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THESIS

INVESTIGATION OF GROUNDWATER POTENTIAL USING GEOPHYSICAL ELECTRICAL RESISTIVITY METHOD IN DHOBLEY DISTRICT, JUBALAND STATE, SOMALIA

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SUPERVISOR APPROVAL

The thesis entitled "**Investigation of Groundwater Potential Using Geophysical Electrical Resistivity Method in Dhobley District, Jubaland State, Somalia"** has been approved and accepted to be examined in the final examination by the examination committee of Bachelor degree of science in Geology at Somali national university, to fulfill a requirement for the award of Bachelor degree in department of geology it has conducted from July 2023 to January 2024.

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DECLARATION

We declare this thesis entitled ‘’**Investigation of Groundwater Potential using Geophysical Electrical Resistivity method in Dhobley District, Jubaland State, Somalia**’’ This research is our own work and effort. This thesis has never been submitted and/or presented for any award in anyuniversity or institution of higher learning.

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DEDICATION

We dedicate this work to the almighty for their gift of life to us, our parents that we appreciate their endless love, care, moral and spiritual guidance and who taught us control, patience, and self-righteousness. May Allah reward and keep them prosperous and wellbeing. May the almighty bless them abundantly.

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LIST OF ABBREVIATIONS

DEM:	Digital Elevation Model
EC:	Electrical Conductivity
GIS:	Geographic Information System
GPS:	Geographic Position System
A.S.L:	Above Sea Level
SAR:	Synthetic Aperture Radar
SRTM:	Shuttle Radar Terrain Mission
SWALIM:	Somalia Water and Land Information Management
SWL:	Static Water Level
TDS:	Total Dissolved Solid
UTM:	Universal Transverse Mercator
USGS:	United States Geological Survey
VES:	Vertical Electrical Sounding
WMO:	World Meteorological Organization
NWDA:	National Water Development Agency
ERS:	Electrical Resistivity Survey
NDVI:	Normalized Difference Vegetation Index
IDWA:	Inverse Distance Weighted Averaging
LST:	Land Surface Temperature
SMI:	Vertical Electrical Sounding

FAO:	Food and Agriculture Organization
Berkad:	Underground reservoir, lined or un-lined, excavated to store surface runoff
Deyr:	October to November, minor wet season
Gu:	April to June, major wet season
Hagaa:	July to September dry and cool season
Jilaal:	Dry season from December to March
Wadi:	A non-perennial (seasonal) stream which is wide and shallow
War:	Unlined dug-out (dam), usually 2 to3 m deep
NGO	Non-Governmental Organization
HEP	The Horizontal Electrical Profiling
ERT	Electrical Resistivity Traverse
CST	Constant Separation Traverse
Km	Kilometer
M	Meter
Km^2	Square meter
Ωm	Ohm- meter
N	North
S	South
E	East
W	West

ABSTRACT

This study aims to investigate the groundwater potential in Dhobley district, Jubaland state, Somalia, using the geophysical electrical resistivity method. Groundwater is a vital resource in arid and semi-arid regions, such as Somalia, where access to clean water is limited. The electrical resistivity method is a widely used geophysical technique for assessing subsurface hydrogeological conditions and has the potential to identify areas with high groundwater yield. The study area is located within the sedimentary rocks with alluvial as common types of rocks. The data acquired from seven (7) VES stations using ABEM Terrameter (SAS 1000) was tabulated in a **Table 4.9** which shows the resistivity, the thicknesses and the number of layers for each VES station. The data was analyzed using computer software called IPI2WIN, which yield an automatic interpretation of the apparent resistivity. The VES result revealed that the study comprises the top soil, clay, sandy clay and weathered limestone. The first layer or top soil consists of sandy soil with resistivity range from 23Ωm to 266Ωm and thickness of range from 0.63m to 2.82m (VES 1 to VES 7). The second layer composed of clay its value ranges from 3.57Ωm to 37.7Ωm with thickness varies from 0.898m to 58.5 m (VES 1 to VES 7), and the third layer composed of sandy clay with resistivity ranges from 5.54Ωm to 121Ωm with thickness varies from 2.26m to 19.1m (VES 1, VES 2, VES 5 and VES 7). And the fourth layer composed of clay its value ranges from 3.78Ωm to 54.3Ωm with thickness varies from 22.8m to 48.7m (VES 2 and VES 5). The fifth layer of VES 2 indicates the presence of weathered limestone with a resistivity value of 355Ωm and a thickness of 31.7m. However, by considering the result obtained it is an indication that the study area has a good land for boreholes and other engineering and architectural activities, due to the features that enhance groundwater permeability and storage. For safety measures, in the deep aquifers which are ranges from 250m to 270m, the random dumping of waste products such as solid and liquid materials must to be avoided in nearby boreholes area in order to prevent waste contaminate to aquifer replenishment.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In this chapter, we discuss the need for improved hydrogeological characterization and monitoring approaches. We briefly describe the evolution of this research area in recent years in order to better understand and manage hydrological systems. Various government agencies, companies, and the national water development agency (NWDA) of Somalia have conducted groundwater resource studies in different areas of the country. These studies aimed to determine the boundaries of major basins and develop the water resources of Somalia, necessitating more comprehensive and intensive studies of the aquifer system.

The Dhobley district is located in southern Somalia, bordered to the southwest by Liboy Kenya and to the west by Afmadow. It extends to Longitude: 0.408799° and Latitude: 41.008975°, covering an area of approximately 21.66 Km². The case study focuses on the Dhobley district in Lower Juba region of Somalia, with the project's expected output being water point mapping and hydrogeological surveys using vertical electrical soundings (VES) in the Dhobley district. The Dhobley was a part of Afmadow district before 2010. Today It is a strategic border town located approximately 0.2 KM from the Kenya border.

Groundwater is a vital resource in rural and urban communities in southern Somalia, there has been increasing interest in recent years in understanding the source of groundwater. The hydrogeological survey utilizes integrated geophysical and hydrogeological methods to evaluate the groundwater potential of the Dhobley district.

During the Study, researchers will use 7 vertical electrical sounding (VES) stations in the Dhobley district. The resulting data will be interpreted qualitatively and quantitatively. The study comprises four parts: remote sensing analysis of satellite images, a desk study and review of previous investigations in southern Somalia, interpretation of collected hydrogeological and geophysical data, and finally, the collation of all results into maps and reports.

1.2 Background of The Project

Somalia is currently facing challenges in meeting both human and ecological water needs. The combination of population growth, urbanization, and rising standards of living is putting a significant amount of stress on water resources and leading to conflicts. Additionally, catchment degradation and poor waste management practices are further reducing the availability of freshwater, and all of these factors are being exacerbated by climate change.

When it comes to hydrogeological studies in southern Somalia, the most recent investigations date back to the 1950s, when Italian administrations attempted to find water for rural villages through drilling. Notable studies were conducted by Wilson in 1958 and by Katskov and Slartsev in 1968. These studies provided a hydrogeological description of the area and reported the results of local investigations in the Buur Hakaba areas.

The United Nations also conducted a project, inventorying hand-dug wells and providing a general overview of the area. While geophysical investigations were carried out in various areas, drilling activities were not included in the program. Water samples collected from the inventoried hand-dug wells were tested in the field (Faillace, 1986).

In terms of historical weather monitoring, the network in southern Somalia is mainly concentrated along the Juba and Shabelle river valleys, which has resulted in limited hydrological data in the Lower Juba region. The Dhobley district, located in the semi-arid southwest Somalia and covered by the Lag Dera basins, contributes to the seasonal peak flows of the Juba.

