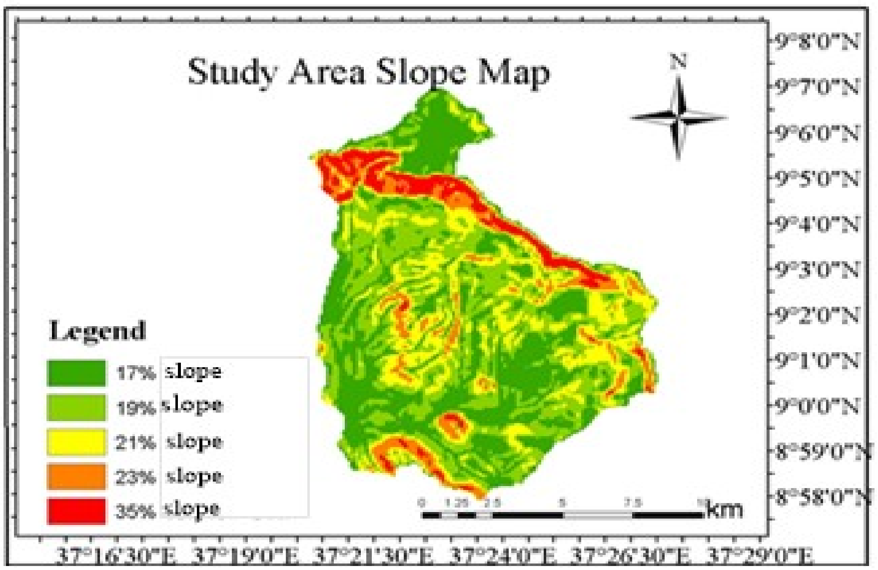


Figure 4-4: Slope Map of Study Area

Low-slope regions of the south-west part of the study area (17%–19%) slope have low surface runoff and high percolation rates, whereas steep slopes in the central part of the study area and the north-east of the study area (21%–23%) slope have meteoric fluid runoff to drainage. In order to get high groundwater potential, flat slopes are preferable to extremely steep slopes. So, a very low-slope area has high groundwater potential around the very green color map of the study area.

4.1.1.2 Lineament Density

Lineament density is the expression of the ratio of linear length to length area, and lineament is a quantitative measure of the linear length characteristics of lithological structures. Lineament gives useful hints on the flow and storage of subsurface groundwater. A higher lineament density corresponds to a larger groundwater potential. Geological features known as lineaments have an impact on the hydraulic characteristics of geological formations, including their transmissivity and storability. Thus, groundwater occurrence, storage, and flow are significantly influenced by the lineament's density and connectedness.

The lineament (geological fractures) are commonly abundant in the central part of the study at the point location of 8º59'30'N to 9º09'30'N and 37°13'00'E to 37°28'00'E coordinate system. So the catchment of the study area is included in the extension above the coordinates. The lineament density map is only from the catchment; it also includes the wide area of study because its presence or absence affects the groundwater potential zone.

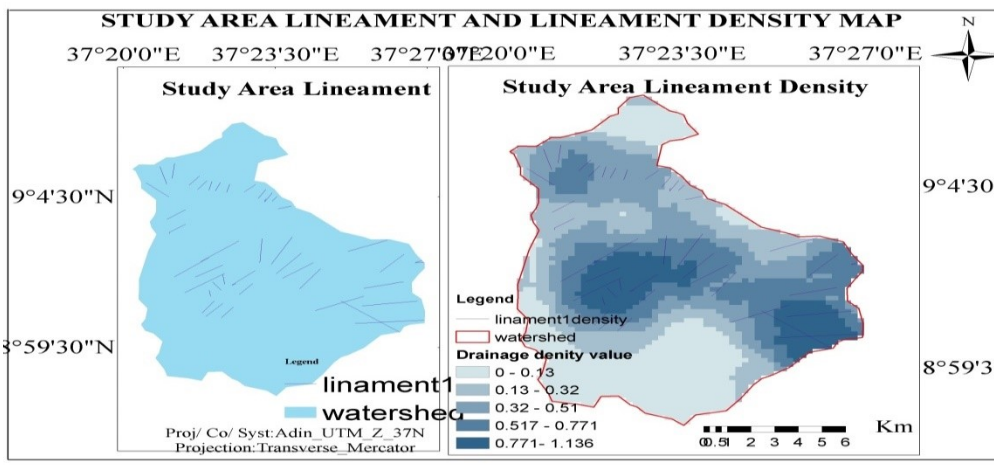


Figure 4-5: Lineament density Map of Study Area

Lineaments provide crucial guidelines for groundwater circulation and storage potential in the projected zone. Since structural elements like fractures serve as channels for groundwater and precipitation stored in the primary or secondary porosity of rocks, lineament analysis is a crucial stage in the groundwater exploration process. There is more groundwater in areas with high lineament densities in the research area's center.

4.1.1.3 Drainage density

The stream and drainage are the subjects of this conversation. Because of the erosion, flooding, and the elements that contribute to a drainage area's resistance are constantly interacting, drainage density is a crucial component form a geomorphological and hydrological standpoint. A stream interaction (join) is considered a part of the landscape from an earlier perspective, and its spatial distribution within a drainage basin has a significant impact on the kinds and intensities of specific geomorphological processes. Drainage density is given by summations of stream length per area of the study area.

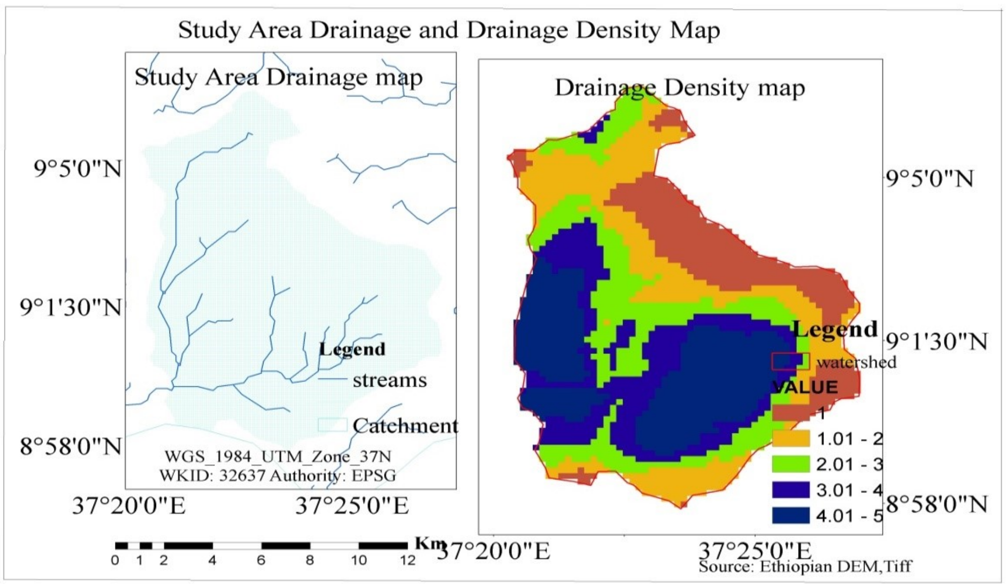


Figure 4-6: Drainage density Map of Study Area

A key morphometric indicator, stream density, can reveal further details about how drainage basins react to runoff processes. The number of flow order joining of progressively increasing orders, as represented by a diminishing geometric progression, can be used to compute the stream segment density. Drainage density is vital to hydrologists because it affects surface runoff processes, which in turn affects how intense torrential floods are, how concentrated they are, how much debris they carry, and even how much water is in the drainage basin. Subsurface flow and rapid flow proportions may grow as the watershed's mean slope rises, but surface flow percentages may decline.

A region with a very high drainage density around blue-colored legends will have many drainage channels, and a region with a low drainage density will have less runoff and a higher likelihood of recharging and groundwater potential. Numerous factors, including altered precipitation patterns or harsh weather, altered land use, and ground subsidence that permits a higher rate of infiltration, can contribute to an increase in drainage. The surge in drainage can be caused by a number of circumstances, including changes in precipitation patterns or harsh weather. The majority of drainage problem is usually caused by an inadequate pitch or slope in the study area, which keeps water runoff from being diverted away from the house.

4.1.1.4 Topography

The subsurface capture zone's characteristics, rather than the surface capture zone's size or topographic rise, govern the groundwater potential storage and groundwater flow subsystems. A significant additional component affecting the formation of stream flow or groundwater potential is topography.

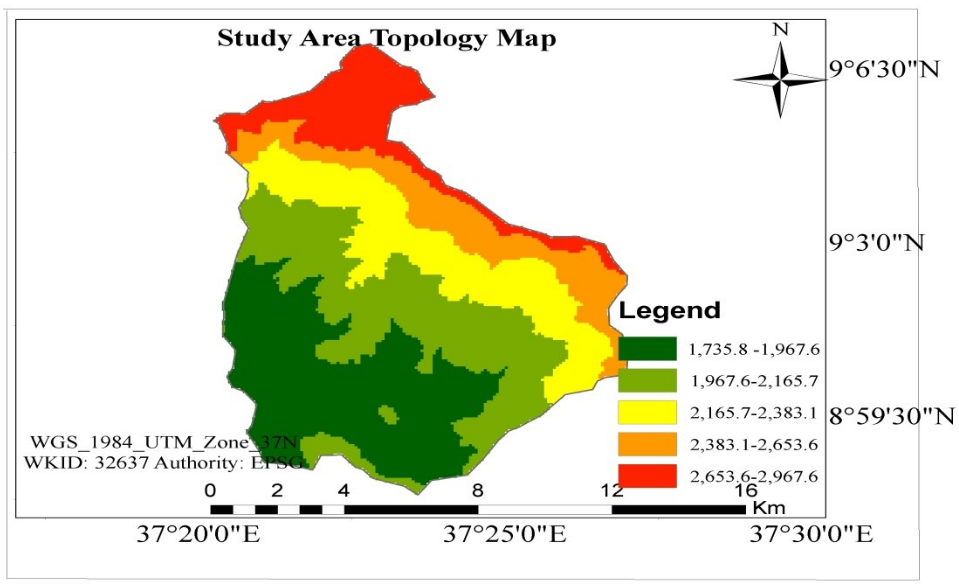


Figure 4-7: Contour polygon Map of study Area

In all examples, the topography clearly exerts an influence on the penetration depth in average flow patterns. Topography may significantly affect base flow processes and water transmission rates, especially in locations with a high relief ratio. The research area's polygon contour map is displayed in the above figure. Moreover, the creation of bedrock and soil, which in turn influence the storage of subsurface flows, may be influenced by topography.

Changes in a watershed's topography can have a positive or negative impact on how land use affects stream flow yields and dynamics. Though a watershed may be identified by contrasting land use and topography, the impacts of topography or land use on stream flow production are most often studied independently from paired watersheds with comparable terrain but differing land use, or vice versa.

4.1.1.5 Aspect Value

A hillside's aspect is generally the direction that the slope faces on a compass. A slope that faces south is sometimes referred to as a southern aspect. Digital elevation data (elevation points, contour lines, digital elevation models, etc.) may be analyzed by a variety of geographic information systems (GIS) to provide slope and aspect data sets in Arc-GIS software version 10.8.

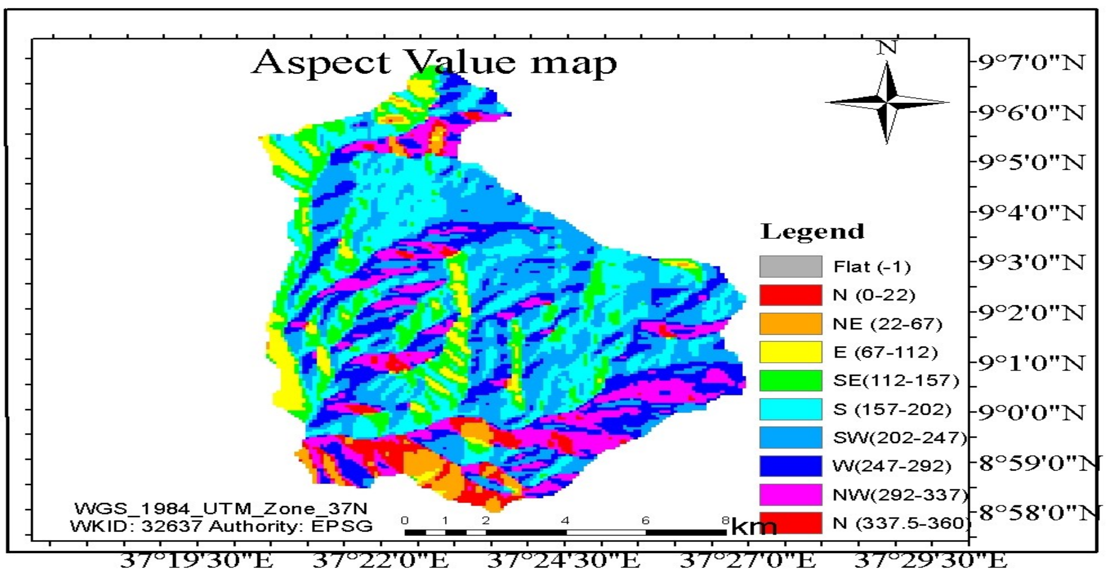


Figure 4-8: Aspect Map of Study Area

Depending on their aspect, hillsides receive varying amounts of sunlight. As general, true south-facing slopes receive the most sunlight, while the west and east portions get some time. The slope of a hill determines how much sunshine it receives; hillsides facing northward receive little to no sunlight, while slopes facing southward receive more. Aspect value has a great effect on the local climate, or microclimate, when temperatures are at their highest (unless large-scale rainfall impacts mandate otherwise).

4.1.1.6 Land use and land cover

Lu/Lc has great value for groundwater potential distribution and occurrence. As many studies and journals propose, Lu/Lc is used for groundwater potential assessment and investigation. Those are forest covers that have a high water potential content in terms of reducing the amount of flood infiltration. The second water potential is Agricultural areas having fewer amounts when related to agriculture but have greater value than grassland. It also shares common principles of land cover and land use and vegetation's land features. It also deals with classification, description, and form.

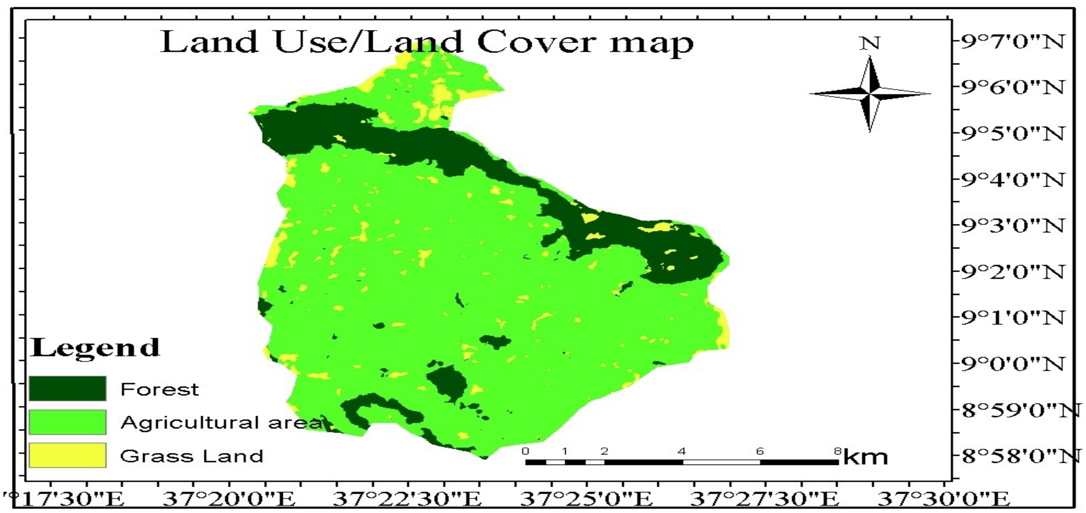


Figure 4-9: Land use/Land covers Map of Study Area

The lowest water potential is found in the grasslands. Groundwater recharge can be enhanced by various natural features such as lakes, ponds, streams, forests, and shrublands. These features allow water to percolate through their root systems and prevent it from flowing overland. On the other hand, barren land, grassland, and rocky terrain allow more surface flow, which reduces their contribution to groundwater recharge (Sanjib Sapkota, 2021).

4.1.2 Lithological Properties Considerations

Each unit's unique geology affects how groundwater arrives, moves through, and is held in an aquifer. Grain size and distribution, lithology, and stratigraphy are some of the characteristics of the sediments that make up the aquifer that determine whether or not alluvial sediments have the capacity to act as a reservoir for water. The weathering of basaltic rock is one example of a geologic property that affects groundwater flow and storage.

Basaltic rock usually weathers to clay and colloids, which reduce reservoir porosity and permeability. Thus, the majority of the research fields are in lithology, particularly basaltic rocks. Groundwater prospect sites on fractured bedrock are often determined by groundwater exploration using straight to curved geological discontinuities, such as joints, fractures, and faults. There are similarities in the structural history, digenesis, and fundamental inter- or secondary (karst or solution) porosity across time. Grasping and evaluating the hydrogeology (groundwater) requires careful mapping and a thorough grasp of the paleogeography as well as the geologic and structural environment.

4.2 Geologic Formations, Geomorphologic Features, and Surface Configuration on Groundwater Potential

Geological formation affects groundwater availability in many direct and indirect interactions. Cheia Wareda is generally covered by quaternary volcanic rocks. Those volcanic rocks are mostly basaltic rocks, and some sedimentary deposition extended from main Ethiopian rift valley deposition. Those basaltic rocks dominate the area are fractured due to uplift processes. These behaviors help the study area store more groundwater potential. In most cases, the geology that contains more water potential is metamorphic rocks as a science.

According to Al et al. (2020), lithology can determine the kind of porosity and permeability in addition to the occurrence, movement, and storage of groundwater. Porousness determines both the volume of water that may be stored and the ease with which water can be retrieved for usage. Intergranular porosity is predominant in unconsolidated sediments, but fracture porosity is present in consolidated rocks, and double porosity is present in some cemented volcanic and sedimentary rocks. This is one of the most delicate aspects that influence the likelihood of groundwater availability in the study area.

4.2.1 Geology of study area

The lithology formations known in the study area are intra-continental rift stages and post-rift stages. This lithology extended from the main Ethiopian rift to ward central is sedimentary and volcanic lithology. It is predominantly characterized by sandstones rocks. Sandstone rocks are mostly associated with conglomerate rocks, which have a high amount of porosity and permeability.

The presence of permeability and porosity shows the highest amount of groundwater potential. Following is the sandstone facies, which is separated between thick, massive sandstone and fine- to medium-grained gravels. With fine grains at the top and medium grains at the base, the study's grain size decreases. When tertiary lithology was being formed, a crack caused the other rocks in the trap series to erupt, making them the oldest group of volcanic rocks. These are mostly composed of porphyritic olivine basalt (black basalt), which is covered with ignimbrites and flood basalt that are on top of shield volcanic. Geomorphology is the lateral form or shape of the earth; it is principally related to the land feature of the earth surface.

Geomorphology description: land surface control, water percolation, and runoff production This includes surface structural elements like upper geological unity, soil cover, vegetation properties, and agricultural area **(Figure 4-9**). These studies suggest a significant increase in infiltration among vegetation plants. Fractured rock outcrops, as well as an increase in vegetation, are automatically related to groundwater potential occurrence, recharge, and discharge in terms of altering hydrological cycles such as interception and transpiration.

Understanding the processes and lithology related to groundwater occurrence and potentials is aided by the depiction of significant landscape and underlain geology on geomorphological topology maps (Error! Reference source not found.). Zone of Groundwater Potential On the process theme layer created, a map is displayed. Satellite imagery has been extensively utilized in geomorphologic mapping ever since the initial Landsat data became accessible. Classifying landforms, characterizing processes, and examining the connection between processes and landforms have been the main uses of satellite imaging. However, data on landform distribution, location, composition of the surface and subsurface, and elevation may also be obtained using remote sensing (Smith, 2009).

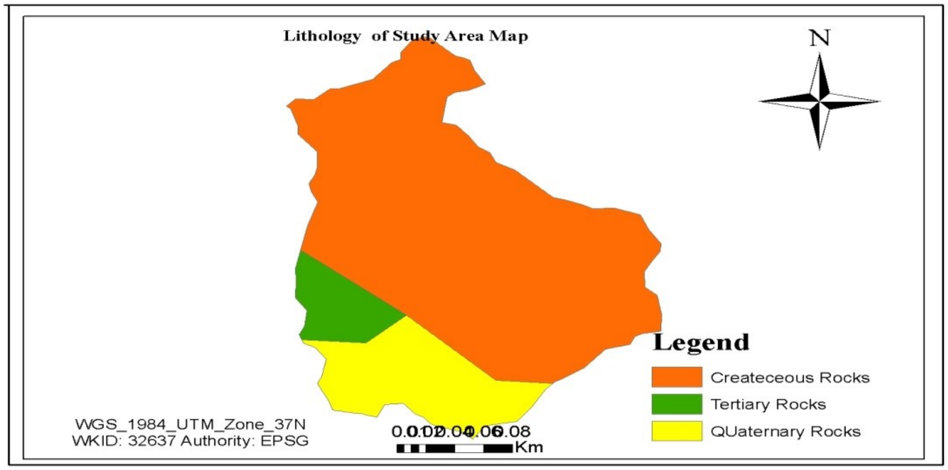


Figure 4-10: lithology Map of Study Area

The earth's surface configuration reflects virtually all exogenic formations on the surface and depth of the earth. Those features are mountain ranges, erosion processes, weathering, and soil formation. Those also include transportation materials, run-off, wind erosion, landslides, etc. Those are known as destruction and construction processes. Changes in the previous land forms can affect the presence or absence of groundwater potential.

4.2.2 Soil Data of Study area

A) Eutric cambisols

Eutric cambisol covers most of the study area, and motley coverage is found all over the world. Its deposition and erosion cycles explain why it formed in a mountain area. These soils are less common in the tropical region, where there is high erosion. Cambisols occur in some geologic active areas where their soil type has an association with mature soil type. These types of soil occur in the study area in small amounts around the south-west of the study area. The soil type of this is dominantly at the cool temperature of alluvial deposits that are formed from free-weathered material.

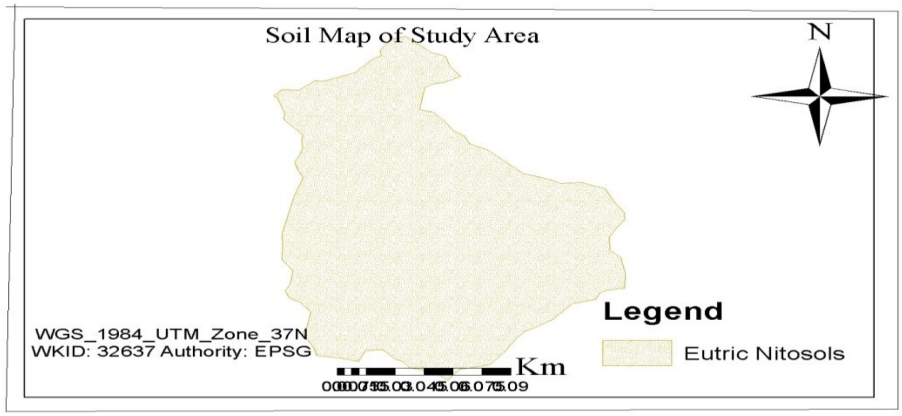


Figure 4-11: Soil Map of Study Area

4.3 Metrological Data Interpretations

4.3.1 Rainfall

Rainfall is the main source of groundwater, and the slope gradient directly affects the infiltration of rainfall into the ground. The groundwater potential increases as the rainfall increases.

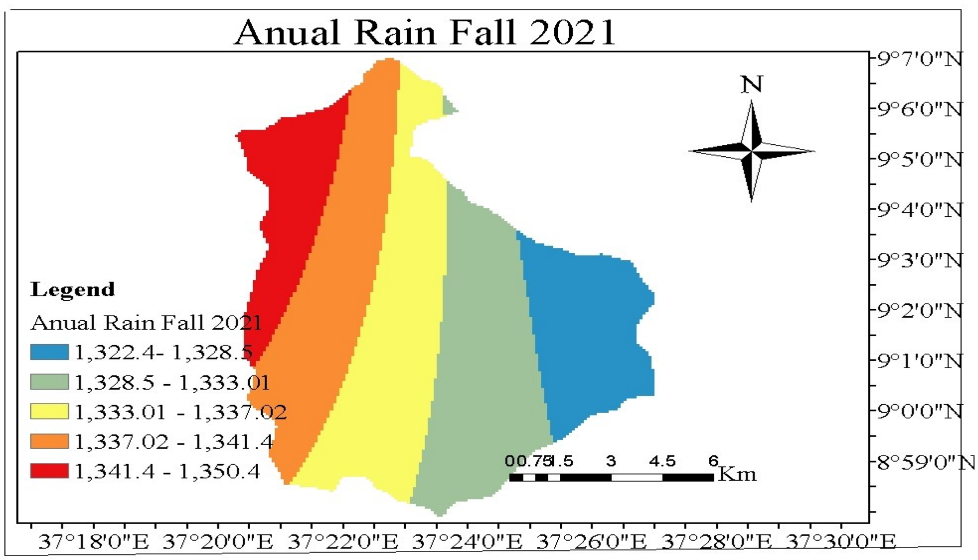


Figure 4-12: Annual Rain fall Interpolation map

The surface water that is mostly obtained from precipitation will have more time to stay on the ground surface and seep into the subsurface when the slope percentage is low. A bottom average diagram is recorded from the metrological data given, which is the consequently 20-year collected amount of data from the given study area.

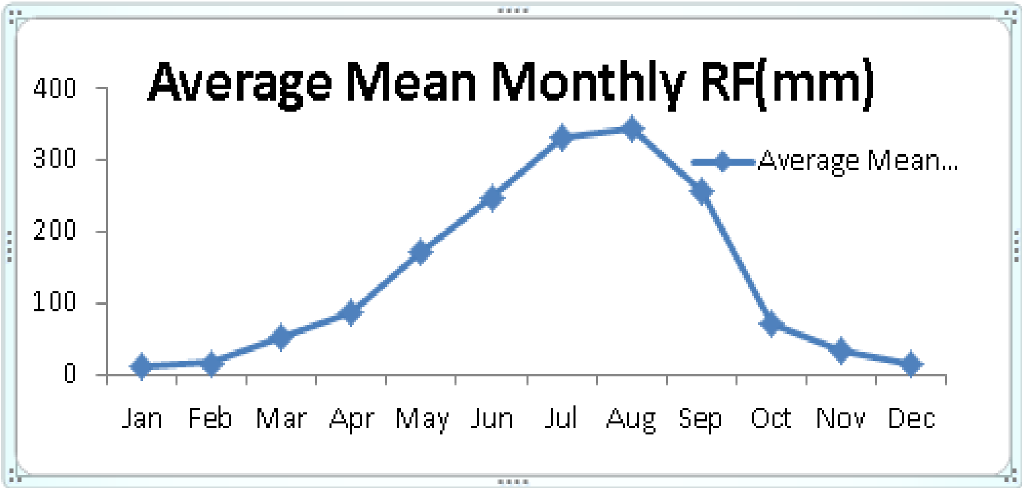


Figure 4-13: Amount of rain Illustration

Metrological data taken from the NMA (online) indicates that Gedo town gets a high amount of rainfall from May to September and a low amount of rainfall from December to February. The highest annual average rainfall for a continuous year from 2001 to 2021 for 21 years is between 1,350.4 ml and the lowest amount of rainfall (1,322.4 ml) recorded in the diagram. The rainfall distribution increased from mid-February to mid-march, then decreased gradually (slightly) in April. The groundwater potential and rainfall amount are directly related to each other. While rainfall amounts decrease, the amount of groundwater in the study area decreases.

4.4 Preparation of thematic layers

The following indicators' were used to create the thematic layer for each indicator (Figure.3-**3**). The watershed's slope, as determined by the DEM, ranges from 17% to 24% and contains 10% groundwater potential weight. A drainage density map with a range of low to high was created by further processing the drainage network that the DEM provided with a weight of a 20% (Error! Reference source not found.). Also, lineaments were to be derived from the lithological map in order to prepare the lineament density map (Error! Reference source not found.) which ranges from 0.1-2.5 km/km^2 with weight a of 15%. Soil texture type contains 5% weight (**Figure 4-11**), land cover/use cover (**Figure 4-9**) 15% weight, topography contour (Error! Reference source not found.) Weight: 10% of rainfall is 15% weight (**Figure 4-12**) and lithology weight is 10% (**Figure 4-10**). The amount of rainfall has a high bearing value on groundwater potential but has a great value on groundwater recharge supply

4.4.1 GIS Modeling Weighted Index Analysis

There is a large variation in the ratings for the integrated groundwater potential zones map. The Arc-GIS Version 10.8 spatial analysis tool facilitates the overlay and weighting of the theme layer map for each unique map.