In September 2015, FAO and SWALIM conducted a hydrogeological study in the Ceel Waaq District of the Gedo Region in Somalia. This study, carried out by a contracting company called SWAS, revealed that Gedo is one of the regions with very poor access to safe water. A recent review of the WASH cluster in the Ceel Waaq and Bardere districts indicated that approximately 30% of all drilled boreholes are not functioning. This is primarily due to poor water quality, low-medium yield, or unsuccessful drilling resulting from a lack of comprehensive hydrogeological information. Furthermore, assessments indicate that 54.8% of residents in the area do not have access to water sources. FAO has recognized that intervention of this nature will greatly improve the precarious water situation in this vulnerable district (FAO, 2015). However, it's important to note that due to security concerns, the study area was limited, which prompted local companies and agencies to propose new sites for groundwater development. In Somalia, the electrical resistivity method is widely used due to its portability, ease of operation, and efficiency in drilling. This method has proven effective in exploring groundwater and correlating geological properties such as porosity and permeability with electrical conductivity signatures. There are two main sources of groundwater in the Buur area: springs along the limestone escarpment and hand-dug wells near temporary streams and major Burs. Previous boreholes drilled in the 1950s in Dinsoor, Bur Hakaba, Jimcada Dheen, and Madax Maroodi yielded negative results, either due to dryness or high salinity. The deepest borehole, Madax Maroodi, found water at 80 meters, despite being drilled to a depth of 123 meters. Groundwater mainly flows along major surface drainage patterns, with small water-bearing lenses at the base of Burs serving as secondary sources used by small communities during emergencies.

There are good prospects for finding additional water supplies by digging in favorable geological conditions around the Burs. However, locating proper well sites requires careful observation of geological conditions and rock joint systems, as well as the potential for increasing well recharge through runoff water. While fissured zones in crystalline rocks are potential sources of water, the likelihood of finding water in fissures is minimal. By utilizing modern technologies such as satellite imagery, photogeological interpretations, and geophysical investigations, it is possible to develop a drilling program with a higher rate of success compared to the past (Faillace, 1986).

In the Lower Juba Plain, the drainage system is underdeveloped. Drainage occurs along elongated; flat-bottomed depressions called "Laaq" that show no signs of stream beds. Laaq Bissiq, Laaq Dheere, and Laaq Badana are the longest depressions and originate from Kenya. The water from these Laaq is lost through evaporation, evapotranspiration, and infiltration. The alluvial deposits of these Laaq are difficult to distinguish from fluvio-lacustrine sediments.

A study conducted by FAO in 1960 (ref. 22) classified the large area covered by fluvio-lacustrine deposits into several soil types, including the Faafax Dhuun plain, Laaq Dheere plain, Marin plain, Dumali plain, and Shabeelle foot plain. Based on satellite imagery analysis, two main areas in the Juba Valley were identified and labeled as Qcl and Qps. The Qcl area, located south of the Faafax Dhuun plain, is characterized by brown clay loam. According to the FAO report, clay and salt content gradually increase from the surface to a depth of 2m in this area. The remaining area is mainly covered by dark-blue and gray clay, with negligible recharge from precipitation. The Qps area consists of pink to white quartz sand, with favorable conditions for recharge.

In 1979, several deep wells drilled by the Trans-Juba Livestock Project in the Jilib district encountered saline water and had to be abandoned. Similarly, a 202m deep well in Xagar, located 40km north of Afmadow, was abandoned due to its high salinity. The water in all these wells is of the Sodium Chloride type. The sandy sediments cover a large zone of Qps, where both vertical and lateral recharge are possible. Lateral recharge occurs from Kenya along the Laaq Dheere Basin. The recharge areas in Liboy and Tabda have bicarbonate water type. In this promising area, additional wells are justified (Faillace C. F., 1986).

1.3 Statement of The Problem

The problem statement for this investigation is the availability of sufficient water and the prevention of water reduction faced by people in the Dhobley district. The objective is to examine the effectiveness of these methods and determine their potential applications in solving hydrological challenges. Dhobley District faces critical challenges related to its water resources and hydrogeological conditions, which pose significant threats to livelihoods. Additionally, there is a lack of comprehensive data on the availability, depth, and quality of groundwater resources. The absence of detailed information of the present surveys about water resources planning and management.

Geophysical methods play a crucial role in resolving hydrological investigations. Techniques such as Electrical Resistivity Survey (ERS) allow geophysicists to gather valuable information about groundwater resources and help solve hydrological challenges.

To address water problems, a comprehensive Investigation of Groundwater Potential using Geophysical Electrical Resistivity method in Dhobley District, Jubaland State, Somalia needs to be conducted. The investigation demonstrates the effectiveness of coupled hydro-geophysical inversion in solving hydrological challenges. By integrating geophysical methods with traditional approaches, a more comprehensive understanding of water resources can be obtained, leading to improved management and decision-making.

1.4 Purpose of The Project.

The Investigation of Groundwater Potential Using Geophysical Electrical Resistivity Method in Dhobley District, Jubaland State, Somalia aims to assess and understand the region's underground water resources. The main goal is to determine the depth of aquifer of groundwater in the area and to contribute to local capacity building by sharing knowledge and skills related to geophysical methods, empowering local communities to participate actively in the sustainable management of groundwater resources in Dhobley District.

1.5 Project Objectives.

In this research "Investigation of Groundwater Potential Using Geophysical Electrical Resistivity Method in Dhobley District, Jubaland State, Somalia" has the following objectives:

1.5.1 General Objectives.

The main objectives of the Investigation of Groundwater Potential Using Geophysical Electrical Resistivity Method in Dhobley District, Jubaland State, Somalia are:

- ❖ To identify the spatial distribution of groundwater resources, including their potential aquifer by considering the previous investigations of hydrogeology in the Jubaland state of Somalia.
- ❖ To establish hydrogeological zones within Dhobley District based on resistivity variations, facilitating the development of targeted strategies for groundwater

exploration and sustainable resource management of Somalia for organizations and researchers.

- To assess the electrical resistivity data to infer potential water quality, as variations in resistivity can indicate changes in lithology and the likelihood of encountering freshwater or saline conditions.

1.5.2 Specific Objectives

- To determine the characteristics of aquifers, including depth, thickness, and resistivity variations.
- To study the sub surface layer variation by using Electrical resistivity method. These interpretations help identify potential aquifers from the subsurface of study area.
- To conduct detailed depth profiling to determine the optimal depth for well construction, ensuring efficient and sustainable utilization of groundwater resources in the region.
- To determine suitable our Seven locations for drilling wells based on geophysical data, optimizing the placement of water extraction points to maximize yield and sustainability of groundwater sources.

1.6 Justification

The investigation of groundwater potential in Dhobley District, Jubaland State, Somalia using the geophysical electrical resistivity has several important objectives:

The investigation of groundwater potential in Dhobley District, Jubaland State, Somalia using the geophysical electrical resistivity method is justified due to several reasons. Firstly, water scarcity is a major challenge in the region, and identifying potential groundwater sources is essential to alleviate this issue and provide access to clean and safe water for the local population.

Secondly, the geophysical electrical resistivity method is a non-intrusive and cost-effective technique that can provide valuable information about the subsurface characteristics and identify potential water-bearing formations. This method allows for the assessment of the groundwater potential without the need for extensive drilling and excavation. The use of geophysical methods can help optimize the location and depth of future boreholes and wells, reducing the risk of unsuccessful drilling and maximizing the chances of accessing viable groundwater sources. This can save both time and financial resources in the long run.