Table 4-3: Normalized Factors of groundwater potential zone

parameter	Class	Groundwater prospect	Weight (%)	Rank
Slope	Very L/slope 17%	Very high Gwp	10%	5
	Low slope 19%	High Gwp		4
	Medium 21%	Medium Gwp		3
	High Slope 23%	Low Gwp		2
	Very H/Slope 25%	Very low Gwp		1
Lineament	0-0.13 km	very low gwp	15%	1
	0.13-0.32 km	low gwp		2
	0.32-0.51 km	medium gwp		3
	0.51-0.771 km	high gwp		4
	0.771-1.138 km	very high gwp		5
Rain fall	1,322.4-1,328.3 ml	very high gwp	15%	1
	1,328.3-1,333.01ml	high gwp		2
	1,333.01-1,337.1ml	medium gwp		3
	1,337.1-1,341.4 ml	low gwp		4
	1,341.4-1,350.4 ml	very low gwp		5
Topology	1,735.8-1,967.6 m	very high gwp	10%	5
	1,967.6-2,165.7 m	high gwp		4
	2,165.7-2,383.1 m	medium gwp		3
	2,383.1-2,653.6 m	low gwp		2
	2,653.6-2,967.6 m	very low gwp		1
Geology	Cretaceous	Low	10%	1
	Tertiary	Medium		2
	Quaternary	High		3
Soil	Eutric Nitosol	-	5%	-
Drainage	-1	very low gwp	20%	1
	1.01-2	low gwp		2
	2.01-3	medium gwp		3
	3.01-4	high gwp		4
	4.01-above	very high gwp		5
LU/LC	Agricultural area	Highest	15%	3
	Forest	Medium		2
	Grass Land	Lowest		1

The groundwater potential zone map algebra utilized in each Raster computation is as follows:

$$\mathbf{GWPZ}=\sum_i^n(Ax+By):$$

GWPZ= Ground water potential zone, **A**= Thematic Map, **B**= Thematic Map Class

X= weight thematic layer, **Y**= Thematic map rank

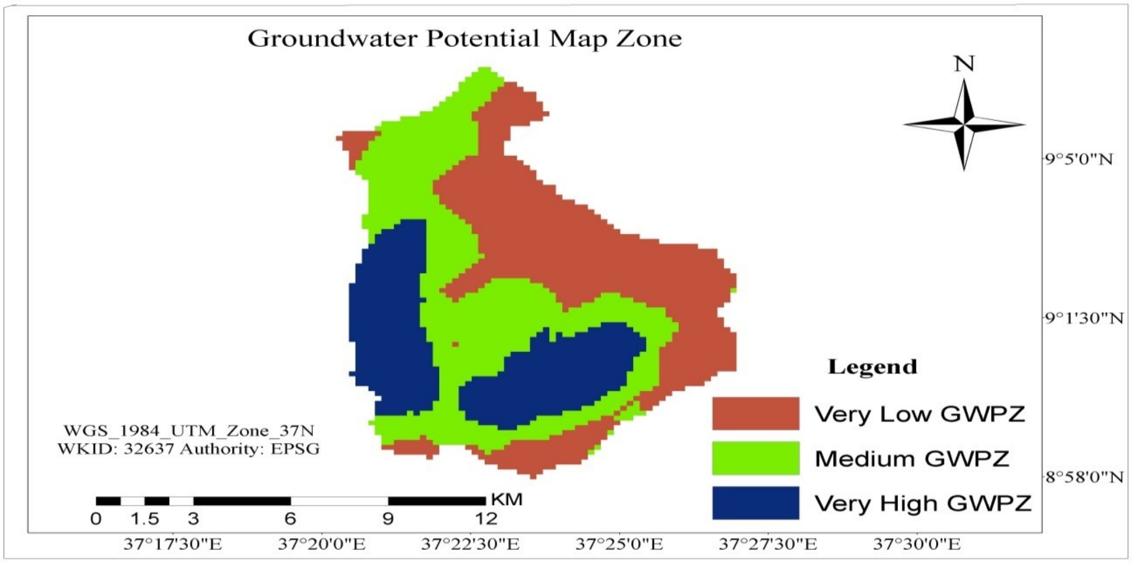


Figure 4-14: Groundwater Potential Map

4.5 Geophysical Methods

A combination of geophysical methods was used. The geological features were outlined in two dimensions using electrical resistivity imaging. Vertical electrical sounding was used in addition to this technique to show the locations of groundwater in the research region. This study identified areas with groundwater potential for society residing in the study area for current and future groundwater exploration and sustainable living (Dhinsa, 2022). Through the study, a broad understanding of how geological formations affect groundwater occurrences in the studied region was attained.

The geological formations and bedrock depths were highly accurately predicted. The study's field data are available for both qualitative and quantitative analysis. The form of the field curve is observed in the qualitative interpretation to gain a qualitative understanding of the quantity and resistivity of layers. The apparent resistivity distribution in the space between the cables and the ground surface AB half-distance extension is qualitatively reflected by the pseudo-section.

The true resistivity and thickness of the geoelectrical section show quantitative parameters. The distribution of layer resistivity and thicknesses is often shown in geo-electric sections, which are thought to provide a more accurate depiction of the true geo-electrical setting in the subsurface. The final model parameters (thickness and resistivity), which were in this case obtained using an Ipwin software inversion, were needed to build the geo-electrical sections. The examination's overall findings suggested that the road collapsed due to weak spots beneath the earth, shallow groundwater, and thick clay soil.

4.5.1 Result of vertical Electrical sounding

In regions with deep-weathering bedrock, VES is a geophysical method that is frequently employed for water prospecting. Resistivity imaging is the recommended method in contemporary surveys for characterizing productive lineaments. The data gathered from the two approaches overlapped in the research region, allowing for a more accurate assessment of the hydrogeological setting of the aquifer being studied. Resistance ranges of 20–100 Ωm are associated with outstanding degradation and aquifer possibilities, according to this categorization, whereas resistivity ranges of 101–150 Ωm are indicative of medium aquifer conditions and potential. Limited weathering and low potential are indicated when the weathered basement resistivity is between 151 and 300 Ωm (Muchingam, 2012).

The vertical electrical sounding of the study area was interpreted by Ipiwin software to detect the layer and resistivity dependencies. On this interpretation, we can get the number of layers and the thickness of the layers. We were correlating the VES data points of field data to its interpreted inversion layer. The interpreted layer accuracy is between 1.98% and 3.98% RMS errors. The corrected resistivity curve, which is the reduced data correction, is also used to show or construct a pseudo-section in order to analyze the lateral and vertical distribution of the resistivity value. In interpretation, the position of the sounding point is indicated by vertical lines. Apparent resistivity values are dotted black lines, observed data are black circle points, and calculated data points represent red lines. The maximum AB depth is 30% to 25% of the extension current electrode. Pseudo-section qualitatively describes apparent resistivity abundant within the subsurface with the comparative electrode at AB half distance.

4.5.1.1 Profile One Curves

Profile one is oriented from NE to SW of the study area catchment, profile line consists of four VES data points (VES$_1$, VES$_2$, VES3, and VES$_4$). Then each of the curves is created by smoothing the apparent resistivity model inverted to reduce the error from the data. From the curve interpretation curve, the black dot lines are the field collected data points, while the red series line is the calculated apparent resistivity curve produced by the computer and inverted to fit together as an overlapped curve. The accuracy of the interpreted data was between 2.6% and 4.8% RMS. Then the interpretation of each VES curve was given as follows (**Figure 4-15**) and the table shows lithology layers and depth.

VES 1 Curve profile

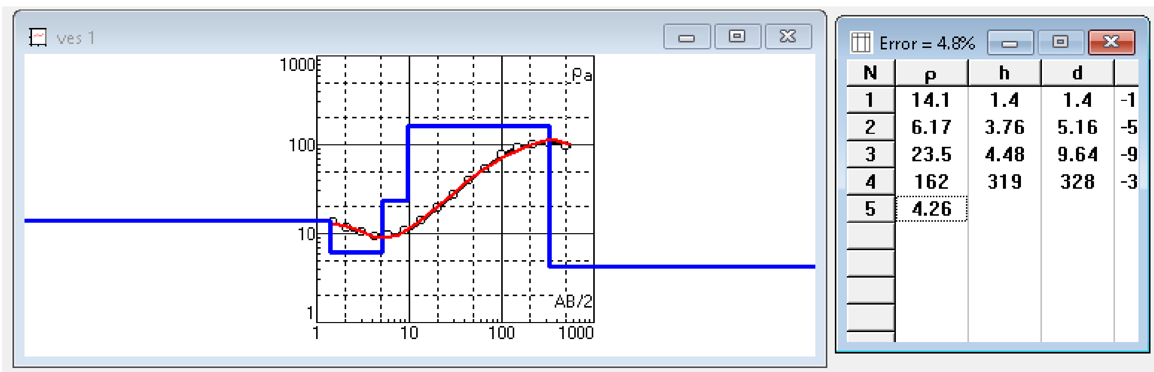


Figure 4-15: Ves-1 profile Curve

The VES 1 figure above has been classified into four layers and their layer depths after resistivity inversion. The VES one point is located on the N-9°1'24.030"N and E-37°27'20.30" E. From the above map, the layer resistivity $\rho_1>\rho_2<\rho_3<\rho_4$ follows the (HA) type of curve format. The total profile depth is 328m. So the interpreted ves data point with layer number, each depth value, and resistivity value are shown in (Table 4-4)

Table 4-4 Ves 1 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	14.1	1.4	1.4	Lose top soil
2	6.17	3.76	5.16	slightly to Moderate fractured Basalt
3	23.5	4.48	9.64	silt with clay and some gravel
4	162	319	328	sandstone

VES 2 Curve profile

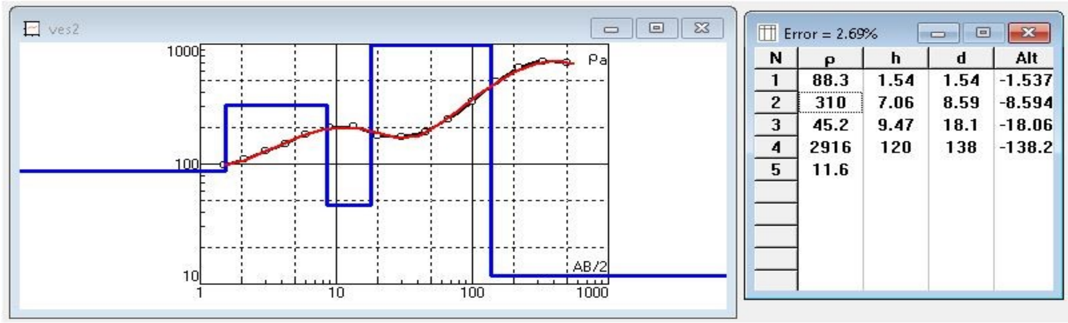


Figure 4-16: Ves-2 profile Curve

Based on the apparent resistivity measured, the curve of VES 2 was categorized into four layers after interpretation and resistivity inversion occurred. The VES point is located on N-9°1'19.66"N and E-37°27'26.95"E. The total depth of the entire layer is 138m. From the above figure, the layer resistivity is $\rho_1<\rho_2>\rho_3<\rho_4$ and follows the (KH) type format of the curve. Then the value of its resistivity, thickness, and depth of each layer were listed in the following table.

Table 4-5 Ves 2 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	88.3	1.54	1.54	Lose top soil
2	310	7.06	8.59	Silt with clay and some gravel
3	45.2	9.47	18.1	slightly to Moderately fractured Basalt
4	2916	120	138	Basalt with sand

VES 3 Curve profile

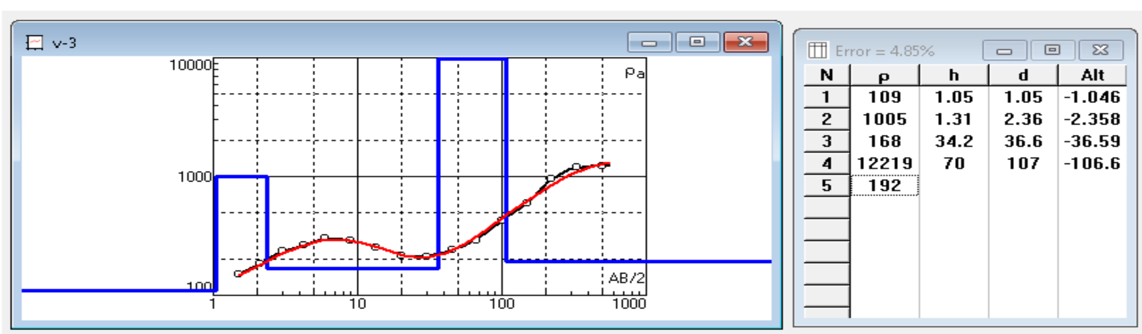


Figure 4-17: Ves-3 profile Curve

The VES 3 figure above has been classified into four layers, with each layer having a having a depth after inversion. The VES three point is located on N-9°1'19.66 N and E-37°27'21.52 E. From the above map, the layer resistivity is $\rho_1<\rho_2>\rho_3<\rho_4$ and follows the (KQ) type format of layer description. The total all-layer depth is 107m. The interpreted ves data point with layer number, each depth value, and resistivity value are shown in the below table.

Table 4-6 Ves 3 lithology profile

Layer	Resistivity	Thick(m)	Depth(m)	Lithology
1	108	1.05	1.05	Lose top soil
2	1005	1.31	2.36	Silt soil and clay
3	168	34.2	36.6	Slightly fractured basalt with calcite filling
4	1221.9	70.1	107	highly fractured basalt

VES 4 Curve profile

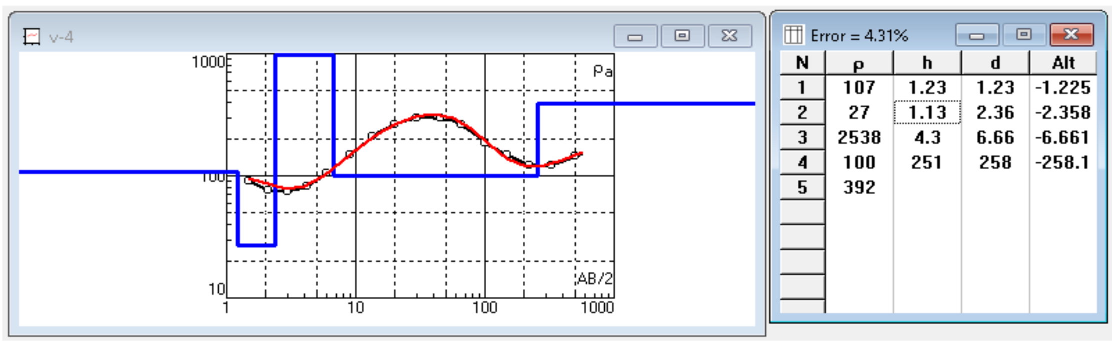


Figure 4-18: Ves-4 profile Curve

The VES`s 4 above figure has been classified into four layers, with each layer having a different having a different depth after correct inversion. The VES one point is located on N-9°1'19.47"N and E-37°27'17.15"E. From the above map, the layer resistivity is $\rho_1>\rho_2<\rho_3>\rho_4$ and follows the (HK) type format with a Ves-3 curve of layer description. The total depth is 258m, so the interpreted ves data point with each depth value and resistivity value is shown in the below table.