Overall, the investigation of groundwater potential in Dhobley District using the geophysical electrical resistivity method is crucial for sustainable water resource management and the improvement of the local community's livelihood. In generally, This study will be beneficial and assist for Government officials, Researchers and students, NGO, Development Agencies and others.

1.7 Definition of key terms

Hydrogeology is the branch of geology that deals with the distribution and movement of groundwater in the soil and rocks of the Earth's crust. Understanding the hydrogeological conditions is fundamental to assessing groundwater potential.

Aquifer is an underground layer of water bearing material, consisting of permeable or fractured rock, or of unconsolidated materials (Gravel, Silt Sand). Aquifers vary greatly in their characteristics.

Groundwater Potential is Refers to the capacity of subsurface formations to yield water and sustain a reliable supply of groundwater.

Resistivity Survey is Involves the measurement of electrical resistivity in the subsurface. Resistivity surveys are conducted to map variations in resistivity, helping identify geological features and potential aquifers.

Lithology is the study of the physical and chemical characteristics of rocks. Lithological variations influence the resistivity of subsurface materials and play a role in identifying potential aquifers.

Geological Features is referring to natural formations in the Earth's crust, such as fault lines, fractures, and rock types. Correlation with geological features aids in interpreting resistivity data and understanding subsurface conditions.

Electrode Configuration is a geometrical pattern of electrodes used in electrical sounding, constant separation traversing, and induced polarization surveys. Usual configurations comprise two current electrodes and two potential electrodes whose separations are known and defined by a geometric factor.

Vertical electrical sounding is a method of measuring that gathers resistivity data at various depths below a single surface point. Although it has various applications, water prospecting is the most common use for it.

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Researchers are able to "sense" facts about the Earth with the use of remotely sensed photos captured by special cameras.

Geographic Information System (GIS) is a computer-based system that captures, stores, manages, analyzes, and presents spatial or geographic data. It integrates various types of data, including maps, satellite imagery, and tabular data, to provide a tool for understanding and interpreting relationships, patterns, and trends in a geographic context.

1.8 Scope and Limitations of The Study

The study focuses specifically on Dhobley District, Jubaland State, Somalia, utilizing geophysical electrical resistivity methods to analyze groundwater potential. This study encompasses on the Conducting resistivity surveys in strategic locations, identifying potential aquifers based on geophysical data and correlating geophysical findings with geological features of Dhobley district, Jubaland state, Somalia. Father more, this Study will carry out from July 2023 to January 2024.

1.9 Study Area

1.9.1 Location

Dhobley, formerly known as Liboy, is a strategic administrative division of the Afmadow district in the south-western region of Somalia's Lower Juba. It is located approximately 0.2km from the Kenya border. Dhobley is a district in the Lower Juba region near the Kenya border. The main economic activity for the population is livestock grazing. The population mainly relies on boreholes, surface dams, and earth paths as their main water sources, which are in very bad condition. The access to the surface dams and earth pans is very difficult, especially for women and children who are responsible for collecting water for their families.

During the dry season, the surface dams and earth pans dry up, forcing the community to find their own ways to cope with the drought. This includes either migrating to areas where their needs can be met or using camel-mounted jerry cans and locally-made containers to gather water from distant places. The surface dams and earth pans are unprotected, putting the community's health at risk and exposing them to chronic water-borne diseases like dysentery and acute watery diarrhoea.

Figure 1.1 Location map of study area.

1.9.2 Physiography

In this section, we will focus on the physiography of Dhobley District in Lower Juba, Somalia. Although no previous studies have been conducted on this area and it is currently inaccessible for field exploration, we will examine the physiography of the study area by gathering information about the Juba River in southern Somalia and the surrounding landscapes. Livestock farming plays a vital role in the economy of Dhobley District, with a significant presence of goats, sheep, and camels. The pastoral communities in the area depend on access to water sources and grazing land for their livelihoods.

The Jubba River valley is characterized by the presence of sedimentary rocks, primarily clays and sand, for the first 250 km from the river mouth. From that point to the border with Ethiopia, the valley sides are dominated by old sedimentary limestones and sandstones, with some young basaltic flows on top of hills. The valleys themselves are mainly composed of alluvial deposits, consisting of sand, silt, and gravel, which make up 97% of their area. These valleys are predominantly floodplains (97%). In lateral valleys, the most common relief is river plain (82%). The last type, confined valley, is characterized by very steep rocky walls, with the floor composed of quaternary unconsolidated deposits (100%). Within this landscape, the only relief found is confined valley (100%). (FAO-SWALIM, 2007)

The QCL area, located south of the Faafaxdhuun plain, is covered by brown clay loam. The FAO report indicates that in this area, the clay and salt content progressively increase from the surface to a depth of 2m. The remaining area is primarily covered by dark-blue and grey clays, with negligible recharge from precipitation. The QPS area is covered by pink to white quartz sand, and conditions for recharge are favorable. The area covered by sandy sediments deposited by Laaq Dheere in lagoon or shallow seas offers good prospects of finding water of better quality. The area is represented in maps with the symbol QPS (E.R. FAILLACE, 1986). In (**Figure 1.2**) the sands discovered in the Dhobley District most likely indicate the involvement of both wind and water in the sediment deposition process. These sands can vary in size and composition, and they play a significant role in determining the environment and soil characteristics. The presence of fine-grained silts and coarser gravels highlights the geological diversity of the area, emphasizing its dynamic nature.

In the Lower Juba region of Somalia, the geologic settings of Dhobley District consist of a variety of sedimentary deposits, including sands, silts, gravels, dark gray clays, and pink to white quartz sands, as shown in **Figure (1.2).** These sediments provide insights into the historical environmental conditions and sedimentation processes. To fully understand the geological composition of Dhobley District and its implications for the local landscape, further analysis and investigation are required, we sure that, the predominant dark gray clays are a distinctive feature of the district and are often mineral-rich.

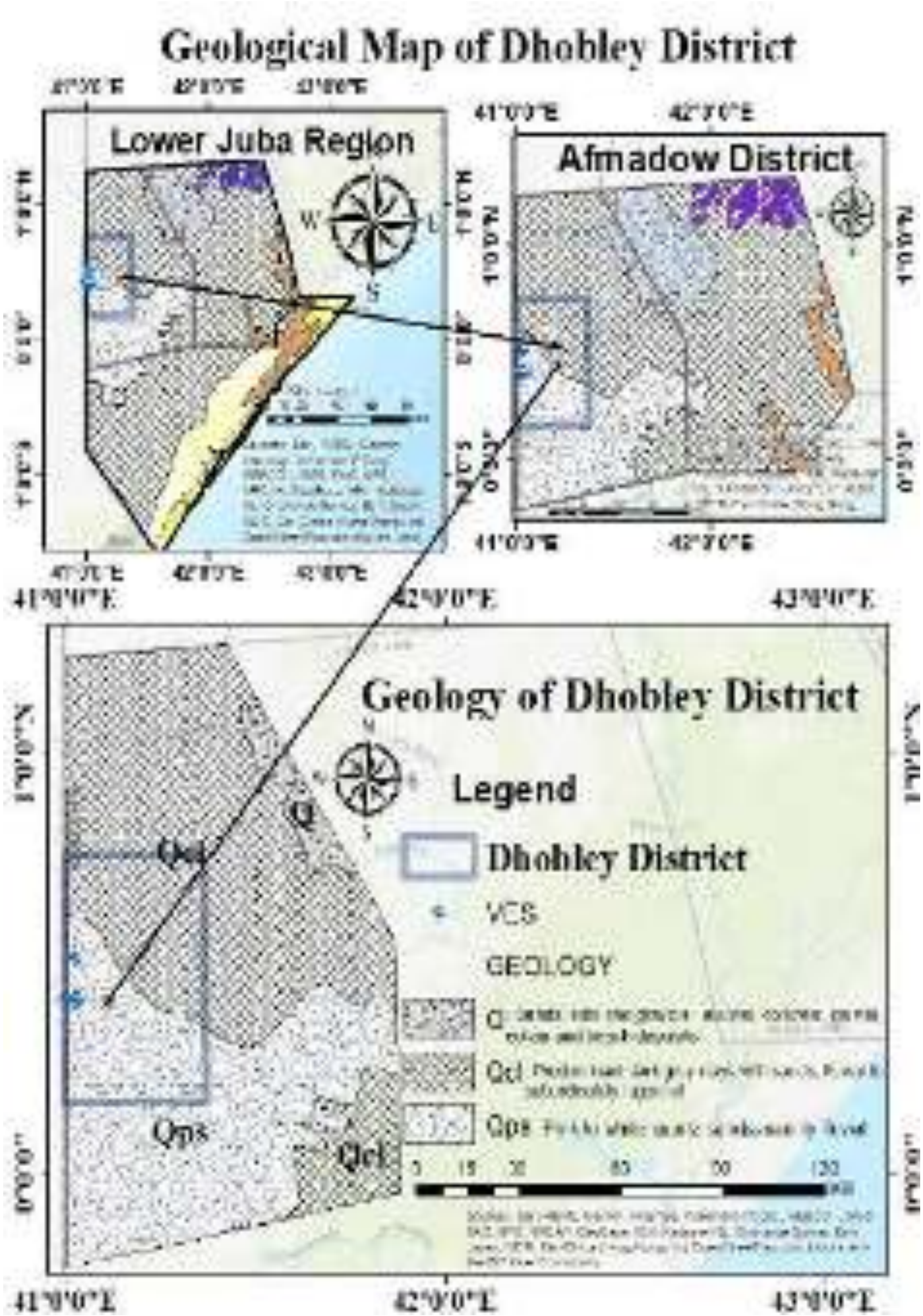

Figure 1.2 Geological map of Dhobley district by E. Abbate 1994

1.9.3 Climate

The climate in Somalia is primarily arid to semi-arid, with rainfall being the key characteristic. The country has two rainy seasons: the Gu and the Deyr. The Rainfall in both seasons is caused by moist air from the Indian Ocean in the southerly air stream. The success of agricultural activities depends on seasonal and within-season variations.

The Somalia climate archive held within SWALIM contains data as far back as 1894 (for Kismayo) and 1904 (in Mogadishu). However, the information is characterised by huge periods where data is missing. In this analysis, the most recent consistent available data has been used, most of which has been extracted from the FAO global climate database for the period between 1963 - 1990. However, the database is missing information for some periods from some stations. In such cases missing data was extrapolated to improve the analysis. Figure 3 shows some of the pre-war monitoring stations whose data has been included in this technical report. Some stations have been deliberately omitted because they have very large gaps of missing data, while others have so little data that the information is almost useless for climate analysis. (Management, Climate of Somalia, 2007)

Temperatures in Somalia are high throughout the year, with the hottest areas being inland, particularly Zeylac, Barbera, Bosaso, and Luuq. Luuq, located in the Gedo area near the borders of Ethiopia and Kenya, has the highest average yearly temperature in the country, exceeding 30°C. The north shore of Somalia is nearly as warm as the majority of inland regions, which are only slightly cooler. The southern shore has lower temperatures compared to the northern shore. Overall, the country experiences an average monthly temperature higher than 30°C, as shown in (**Figure 1.3**) depicting annual air temperature patterns over Somalia.

The highest mean temperature in Somalia, over 31°C, is recorded in Luuq, in the Gedo area near the borders of Ethiopia and Kenya. Inland areas of the south experience the highest temperatures. The southern coast has lower temperatures due to cool ocean currents. Lower Juba, specifically around Afmadow and Dhobley Districts, maintains average monthly temperatures of 28-30°C throughout the year. While some local communities in certain areas of lower Juba have reported warmer temperatures, these observations were not utilized in this study. Southern Somalia experiences the hottest temperatures from December to March. The Kenya-Somalia-Ethiopia borders have the highest temperatures (over 30°C), gradually decreasing towards the ocean (28°C). July and August are the coolest months in southern Somalia, while June to September bring the highest temperatures to the north, particularly in the Awdal and Bosaso regions. Additionally, the north experiences colder temperatures in January and February.

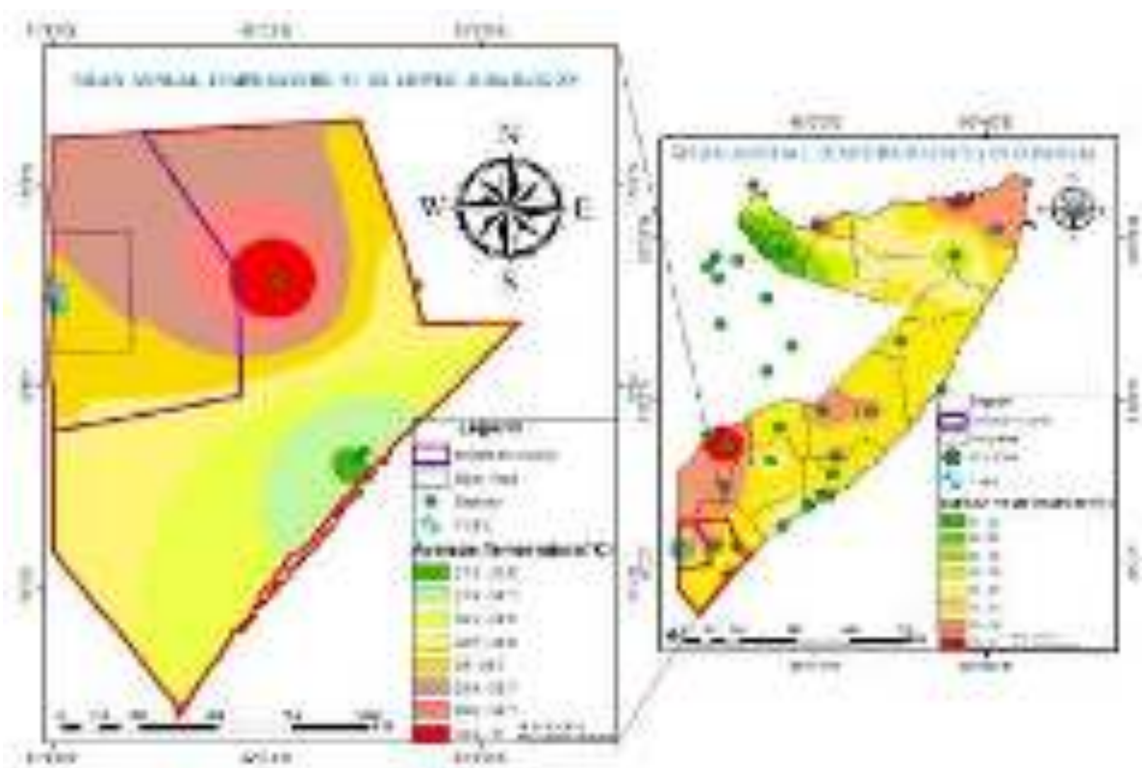

Figure 1.3 Mean Annual Temperature in Somalia and Lower Juba region of Somalia.

Table 1.1 Long term average climatic values in Lower Juba Region (Source: SWALIM).