Table 4-7 Ves 4 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	107	1.23	1.23	Lose top soil
2	27	1.13	2.36	Sand with silt soil
3	2538	4.3	6.66	Silt with clay and some gravel
4	100	251	258	Sandstone

4.3.1.2 Pseudo Depth Section one

(

Figure 4-19) below is the pseudo-depth section built for the profiles VES_1, VES_2, VES3, and Ves_4 that are on profile 1. This figure demonstrates the section's upper part's observable high resistivity top zone and vertical resistivity variability. This zone of high resistivity extends along profiles three and four to a considerable depth. If not, the large area covered by the section exhibits a wide distribution of low resistivity. Particularly below the Ves-2 to Ves-4 very low resistivity signal, at this point there is groundwater presence with an average length of 200m and an average depth of 95m. The bottom layer on this section is a high-resistivity lithology, which lacks the permeability that stores groundwater as an aquifer.

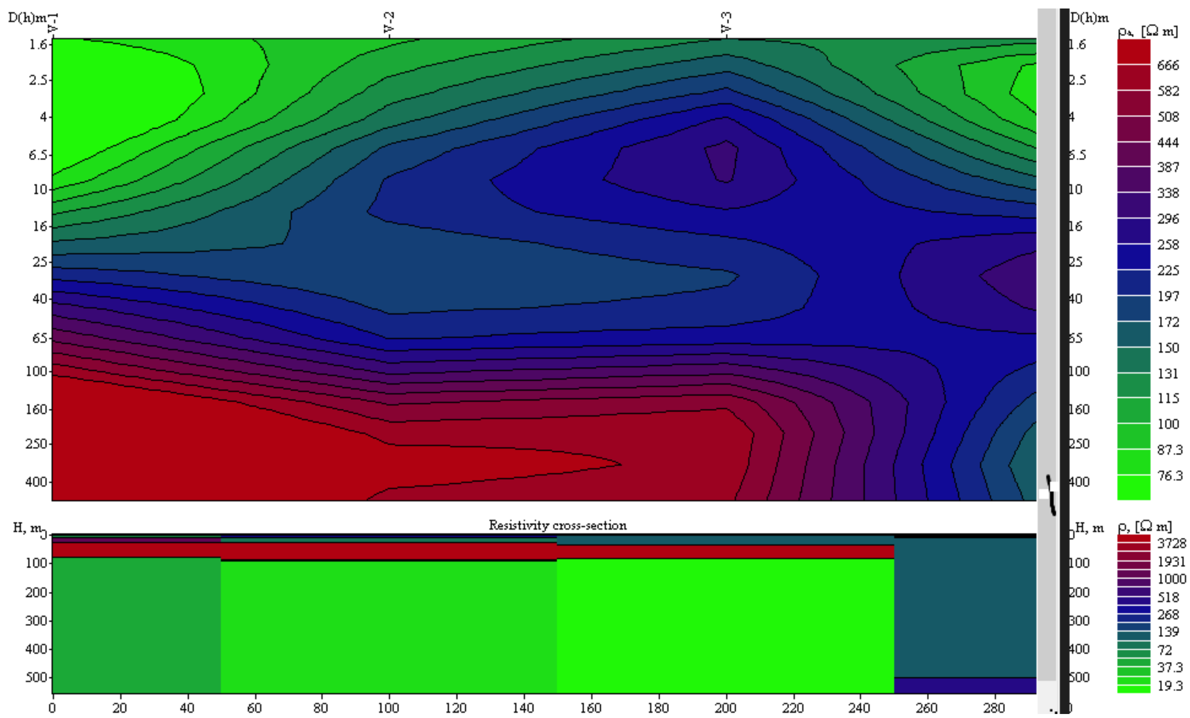


Figure 4-19: Pseudo Section of V1, V2, V3 and V4 map

4.5.1.3 Geo-Electric Section of profile one

Unconsolidated sediment

The geoelectrical section of the interpreted parameters from the Ves layer descriptions are mapped bellow. The description map is moderately flat plateaus lithological structure. The general depth of lithology layer is depending on the described vertical electrical sounding points. The main types of unconsolidated or granular sediments are boulders and clay-silt (Valenta, 2021). These deposits often take place in valleys. According to their origin, they are categorized as Aeolian, marine, colluvium, and so on. The size, shape, and degree of sorting of the grains, influence the hydrological qualities of unconsolidated sediments.

The lithology of study area extensively dominated by sedimentary rocks and a wide range of igneous rocks underlain the sedimentary rocks. Sandstone makes up around 25% of the world's sedimentary rock. Sandstone layers provide regional aquifers with enormous amounts of drinkable water in many different nations (Nwankwo, 2022). A variety of depositional habitats, and turbidity-current environments, are the source of sandstone formations of significant hydrologic significance.

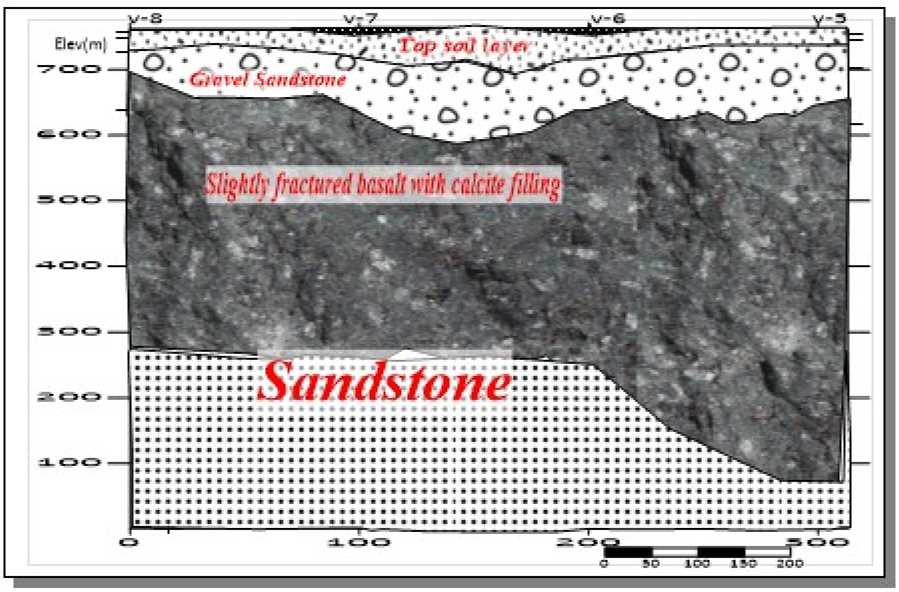


Figure 4-20: Geo-electric section of (v1-v4)

4.5.1.4 Profile Two Curves

Profile two is oriented from NE to SW of the study area catchment, profile line consist of four VES data points (VES_5, VES_6, VES_7, and VES_8). Then each of curves is created by smoothing the apparent resistivity model inverted to reduce the error from the data. The general resistivity correction error is between 2.25%-4.34% RMS. From the curve interpretation curve the black dot lines are the field collected data points while the red series line is the apparent resistivity curve produced by computer and inverted to fit together and over lapped curve.

VES 5 Curve profile

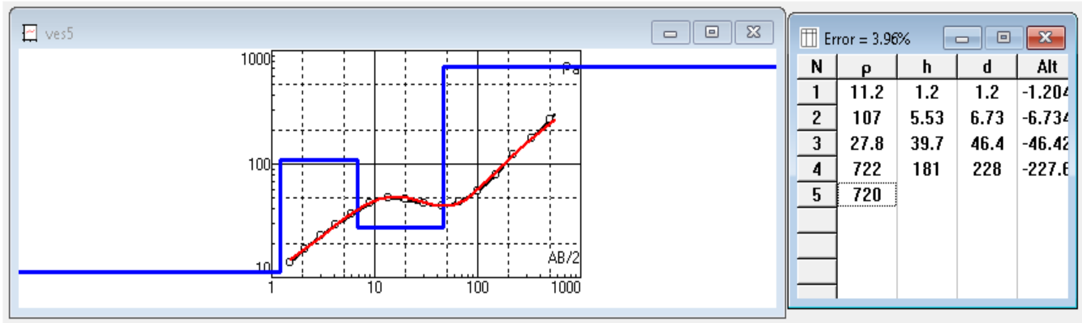


Figure 4-21: Ves-5 profile Curve

The VES 5 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'15.18"N and E-37°27'23.56"E. From the above map the layer resistivity $\rho_1<\rho_2>\rho_3<\rho_4$ and follows the (KH) type format of layer description. The total layers depth is 228m. The 3.06% RMS error curve profile So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-8 Ves 5 lithology profile

Layer	Resistivity Rho	Thick(m)	Depth(m)	Lithology
1	11.2	1.2	1.2	Lose top soil
2	107	5.53	6.73	Silt soil and clay
3	27.8	39.7	46.4	Slightly fractured basalt with calcite filling
4	722	181	228	Sandstone

VES 6 Curve profile

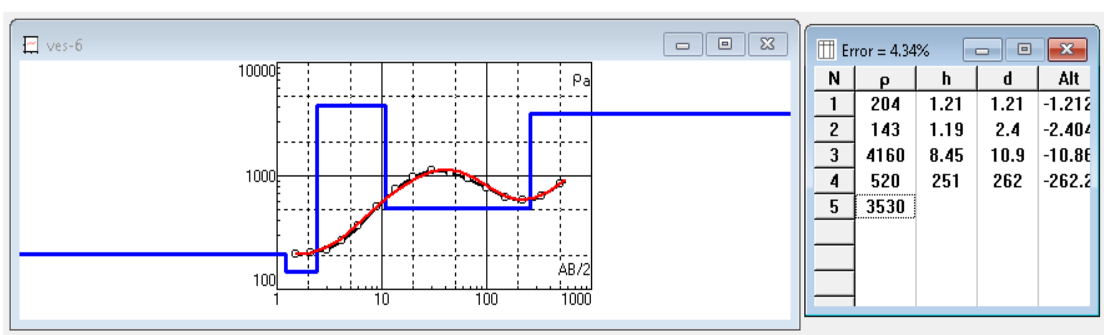


Figure 4-22: Ves-6 profile Curve

The VES`s 6 figure above has been classified into five layers and with each layer depth after inversion. VES one point is located on the N-9°1'16.13"N and E-37°27'17.39"E. From the above map the layer resistivity $\rho_1>\rho_2<\rho_3<\rho_4$ and follows the (HAK) type format of layer description. The total profile layer depth is 262m. It seems to the Ves 1 profile curve with slight depth difference. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table

Table 4-9 Ves 6 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	204	1.21	1.21	Lose top soil
2	143	1.19	2.4	Sand with silt soil
3	4160	8.45	10.9	Silt with clay and some gravel
4	520	251	262	Sandstone

VES 7 Curve profile

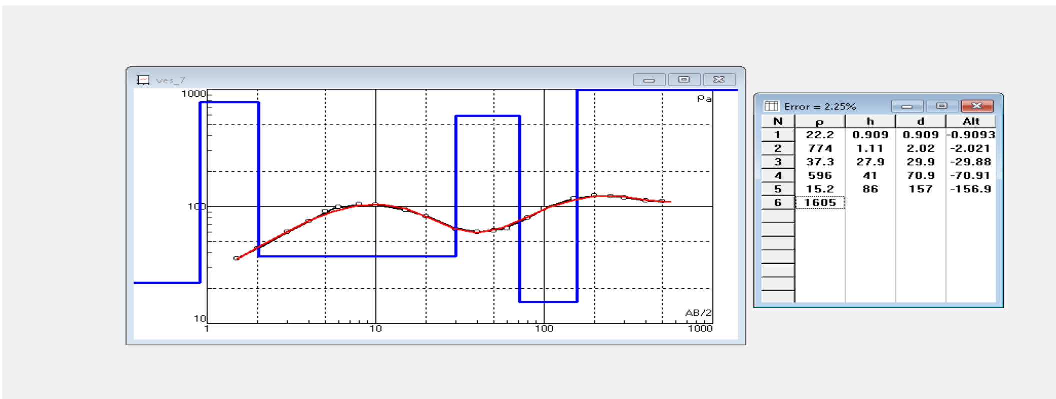


Figure 4-23: Ves-7 profile Curve

The VES 7 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'16.29 " N and E-37`27'22.83 " E. From the above map the layer resistivity $\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$ and follows the (KHK) type format of layer description. The total all layers depth is 157m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-10 Ves 7 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	22.2	0.909	0.909	Lose top soil
2	774	27.9	2.02	Sand with silt soil
3	37.3	41	29.9	highly fractured basalt and welded Tuff
4	595	86	70.9	Moderately fractured basalt
5	15.2	86.1	157	Basalt with sand

VES 8 Curve profile

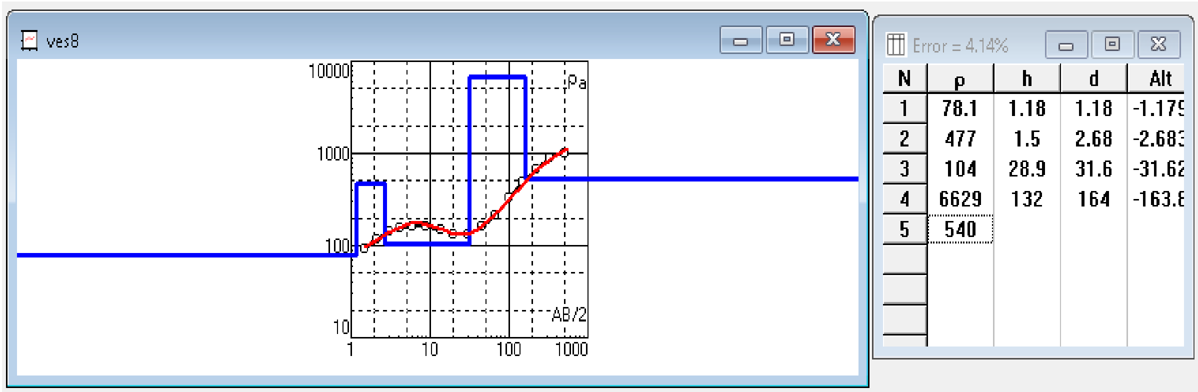


Figure 4-24: Ves-8 profile Curve

The VES 8 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'16.40"N and E-37°27'28.21 " E. From the above map the layer resistivity $\rho_1<\rho_2>\rho_3<\rho_4$ and follows the (KH) type format of layer description nearly similar with Ves 7 profile curve. The total all layers depth is 35.3m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-11 Ves 8 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	78.4	1.18	1.18	Lose top soil
2	477	1.5	2.68	Sand with silt soil
3	104	28.9	31.6	highly fractured basalt and welded Tuff
4	6629	132	164	Basalt with sand

4.5.1.5 Pseudo Depth Section Two

The pseudo-depth section created for the profiles VES5, VES6, VES7, and VES8 is provided by figure bellow. The top portion of the section has a vertical resistivity variation, as seen in this figure, with a noticeable high resistivity top zone. There is the low resistivity value under the VES_5 and VES_6, with the average length of 110m. As well as 40m average depth area covered by the section.

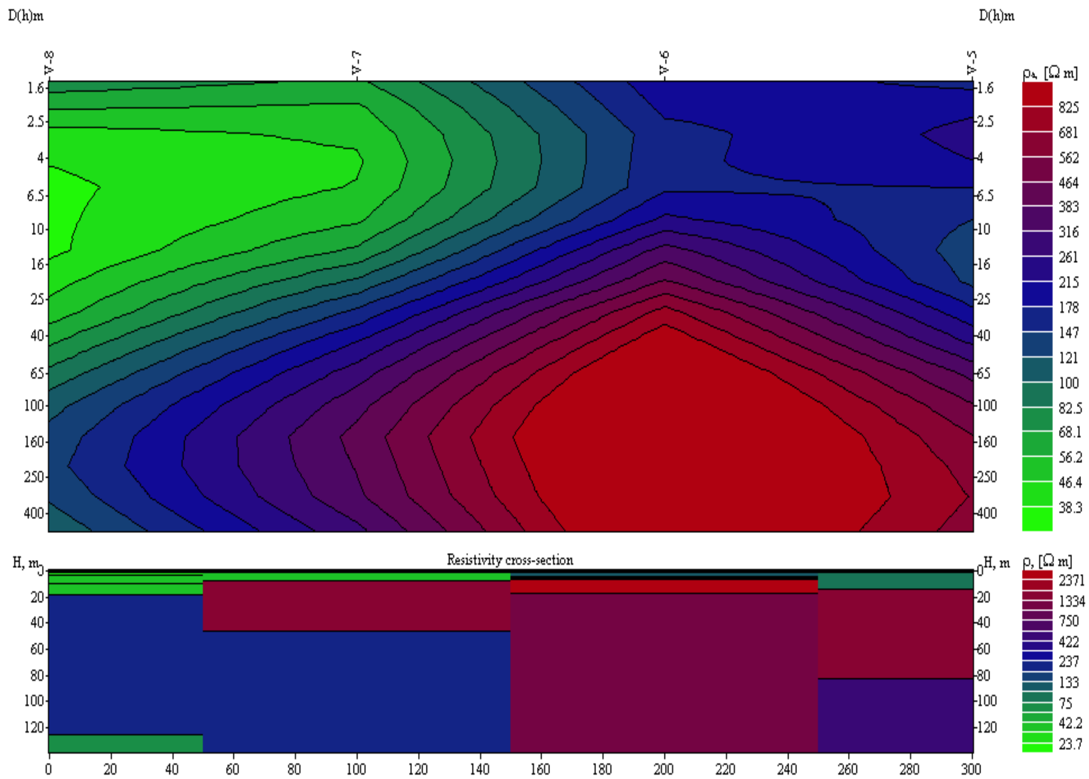


Figure 4-25: Pseudo Section of V5, V6, V7 and V8 map

The resistivity range is averaged to 100 Ohm-m of this low resistivity region are indicative low resistivity value but it has no extension. It shows much fractured area of study area. Around the VES-5 and VES-6 there is the extensively high region of low resistivity above the high resistivity value may be rock layer. As the researcher idea the resistivity between VES-5 and VES-6 indicate high groundwater potential presence. The area between VES-7 and VES-8 is extensively low resistivity relatively clay and soil.

4.5.1.6 Geo-Electric Section of profile Two

The top portion of the geologic sections of platform (plain) areas, intermundane and sub-montane depressions, is the principal locations for loose, unconsolidated mountain rocks (Xiang, 2023). Rocks are composed of sand, sandy loam, loam, shingle, and clays. They are also gravel-sandy. The majority of the deposits are Quaternary and Neogene Quaternary in age; Paleogene-Neogene deposits are less common.

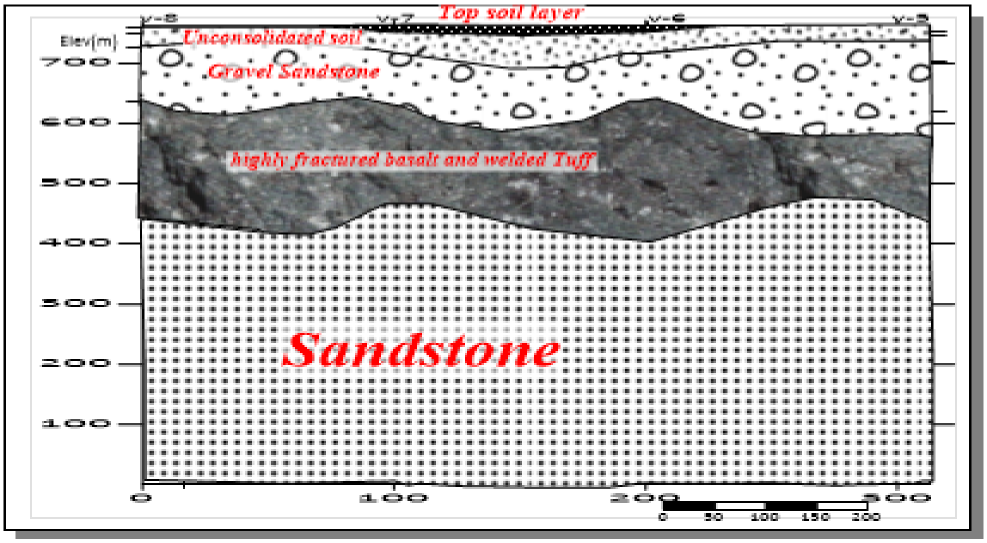


Figure 4-26; Geo-electric section of (v5-v8)

Later, the term "M-type granite" was coined to refer to granites that were unmistakably formed of crystallized mafic magmas, which are typically derived from the mantle. Small amounts of granites can occasionally be discovered in island arcs as a result of the fractional crystallization of basaltic melts, but these granites must exist with substantial volumes of basaltic rocks. Granite is utilized in pavement construction. This is due to its exceptional durability, permeability, and low needs for upkeep (Brattebo, 2003).

4.5.1.7 Profile three curves

Profile three is oriented from NE to SW of the study area catchment, profile line consist of three VES data points (VES$_9$, VES$_{10}$, VES$_{11}$ and VES$_{12}$). From the curve interpretation curve the black dot lines are the field collected data points while the red series line is the apparent resistivity curve produced by computer and inverted to fit together and over lapped curve.

VES 9 Curve profile

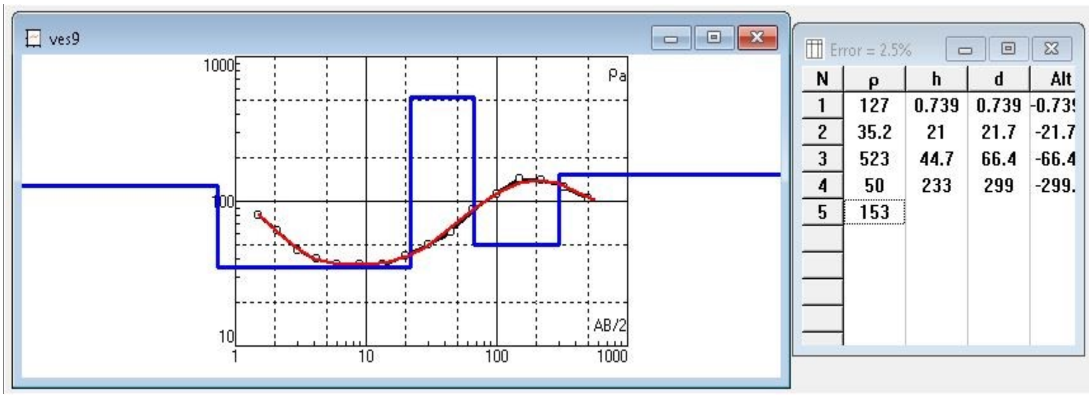


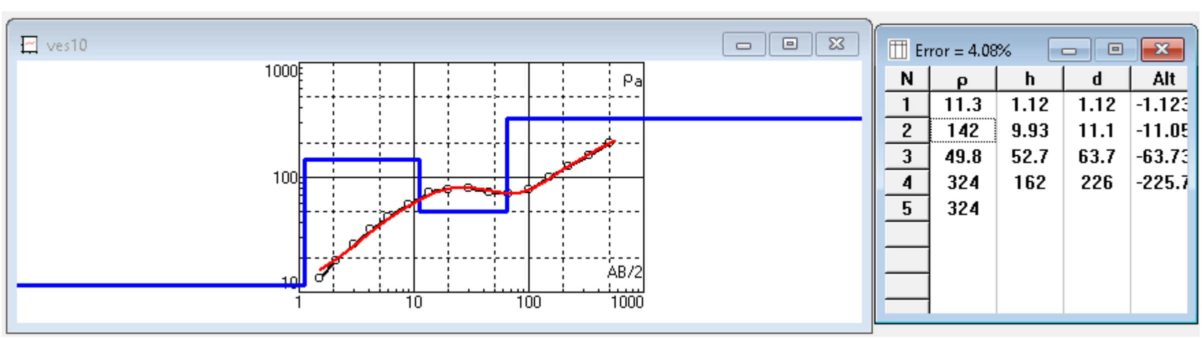
Figure 4-27: Ves-9 profile Curve

The VES 9 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'13.46"N and E-37°27'28.57"E. From the above map the layer resistivity $\rho_1>\rho_2<\rho_3>\rho_4$ and follows the (HK) type format of layer description. The total all layers depth is 299m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-12 Ves 9 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	127	0.739	0.739	Lose top soil
2	35.2	21	21.7	Sand with silt soil
3	523	44.7	66.4	Moderately fractured Basalt
4	50	233	299	sandstone rock

VES 10 Curve profile



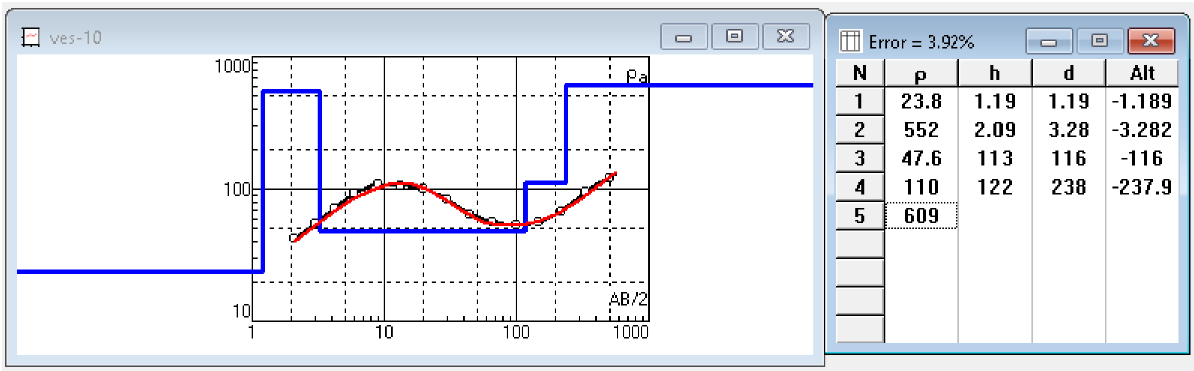


Figure 4-28: Ves-10 profile Curve

The VES 10 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'10.06 " N and E-37°27'31.63 " E. From the above map the layer resistivity $\rho_1<\rho_2>\rho_3<\rho_4$ and follows the (K) type format of layer description. The total all layers depth is 238m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table

Table 4-13 Ves 10 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	23.8	1.19	1.19	Lose top soil
2	552	2.09	3.28	Sand with silt soil
3	47.6	113	116	highly fractured basalt with calcite filling
4	110	122	238	Sandstone rock

VES 11 Curve profile

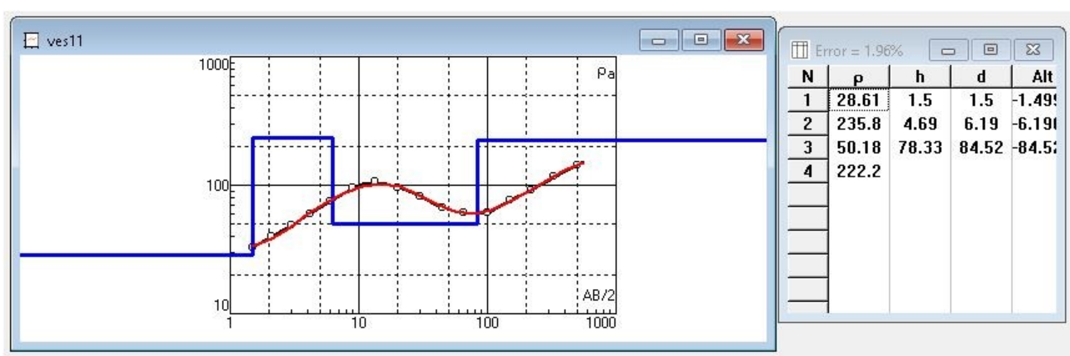


Figure 4-29: Ves-11 profile Curve

The VES 11 figure above has been classified into three layers and with each layer depth after correct inversion. The VES-1 point is located on the N-9°1'10.13 " N and E-37°27'25.06 " E.