Climatic Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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1.9.4 Rainfall

Somalia experiences two main rainy seasons, Gu and Deyr. Gu occurs between March and July, while Deyr occurs between August and November. The months with the heaviest rainfall are typically April to June and October to November. The dry seasons are called Jilaal (December to March) and Haggai (July to August). Here is a summary of each season:

A. **Jilaal season:** Lasts from December to March. Characterized by dry and warm conditions due to the northeast monsoon.

B. **Gu season:** April to June. Brings transitional weather with rain and heat.

C. **Haggai season:** July to September. Dominated by the southwest monsoon, bringing cold weather and showers along the coast while inland areas remain dry.

D. **Deyr season:** October to November. Similar to Gu but with less rainfall. Gu is still the main farming season due to its higher quantity and consistency of rainfall.

Somalia's location on the leeward side of the highlands of Kenya and Ethiopia leads to lower precipitation. Overall, Somalia has a desert to arid sub-humid climate. The start of the rainy seasons varies across the country. In some regions, Gu rains begin as early as the second half of March, while the northeastern coast experiences the least rainfall. The northwestern region sees a combination of Gu and short rains in September cut. The Gu season receives the majority of the annual rainfall, making it the primary cropping season. However, the Deyr season contributes 25 to 30% of the rain in inland areas. The amount of rainfall in different seasons is also influenced by elevation in Southern Somalia. The Gu rainy season in Somalia takes place from April to May. Although the Gu season can start at any time, topographic factors cause it to begin earlier on the plateau. (Management, Climate of Somalia, 2007).

The amount of rainfall differs significantly between the plateau and the middle Juba. Rainfall is more frequent during the Gu season compared to the Deyr season. The Lower Juba receives a higher amount of rainfall throughout the year, with up to 400 mm/year (**Figure 1.4**). As one moves further inland in the Southwest, rainfall decreases. The Lower Juba and the Dhobley district area receive up to 280 mm of rain annually. According to the FOA report in 2007, Deyr rains occur in Somalia during the Deyr season, which typically starts in September, intensifies in October, and ends in November. However, there are regional variations across the country. Kismayo experiences smaller Deyr rains compared to other areas. Despite the lower amount, Deyr rains have a similar distribution to Gu showers. The Deyr season brings up to 300 mm of rain each year to the southern region. Deyr rains are generally shorter and less frequent compared to the Gu season.

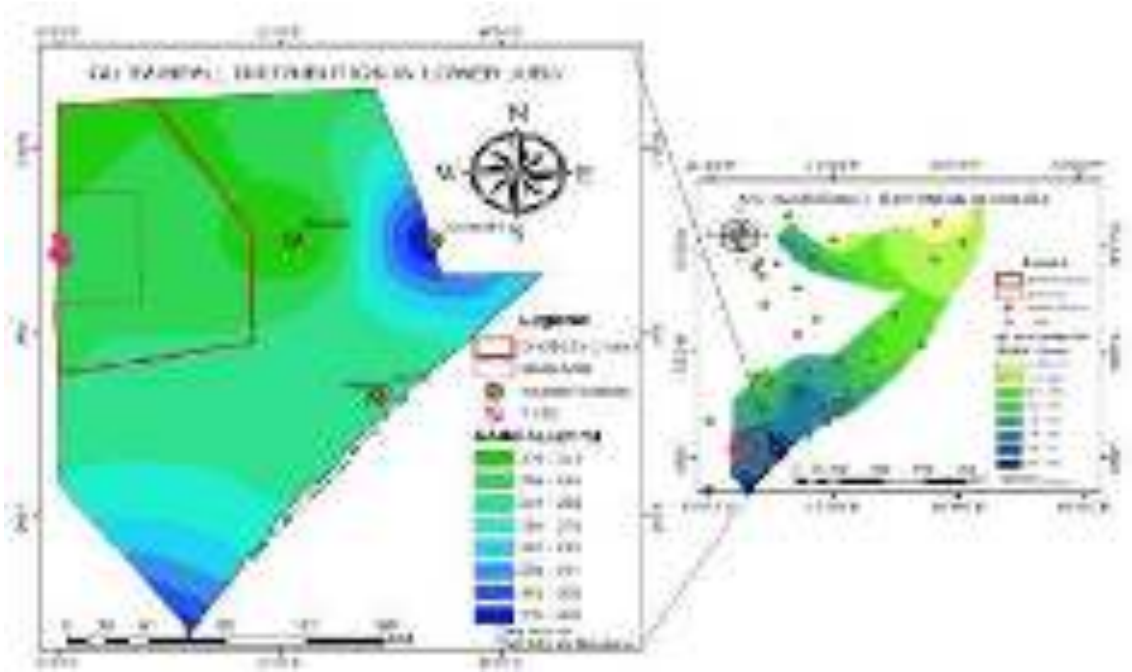

Figure 1.4 Gu distribution Rainfall (Mm) In Somalia and In Lower Juba Region.

The amount of rainfall in Somalia varies from season to season and has a significant impact on surface runoff, stream flow, groundwater recharge, growing seasons, and agricultural activities. Certain regions, particularly those near Baidoa, north of Lower Juba, and the surrounding areas of middle Juba and upper portions of Lower Shabelle, are selected during the Deyr rains. In comparison, the Gu rains are more beneficial across the entire country compared to the Deyr rains. Although there is a smaller time difference between the Gu and Deyr seasons, the rainfall pattern is similar in northern Somalia.

In (Figure 1.5) The middle and lower Juba, as well as the coastal region of middle Shabelle, receive higher rainfall rates between 30 to 300 mm/year. Rainfall decreases as one moves further inland in the north of Lower Juba, and the Afmadow area receives up to 300 mm of rain annually. Only a few rainfall events occur in the southern regions of the country in December.