From the above map the layer resistivity $\rho_1<\rho_2>\rho_3$ and follows the (K) type format of layer description. The total all layers depth is 84.52m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-14 Ves 11 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	28.61	1.5	1.5	Lose top soil
2	235.8	4.69	6.19	Sand with silt soil
3	58.18	78.33	84.52	slightly to Moderately fractured Basalt

VES 12 Curve profile

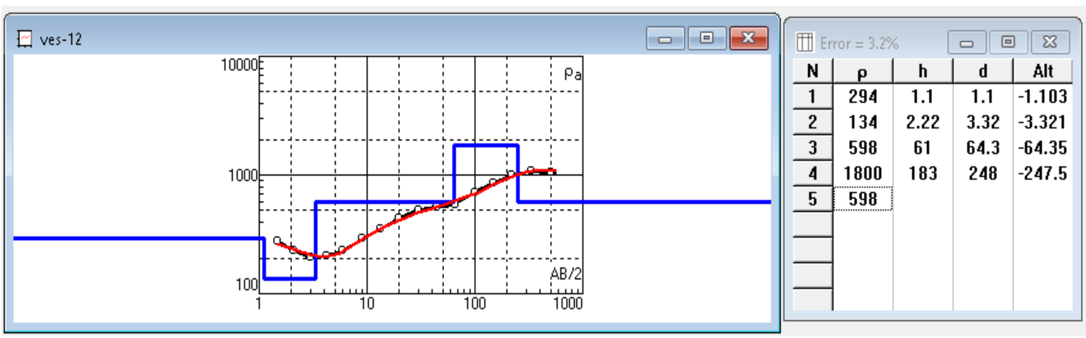


Figure 4-30: Ves-12 profile Curve

The VES 12 figure above has been classified into five layers and with each layer depth after correct inversion. The VES one point is located on the N-9°1'9.76 " N and E-37°27'18.96 " E. From the above map the layer resistivity $\rho_1>\rho_2<\rho_3<\rho_4$ and follows the (HA) type curve of layer description. The total all layers depth is 248m. So the interpreted ves data point with layer number, each depth value and resistivity value are shown in the below table.

Table 4-15 Ves 12 lithology profile

Layer	Resistivity Rho	Thick (m)	Depth (m)	Lithology
1	290	1.1	1.1	Lose top soil
2	134	2.22	3.32	Sand with silt soil
3	598	61	64.3	Moderately fractured Basalt
4	1000	183	248	sandstone rock

4.5.1.8 Pseudo Depth Section three

The profile-3-arranged general pseudo-section depths of VES9, VES10, VES11, and VES12 are shown in (**Figure 4-31**); there is a variance in the vertical variation. This zone of high resistivity extends to a considerable depth. If not, the large area covered by the section exhibits a wide distribution of low resistivity.

According to the explanation on the resistivity range from (31.6 to 200) Ohm-m from the legend of this low resistivity zone, this indicates a significant potential water saturation. Specifically on this interpretation high groundwater potential investigated under the VES_{10} and VES_{11} with the average length of 210m as well as 61m depth. However, the region's resistivity range is (31.6–104) Ohm-m. This pseudo-section has a comparatively low resistance covering of clay and dirt at around (31.6) Ohm-m. However, a very high resistivity value dominates the bottom layer of the pseudo section region, which might be a sign of lithological rock deposition.

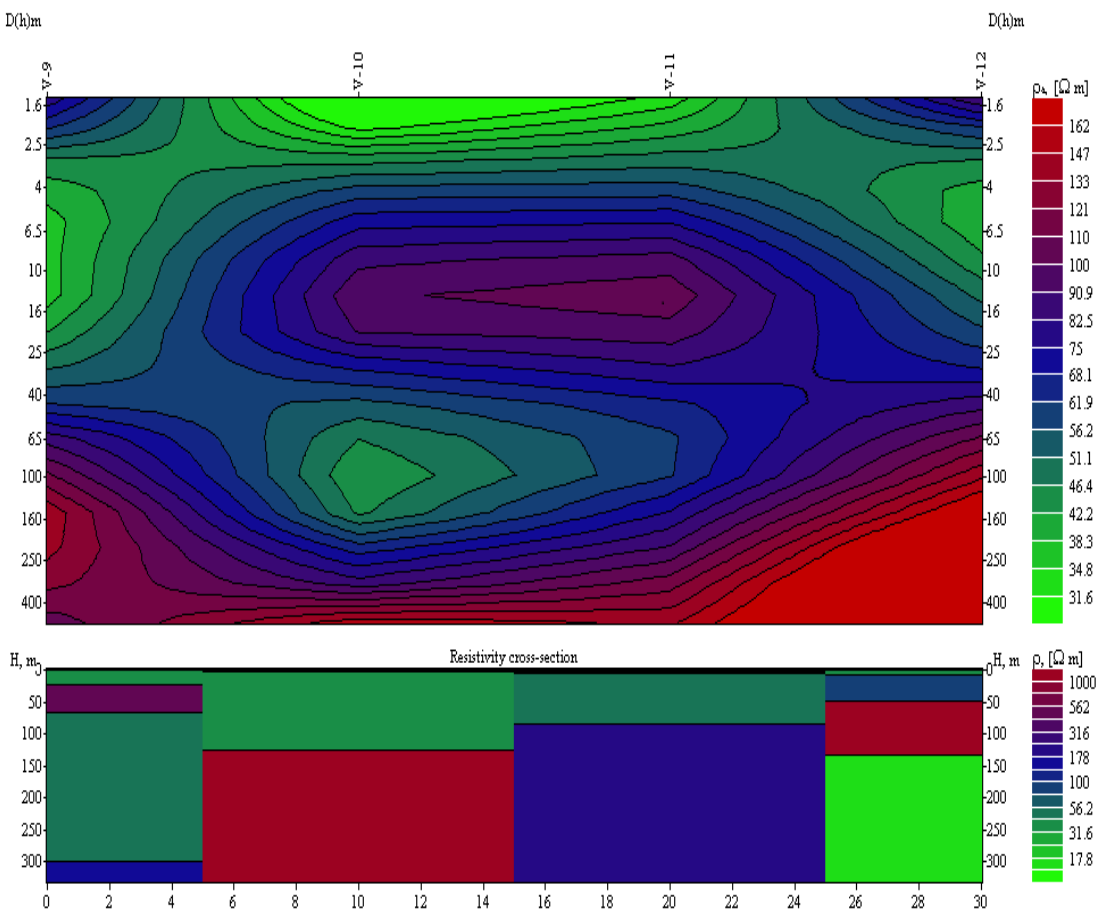


Figure 4-31: Pseudo Section of V9, V10, V11 and V12 map

4.5.1.9 Geo-Electric Section of profile three

Permeability zone dispersion in basalts is inextricably linked to the inner structure of basalts formed during the cooling processes after a magma flood. In comparison with normal granular water reservoirs, study on basalt groundwater is as widespread, despite their global quantity and importance (Postma, 2022).

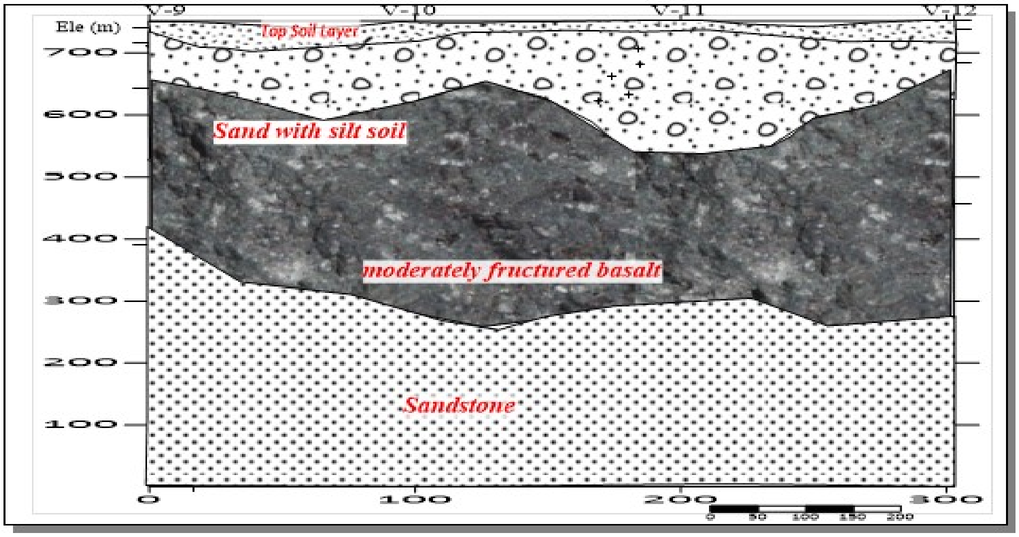


Figure 4-32: Geo-electric section of (v9-v12)

This work attempts to determine the characteristics generated from geophysical logging that enable us to diagnose the facies variation inside flood basalts, as basalt serves as an essential reservoir. Additionally, the goal of this research is to create empirical models that, when combined with geophysical logging, yield accurate estimations of the porosity and permeability of rocks.

4.5.2 Electrical Resistivity Tomography Interpretation

The electrical tomography interpretation is the most important method to identify the presence of the structures that are may be fractures and lineament. Computers Programmers used in this procedure. For the electrical resistivity tomography used in this thesis project, the Syscal switch device recorded around data points. Prosys II software was then used to automatically alter the data, edit data, and export data to the other software interpretation Res2dinvx32 2D Used in this research case. Since, the structures are very important in ground water investigations.

This method has forward processing and reverse forwarding interpretation. But, to get the most clearly structure using inverted processing is used in this thesis. This is accomplished by obtaining the distribution of genuine electrical characteristics by inverting the apparent electrical values that were collected during electrical resistivity tomography surveys. Plotting of the raw measurements of apparent resistivity after conversion and processing is possible in the corresponding pseudo section.

4.5.2.1 Inverse modeling Electrical Resistivity Method

The effectively interpretation of the data model that minimizes the difference between the observed and estimated values must be identified. In order to construct a new earth model that would suit the conductive properties of the recorded raw model, the programmer was used to measure the apparent resistivity pseudo section during the inversion process. This is the process of using mathematical issues in science to change a collection of observed facts and create a new model. The blocks' arrangement in the pseudo section is tangentially related to the data point distribution.

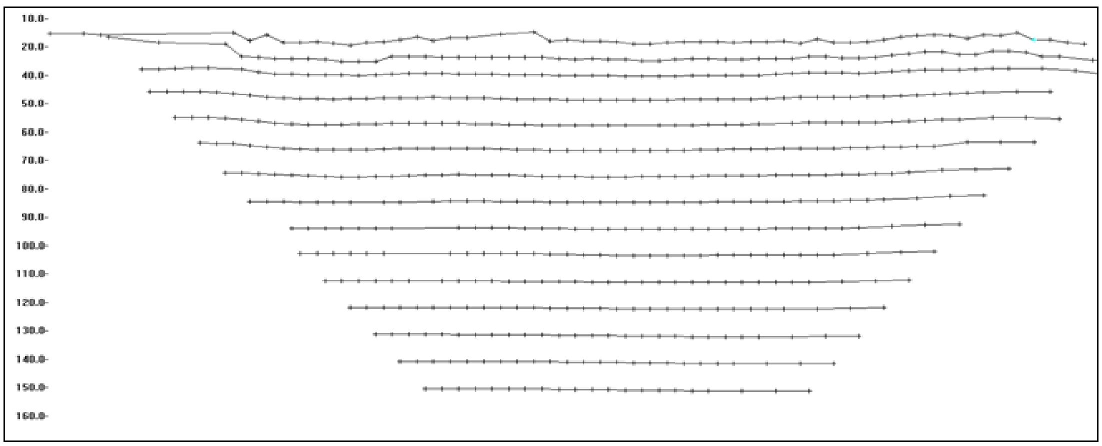


Figure 4-33: Imaging data pre interpretation map

The bottom row of blocks has their depth adjusted to roughly match the corresponding depth of the inquiry. A decent inversion technique should reduce the impact of model parameter and data inaccuracy. As Loke shows that inversion often aims to minimize the square of the difference between the measured and computed apparent resistivity values, provides guidance for data inversion (Loke, 2019).

4.5.2.1.1 Inverse Model Resistivity Profile One

This inversion was modeled using 596 corrected data points, with resistivity ranging from 5.5Ωm to 1131Ωm and maximum depths of around 38.1m. The graphic makes it evident that the subsurface is composed of zones with low resistivity at shallow depths, followed by zones with approximately medium and greater resistivity. With low resistivity values ranging from 15.2Ωm to 212 Ωm, medium resistivity values from 791Ωm to 1028 Ωm, and high resistivity values more than 1028Ωm, this profile shows the resistivity distribution of a homogeneous unit.

At near surface thicknesses of little more than roughly 36 m, it is geologically characterized as mildly unwedded soil with high moisture content resistivity distribution. At a depth of 77.2-98.1 meters on the East side shows high resistivity lithological area. Additionally, the profile doesn't show of the major aquifer water-bearing zone, which is severely worn and fractured, is visible from depths substantial.

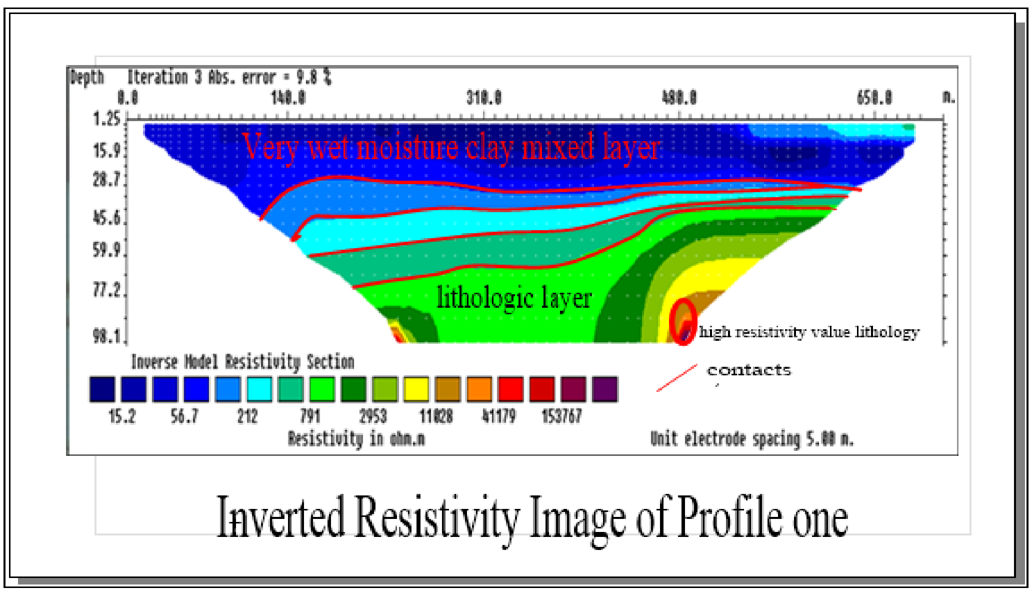


Figure 4-34: Inverted Resistivity Image of profile one

4.5.2.1.2 Inverse Model Resistivity Profile Two

The 2D electrical resistivity survey profile was completed in parallel to profile one from north east to south west with a difference of 100 meters each of all profiles. For this inversion, about 566 corrected data points were used. The observed inverse model resistivity pseudo-section for profile two is displayed.