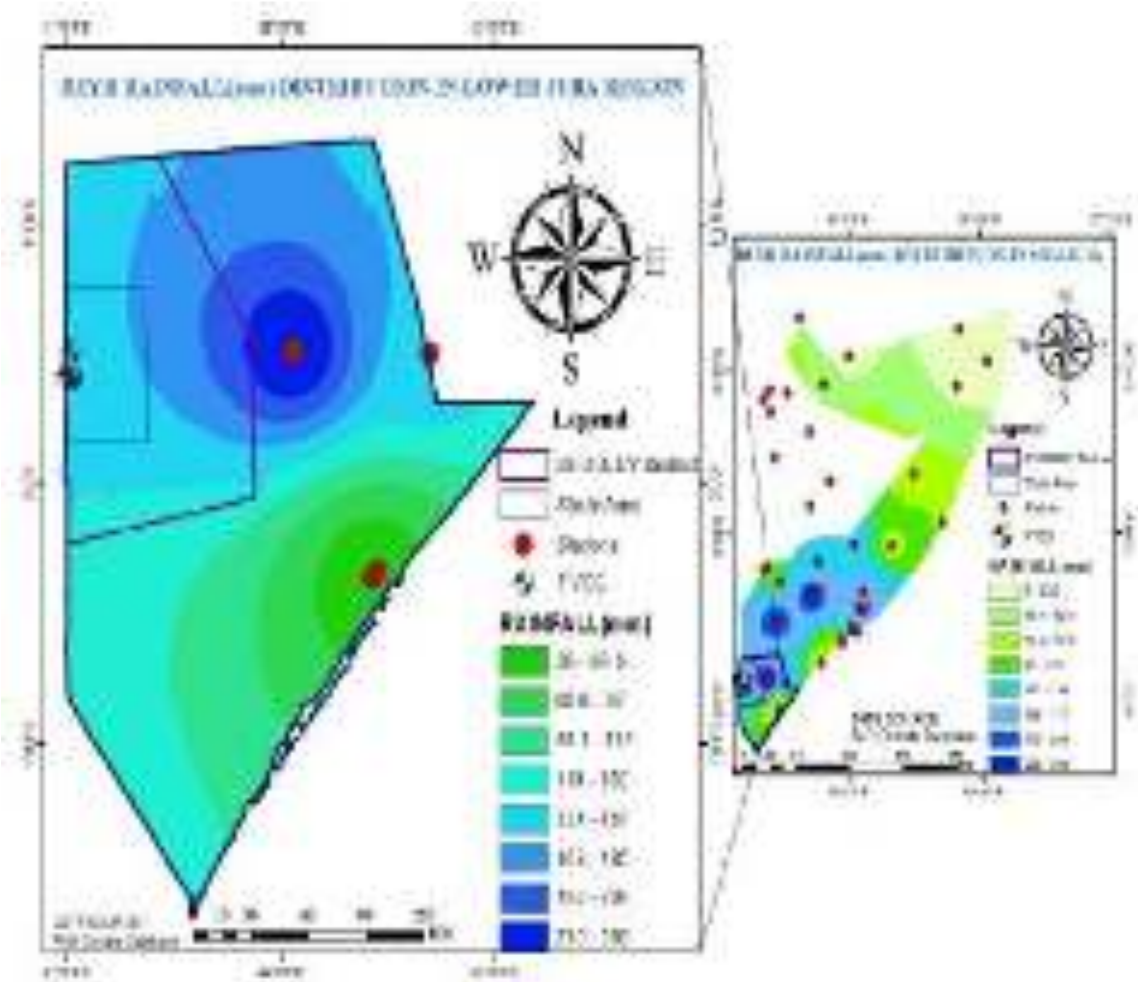

Figure 1.5 Deyr Rainfall (mm) distribution in Somalia and in Lower juba region

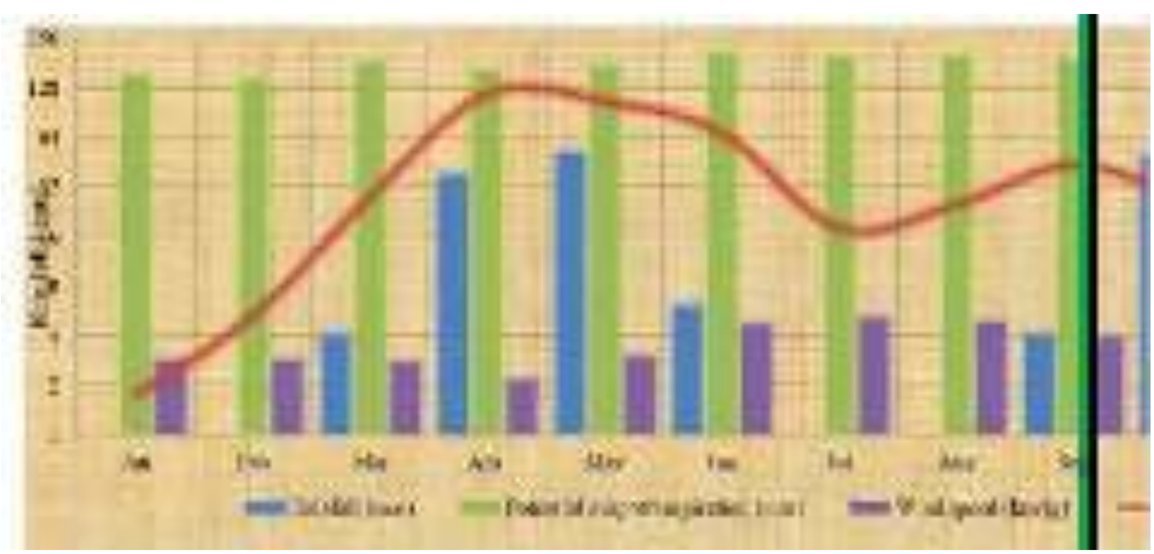

Figure 1.6 Average Monthly Climatic Data of Juba Region (Source: SWALIM).

1.9.5 Drainage

This text provides an overview of the water assessment of the Lag Dera drainage basin in the Lower Juba Region and a brief study of the Lag Badana Basin.

The Lag Dera Basin in Somalia covers two regions: Gedo and the Lower Juba region, passing through five districts. In the Lower Juba region, the districts are Dhobley, Afmadow, and Kismayo, and in Gedo, they are Ceel Waaq, Baardheere, and Saakow. The basin is located between 0° 20' south and 4° 35' north of the Equator and between 36° 12' and 42° 35' east of the Prime Meridian.

The Lag Badana Basin is the general name for this river system. The Lag Badana Basin's drainage zone is located in the far south of Somalia and has one of the highest rainfall totals in the country, despite its thin network of ill-defined seasonal water streams. These river basins are important for the water resources of the Lower Juba region in Somalia. However, there is limited data available on the Lag Dera and Lag Badana basins, as no surface water observations have been made. Surface runoff is believed to occur only after heavy rain.

According to FAO (2007), the flows from Lag Dera rarely reach Juba as most of the water disappears in Deshek Wamo, a large natural depression in the south of the basin. However, there is no data available on the hydrology of the basin or the area of the depression and wetlands within it. Lag Dera originates from the highlands in Kenya and Ethiopia, crossing the border into the Gedo and Lower Juba regions of Somalia. The drainage system is poor, with small ephemeral streams that only run during heavy rainfall (Figure 2.4) displays some of the streams found in the Dhobley and Afmadow escarpments, which are fed by springs. The waters from seasonal rivers in northeast Kenya occasionally reach Juba due to heavy rainfall in December.

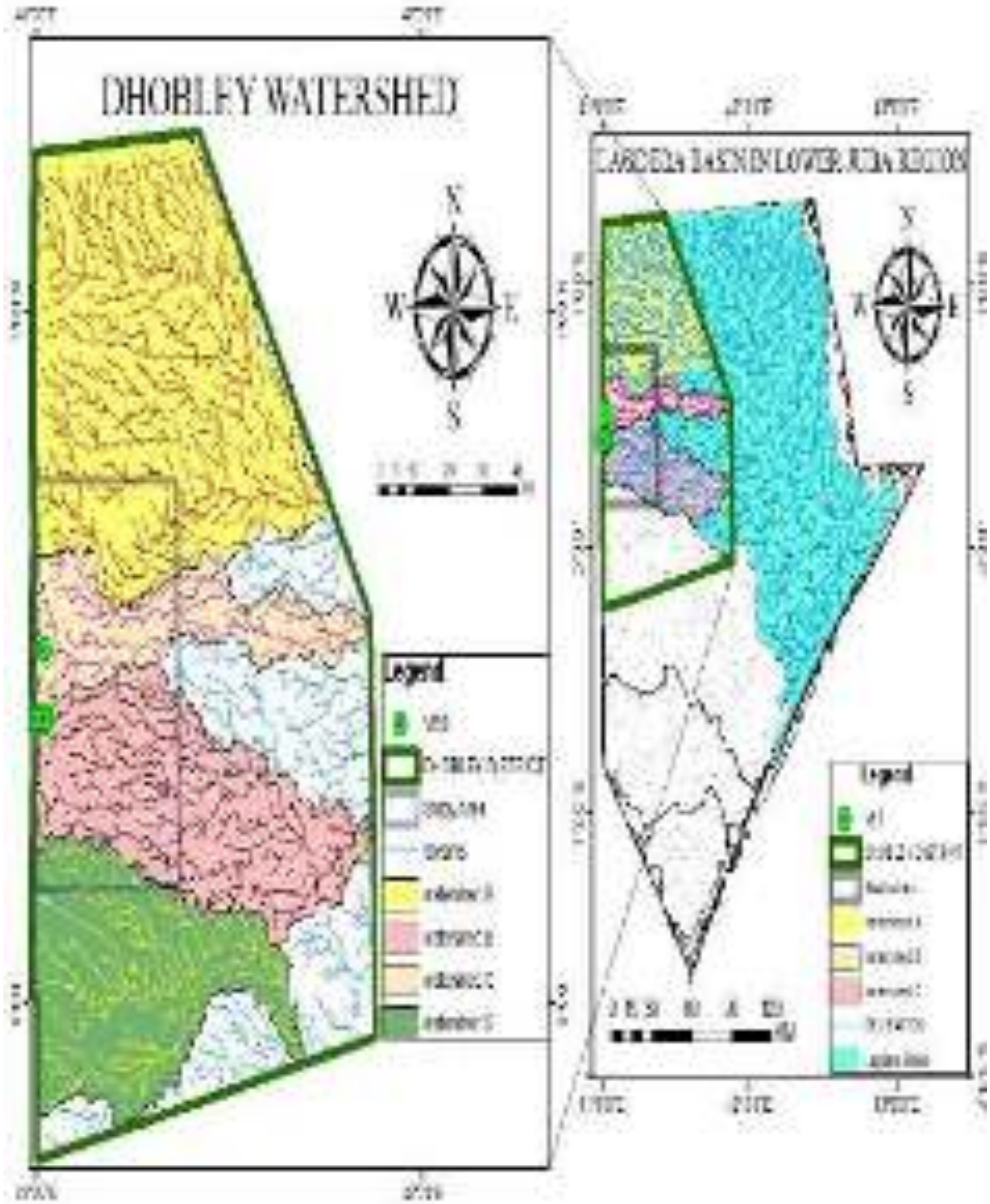

Figure 1.7 Lag Dera Basin in lower juba region.

1.9.6 Vegetation

In the hydrogeological investigation we are conducting in the Dhobley District, Lower Juba region of Somalia, studying vegetation is important for several reasons. Vegetation serves as an indicator of groundwater availability and quality, providing insights into hydrological conditions. Healthy and diverse vegetation suggests the presence of groundwater resources, while the absence or poor health of vegetation can indicate water contamination or scarcity. Therefore, considering vegetation in our investigation is crucial. Remote sensing allows us to gather information about the local climate, soil characteristics, and water table depths by analyzing the type of vegetation in the area.

Furthermore, understanding the relationship between vegetation and hydrogeology helps us identify potential aquifer recharge areas. All of this information emphasizes the significance of vegetation in our investigation. The (**Figure 1.8**) of NDVI Map of the Dhobley District in the Lower Juba Region of Somalia is essential for understanding the local environmental dynamics. The NDVI, or Normalized Difference Vegetation Index, is a remote sensing tool that measures and assesses vegetation health and density using satellite imagery. In this case, the NDVI map shows that the area is mainly characterized by sparse vegetation, shrubland, grassland, and patches of healthy vegetation. The study of vegetation is crucial in investigating groundwater resources. Vegetation serves as a reliable indicator of potential groundwater availability. Areas with healthier vegetation often indicate higher groundwater tables, as plant roots reach down to access moisture. Conversely, sparse vegetation may suggest a lack of available groundwater resources, providing valuable information for water resource planning and management.

Different types of vegetation offer valuable insights during this investigation. Shrubland and grassland indicate environmental conditions that may be associated with seasonal or limited groundwater availability. On the other hand, healthy vegetation suggests areas with more consistent and reliable water sources. These distinctions help identify regions where groundwater resources may need to be conserved or further explored for sustainable water supply. The agricultural land in the district can impact the hydrological system, as farming practices, irrigation, and soil types can affect water availability and quality. In-depth hydrological investigations in the area would likely consider factors such as rainfall patterns, surface water sources, groundwater availability, and potential water-related challenges due to urban and agricultural development in the region.

The NDVI map of the Dhobley District, Lower Juba Region, provides a visual representation of the vegetation cover across the landscape. It uses a colour scale to depict the density of vegetation, with green indicating healthier and more densely vegetated areas, and brown or tan representing areas with less vegetation. **Figure (1.8)** helps decision-makers, researchers, and environmentalists assess the state of the region's ecosystem, predict drought conditions, and plan for water resource management. The combination of sparse vegetation, shrubland, grassland, and patches of healthy vegetation provides a comprehensive picture of the district's environmental characteristics, enabling more informed decisions regarding groundwater resource utilization and conservation.

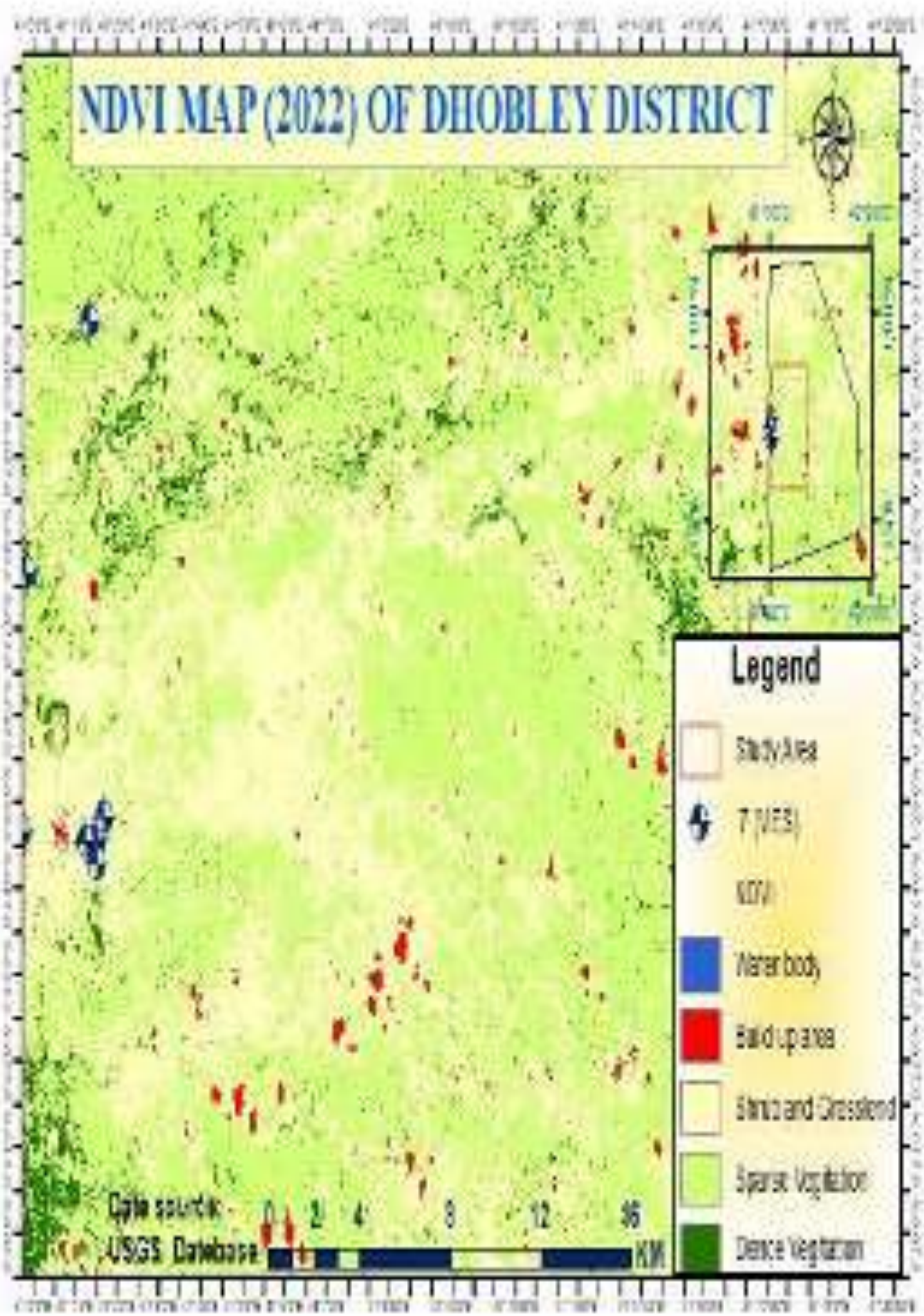

Figure 1.8 Normalized difference vegetation index at Dhobley district on 2-Jan-2022.