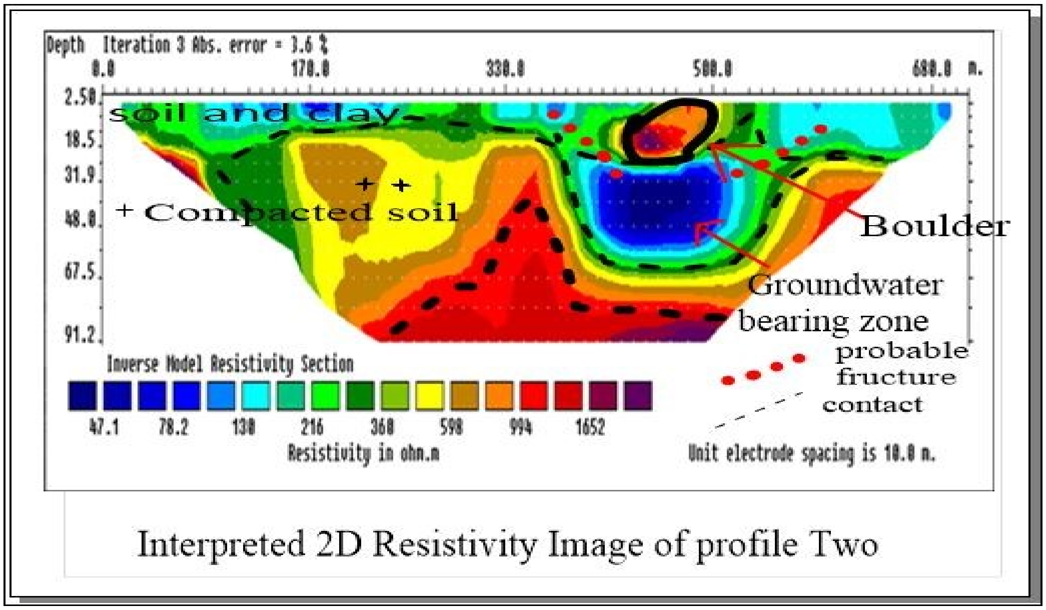


Figure 4-35: Inverted Resistivity Image of profile Two

As shown on from figure blue side area is the most water bearing area which is bounded between the rock layers. The red color uplifted lithology is the basaltic igneous rocks. The bottom black layer indicates the sedimentary basement rock. The distribution of high electrical resistivity values, which range from 47.1Ωm to 1652Ωm at a depth of 9.2 m, is displayed in the result, which is arranged horizontally from the survey's southwest to Northeast. Due to its ability to affect all types of rocks and the high values it may produce, fracturing is one of the most significant regulators on porosity (Fazio, 2021). Fracture zones, joints, and fault lines are common locations for fracture porosity.

4.5.2.1.3 Inverse Model Resistivity Profile Three

In a straight line extending 100 meters from North east to south west, the 2D electrical resistivity survey profile was measured in the direction of profile one. The inverse model resistivity section is the outcome of using 610 data points in this profile. This profile shows very thin, less than 91.2m deep areas of top dry soil with high resistivity. That being said, a highly worn and fractured basalt (major aquifer water bearing zone) was found with low resistivity ranging from 90.4ηm to 134Ωm, stretching from East to West, spatially at the east side of the profile with in depth between (10m to 50m) and on the west side from depth of (20m to 60m).

The most water bearing area is between the profile two and profile three is the most appropriate water bearing from the study area. The specified profiles are bounded between the high resistivity lithology so they accumulate the high amount of water due to their hardly permeable solid layer or due to lack of porosity.

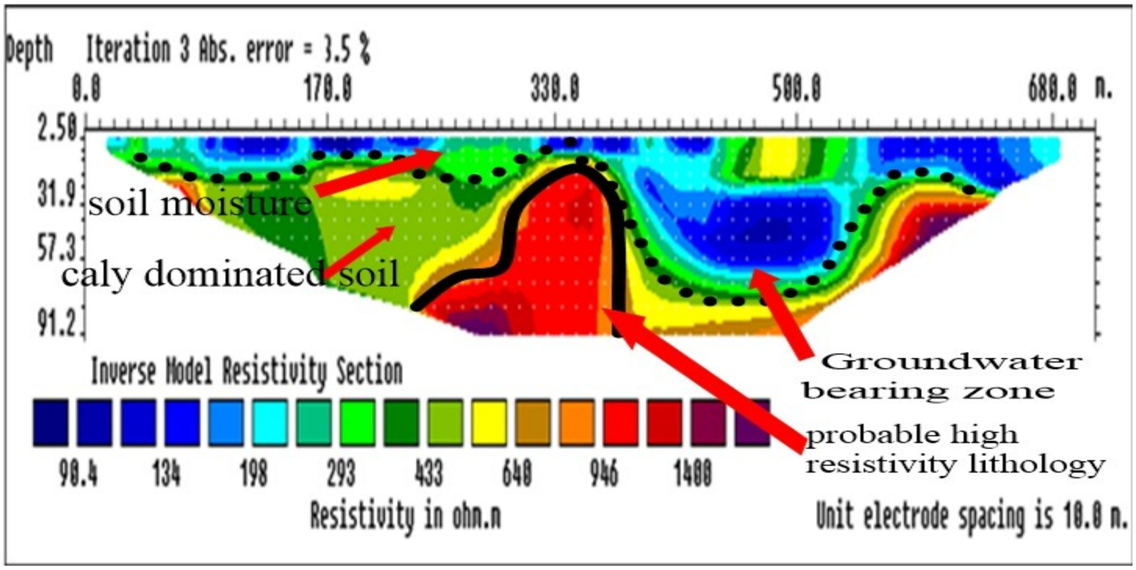


Figure 4-36: Inverted Resistivity Image of profile Three

4.5.2.1.4 Inverse Model Profile Four

The fourth line that electrical resistivity tomography scans were conducted across is virtually parallel to profiles and 685 data points were captured over a 720-meter segment of this profile, spaced 100 meters apart from profile three. Resistivity ranged from 1.1Ωm to 10^5Ωm to penetration depths of 107.9m, according to the result acquired by the inversion procedure. Because the top layer of the soil is so dry, the penetration depth has diminished. This profile's distinctive feature in the region is its horizontal geological strata with a basalt structure that extends to a depth of 91.2 meters. The inverse model cross-section of profile fourth 2D electrical resistivity is shown.

This profile indicates a moderate resistivity area that extends horizontally from the profile's beginning to its end layer, covering a depth range of 67.5 to 91 meters. However, at depths of 60 to 100 meters, extensively fragmented and weathered basalt (aquifer zone) was discovered, with resistivity ranging from 1176 to 8765 Ωm.

The profile layer generally shows the folded structural layer of the lithological structure. The layer shows the (H) type ipi2win software indication of VES interpretation.

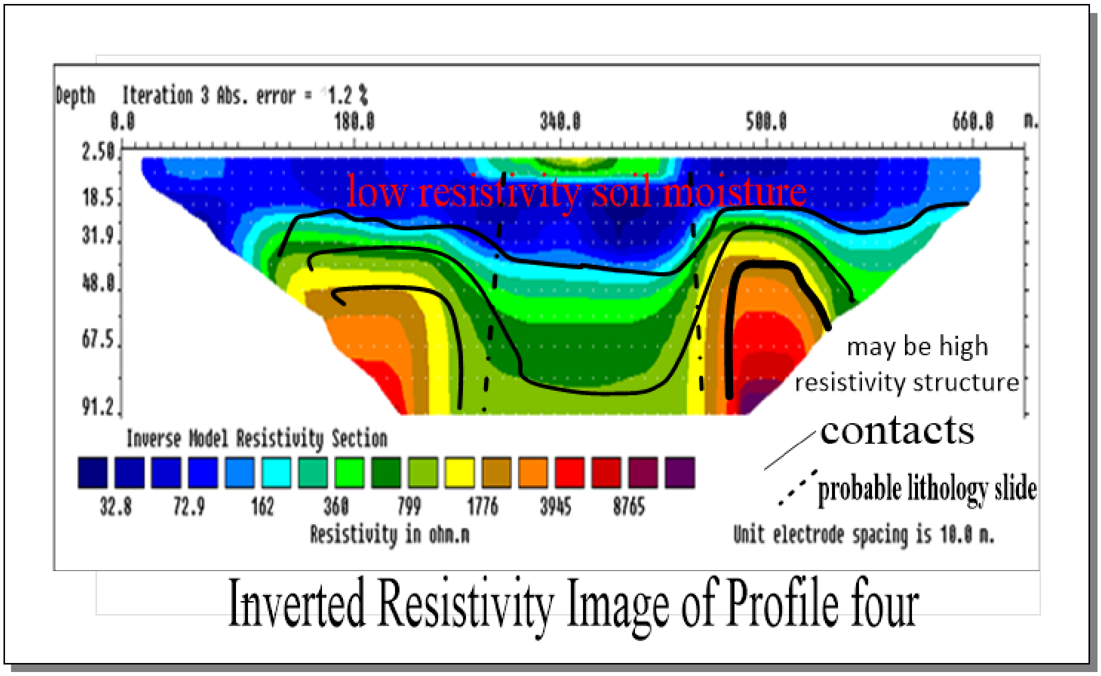


Figure 4-37: Inverted Resistivity Image of profile four

4.5.2.1.5 Inverse Model Profile Five

The 2D electrical resistivity tomography survey's final profile was obtained to parallel to the all profiles. The distributing cables wire that measured from 360 meters in length from north east to south west by five meter between each cables. The part on inverse model resistivity for profile five is depicted from 653 data points. The distribution of low electrical resistivity values, which range and can reach a maximum depth of 45.6 m in the uppermost region of the survey area from the north to the south, is depicted in the result and is understood to represent slightly compacted unwedded.

A layer of severely damaged rocks and fractured basalt, which is the major water-bearing zone of the aquifer in very small depth which is seem to VES Eight profile curve, reveals high resistivity rock in the south west that ranges in resistivity value from 31.5 Ωm and is found between 33.8 and 45m deep, extending from the profile's center to its south side. However, the subsurface in the north has somewhat water potential presence because it occurs on the rock layer top with a resistivity of 2.56 to 3.67 Ωm, oriented downward from the north to the survey line's center.

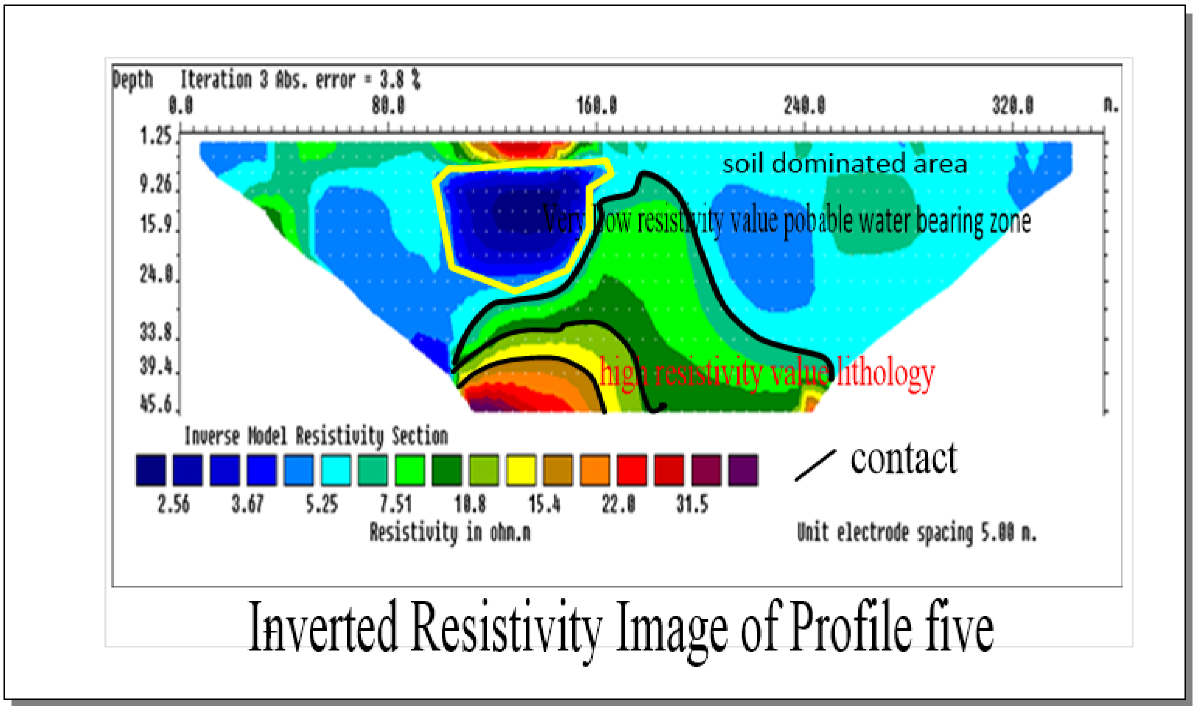


Figure 4-38: Inverted Resistivity Image of profile five

4.6 Validation of Groundwater Potential Map

The performance of the applied approach was assessed using a two-step, straight forward validation procedure. In geospatial method the total normalized over weighted geospatial (**Table 4-3**) parameters are indicated. Groundwater Potential Map first evaluated using different geospatial methods was prepared (**Figure 4-39**) and confirmed accurately by geophysical methods. From different data produced map of groundwater potential was superimposed. At this level, the created map was deemed a appropriate if regions with higher groundwater potential also had more springs (or a higher yield), as the existence of direct indicator of groundwater potential location.

The deeper groundwater system is produced geologic fractures in center of the geographical map, while the shallower system is mostly restricted to the regolith that forms over the basement rocks and unconsolidated sediments in eastern parts. Consequently, sites with shallow groundwater levels are viewed as unreadable and unfavorable groundwater prospective zones, and are consequently assigned the least weight, in comparison to locations with deeper groundwater levels.

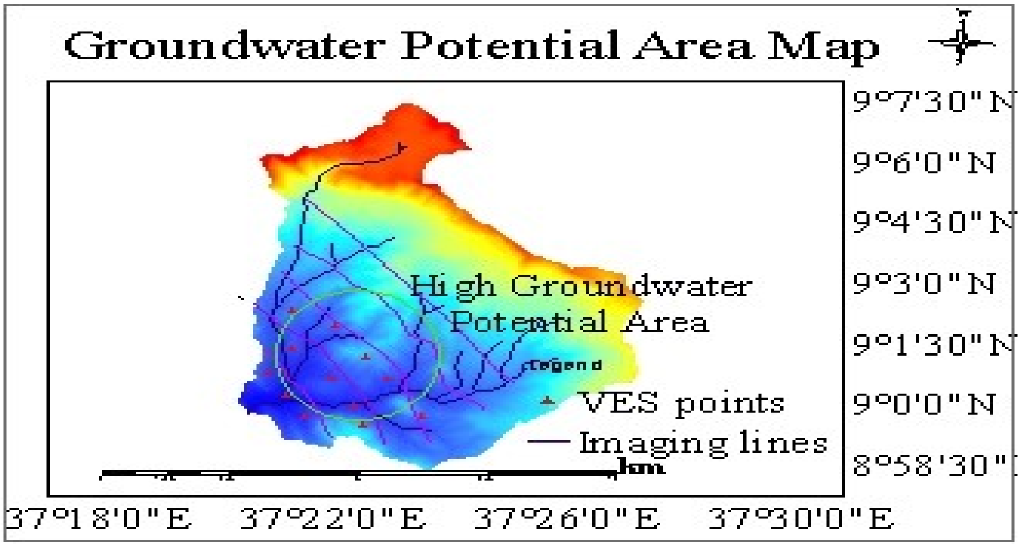


Figure 4-39: Overlay Two method groundwater potential map

The second based on the findings of VES and an ERT survey conducted on specified area. Because of ERT and VES are often utilized in groundwater investigation and prospecting. The resistivity of minerals and the fluid inside the material's pores determine an earth material's electrical resistivity. This map show overlap map of geophysical point data and geospatial map that shat shows groundwater potential map location. These points over lapped from geophysical data recorded by GPS during field data record and interpreted by computer in ArcGIS. Every data points on map are which comes from the field and this general assumption point of groundwater potential investigated.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Groundwater potential can be investigated using different Geospatial and Geophysical methods combining integrated methods of interpretation. This study brings the solution of water scarcity in study area as interpreted in result discussion. Extremely groundwater investigated by geospatial at very low slope of study area, very high drainage density, low topographic feature, high lineament density at blue colored map, Area of Agricultural land use and land cover. Groundwater Potential Map first evaluated using different geospatial methods and confirmed accurately by geophysical methods

Geophysical method shows the clear specific area of groundwater potential at inverted pseuodsection of the (**Figure 4-25**) from vertical electrical sounding result. On Pseuodsection one particularly below the VES_2 to VES_4 very low resistivity signal, at this point there is groundwater presence with the average length of 200m and average depth of 95m. The bottom layer on this section is high resistivity lithology which lacks the permeability stores groundwater as Aquiclude aquifer. There is the low resistivity value under Pseuodsection two on VES_5 and VES_6, with the average length of 110m. As well as 40m average depth area covered by groundwater. Specifically on pseuodsection three interpretation, high groundwater potential investigated under the VES_{10} and VES_{11} with the average length of 210m as well as 61m depth.

Electrical Resistivity Tomography collected data are able to delineate geological structures. In certain Electrical Resistivity Tomography profile there are some weathered and fracture basalt as red regions up to almost above 300Ωm at different depth level. From the electrical tomography result the fracture structures which help water percolation to form groundwater potential occurred. Electrical Resistivity Tomography profile there is some water presence indication like profile two (**Figure 4-35**) and three (**Figure 4-36**). This indicates groundwater presence water aquifer water bearing zone and strength the study accuracy. Resistivity is naturally not distributed equally in the earth subsurface. Those problems come from soil temperature, moisture content, mineral content and compactness of lithological layer.

5.2 Recommendation

- Geophysical technique it's unclear how to interpret. As such, separate geophysical and geological controls are required in order to distinguish between reasonable alternative interpretations of the resistivity data.
- Interpretation is limited to simple structural configurations. Any deviations from these simple situations may be impossible to interpret so that the structural configuration interpretations under the geophysical consideration need powerful understand.
- Deeper fluctuations can be obscured by topography and the impact of near-surface resistivity variations.
- The method's greatest penetration depth is restricted by the physical challenges of installing lengthy cables and the maximum electrical power that can be injected into the earth.
- There is an uneven distribution of resistivity in the earth's subsoil. These issues are caused by variations in soil temperature, moisture content, mineral content, and lithological layer compactness. Therefore, each researcher needs have a thorough grasp of the material's relative resistivity in order to interpret resistivity.

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APPENDEX

Oromia Water, Mineral and Energy Resource Bureau and AZER Construction group deep well data in West Shoa Zone and including lithological deception. Based on this agreement man power, drilling machine, materials and equipment's were deployed to the selected Balame (darimu) site on 30`s December, 2016.

5.1 Lithologic Descriptions

Detail lithological logging conducted following the end of 206m depth drilling. The lithology from drilled well is carefully described along with their respective depth as tabulated here below.

Table 5.1 Litho logical Descriptions of Darimu BH

No	Depth range(Met)		Geological Descriptions
	From	To	
1	0	43.70	Top soil, Clay soil
2	43.70	66.70	Highly Weathered basalt intercalated with clay
3	66.70	98.90	clay
4	98.90	135.70	Slightly fractured Tracky basalt
5	135.7	170.20	Massive tracky basalt
6	170.20	195.50	Slightly fractured Tracky basalt
7	195.50	206	Fresh basalt

5.2 Electrical Logging

LOGGING EQUIPMENT

Instrumentation

Electrical logging was instigated immediately after the drilling was reached the required or target depth. Equipments and materials used for the logging will be listed below

- ✓ SYSCAL type R1 Plus resistivity meter

Figure 40: Darimu well log lithology description

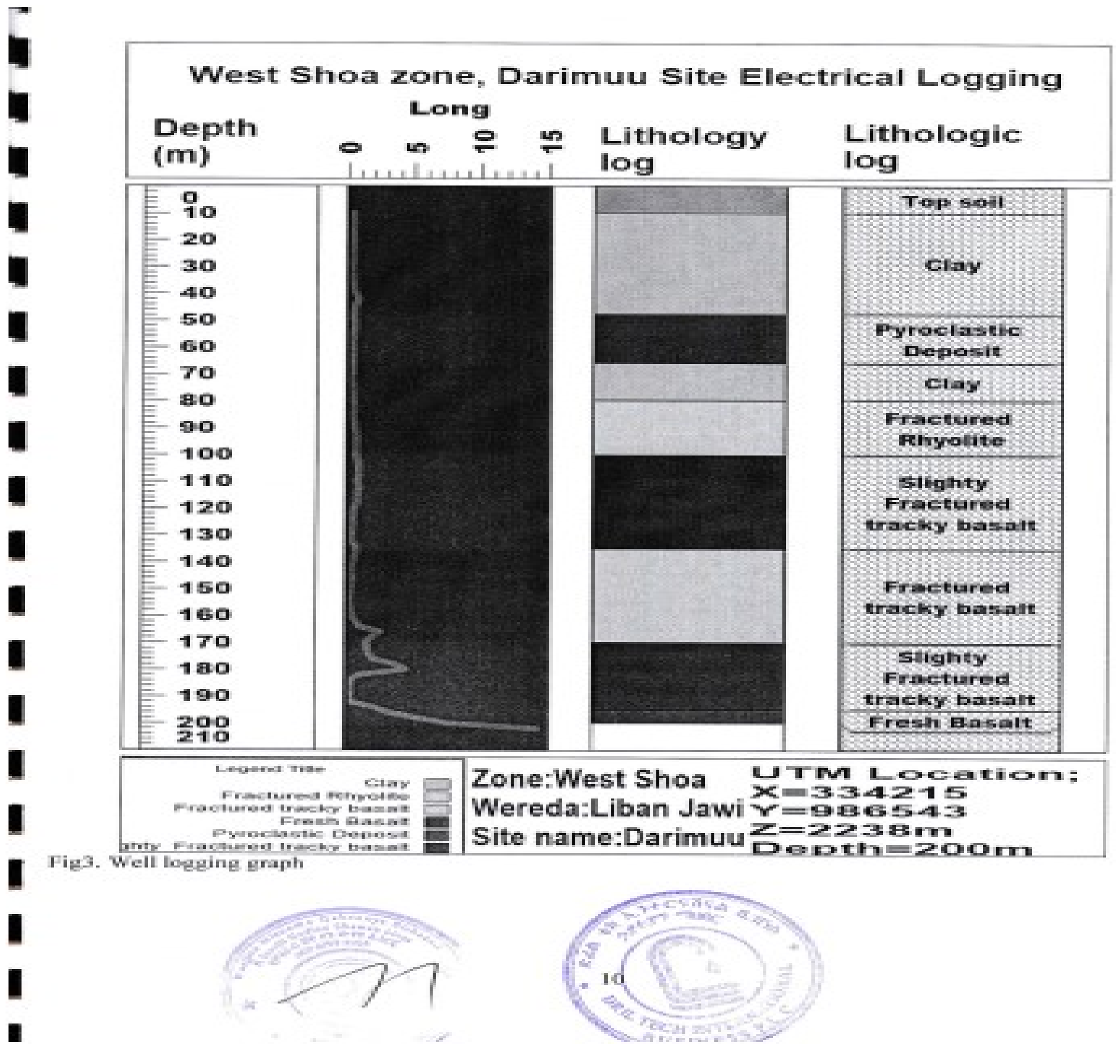

Figure 41: Darimu well log

6West Shoa Zone (Balime Site)

Balemi site- Lithological Description			
S/N	Depth (Meter)		Lithological Description
	From	To	
1	0	2.3	Silty clay soil
2	2.3	4.6	Slightly to Moderately fractured Basalt
3	4.6	13	Silt with clay and some gravel
4	13	23	Slightly to Moderately fractured Basalt
5	23	25.3	Highly fractured basalt and welded Tuff
6	25.3	34.5	Slightly fractured basalt with calcite filling
7	34.5	78.2	Moderately fractured Basalt
8	78.2	87.4	Slightly to Moderately fractured Basalt
9	87.4	89.7	Highly fractured basalt with calcite filling
10	89.7	131.1	Slightly to Moderately fractured and slightly weathered Basalt
11	131.1	133.4	Fine sand
12	133.4	140.3	Basalt with sand
13	140.3	193.2	Moderately fractured basalt with cemented sand
14	193.2	216	Sand

Table 4: Lithological description of well

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Figure 42: Balami well log lithology description

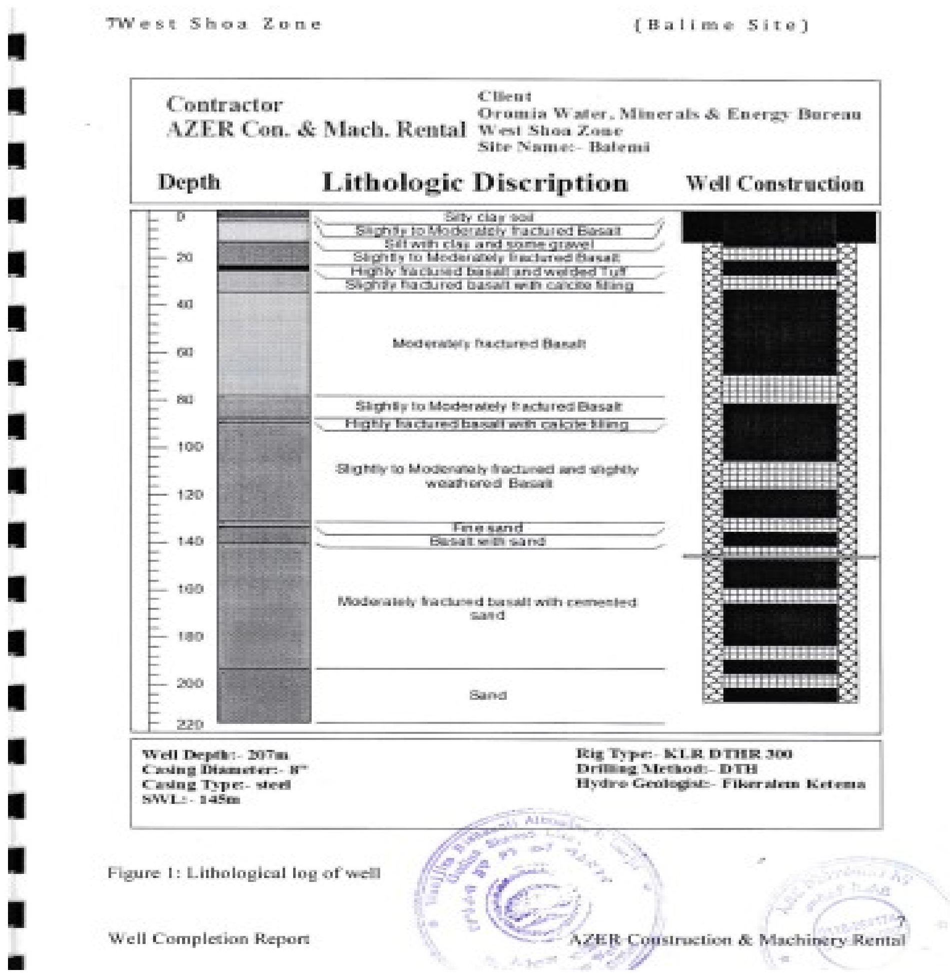

Figure 43: Balami well log

General Information of well log Data

Project: **Drilling and Construction of 5 Deep Well In West Shoa Zone**

Client: **OROMIA REGIONAL STATE WATER, MINERALS AND ENERGY BUREAU**

Date of Contract: **May 13th 2016**

Drilling Contractor: **AZER CONSTRUCTION AND MACHINARY RENTAL**

Drilling started: **December 30th, 2016** Drilling Completed: February 9th, 2017

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Surveying images

Figure 44: During surveying / Field data Collection