1.9.7 Soil

The agricultural land in the district can affect the hydrological system, as farming practices, irrigation, and soil types can impact water availability and quality. Comprehensive hydrological investigations in the area would consider factors such as rainfall patterns, surface water sources, groundwater availability, and potential water-related challenges due to urban and agricultural development in the region.

The Lower Juba region of Somalia's Dhobley District has a diverse landscape with various sedimentary deposits, as shown in **(Figure 1.9)** These deposits include loam, Clay loam and Sandy clay loam, The presence of these different soil texture gives us, the area has a complex geological history and groundwater. The Soil texture play an important role in soil quality and composition.

Different soil classifications have different water infiltration characteristics. Loam, which consists of a balanced mixture of sand, silt, and clay, is generally more permeable and conducive to water infiltration. Clay-rich soils have lower infiltration rates and are less suitable for rapid water absorption. Soils with a mixture of sand, clay, and loam can have varying water infiltration capabilities based on the specific ratio of their components. Loam is highly valued for its water-holding capacity while still allowing for proper drainage. It is ideal for agriculture as it provides a balance between retaining moisture and preventing waterlogging. (Sridhar, 2015). These soils may pose challenges for water supply and agriculture due to slower drainage and potential compaction. However, they have good nutrient retention properties, which can benefit certain crops.

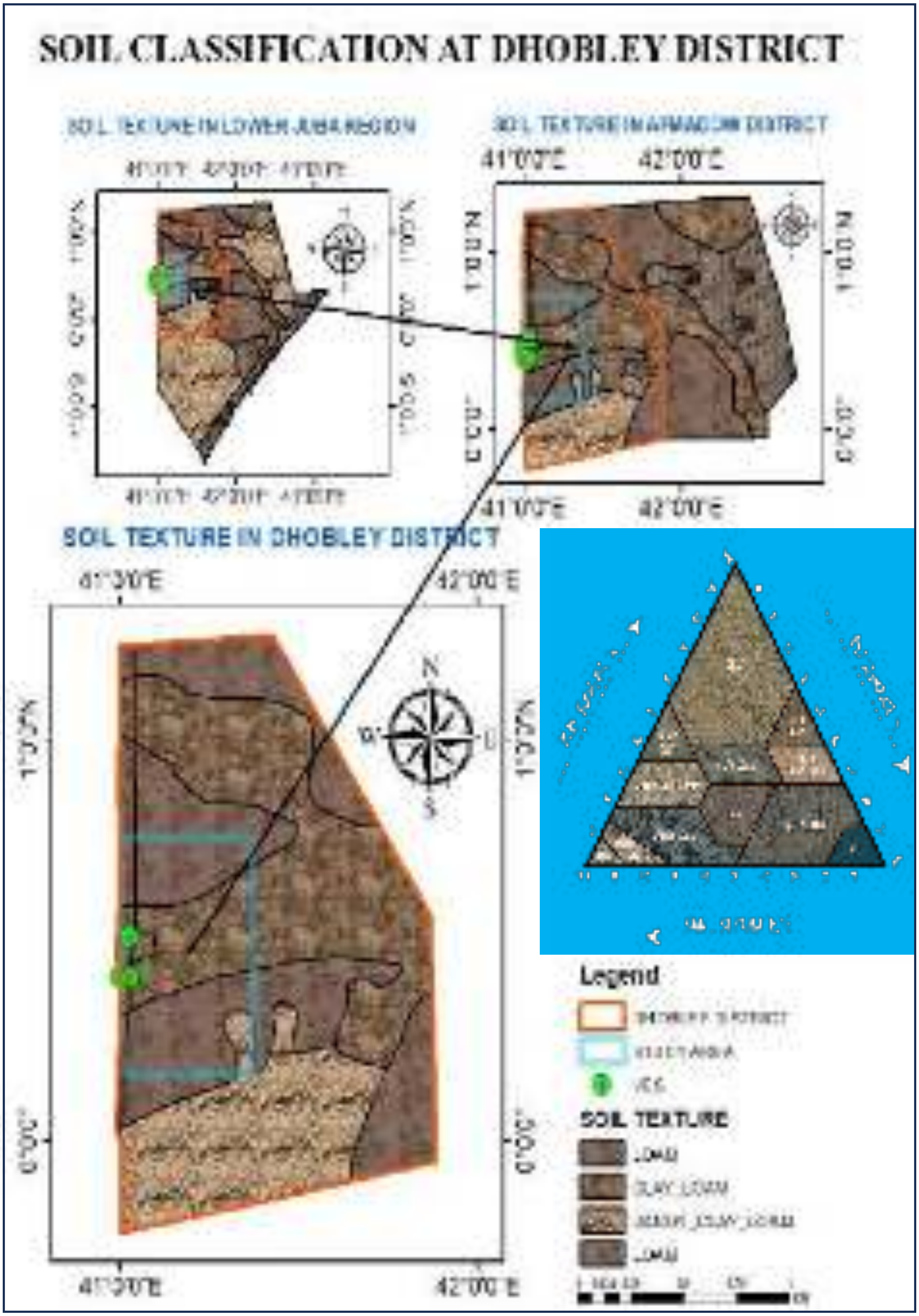

Figure 1.9 Soil classification map in Dhobley District (Source: FAO).

Soil moisture is an important variable in hydrological modelling used for real time flood forecasting and water resources management. However, it is a very challenging task to measure soil moisture over a hydrological catchment using conventional in-situ sensors. (Al-Sharafany, 2021). Also (Arnab Saha *, 2018) defined the Soil moisture is a key parameter which directly or indirectly influences the water cycle. Agriculture production of rabi crops in rainfed areas mainly depend on it as well as irrigation practices based on it.

We applied the remote sensing technique which relies on the use of the soil moisture index (SMI) which uses the data obtained from satellite sensors in its algorithm. The relationship between land surface temperature (LST) and the normalized difference vegetation index (NDVI) are based on experimental parameterization for the soil moisture index. The SMI is categorized into classes from no drought to extreme drought to quantitatively assess drought. The results of the soil moisture index map of September 2023 indicate the soil moisture index was in the range of 0.03 to 0.81 as classified in four color gradients. Most of the study area, as shown in **Figure 1.10** (violet and blue color), has a value close to zero, which was highly affected by water deficit. The values near 1 (red and yellow) are forest cover which has moisture as compared to the rest of the land cover. The results concluded that more than 70 percent of the area was close to zero, which indicates a moisture deficit in the offseason throughout the study area. As per the index, near1 represents a higher presence of water or moisture, and zero indicates minimum moisture content, such as dry areas. Furthermore, the Southern side of Dhobley district has high moisture then northern side which means more moisture indicates possibility of good source of shallow acquirer.

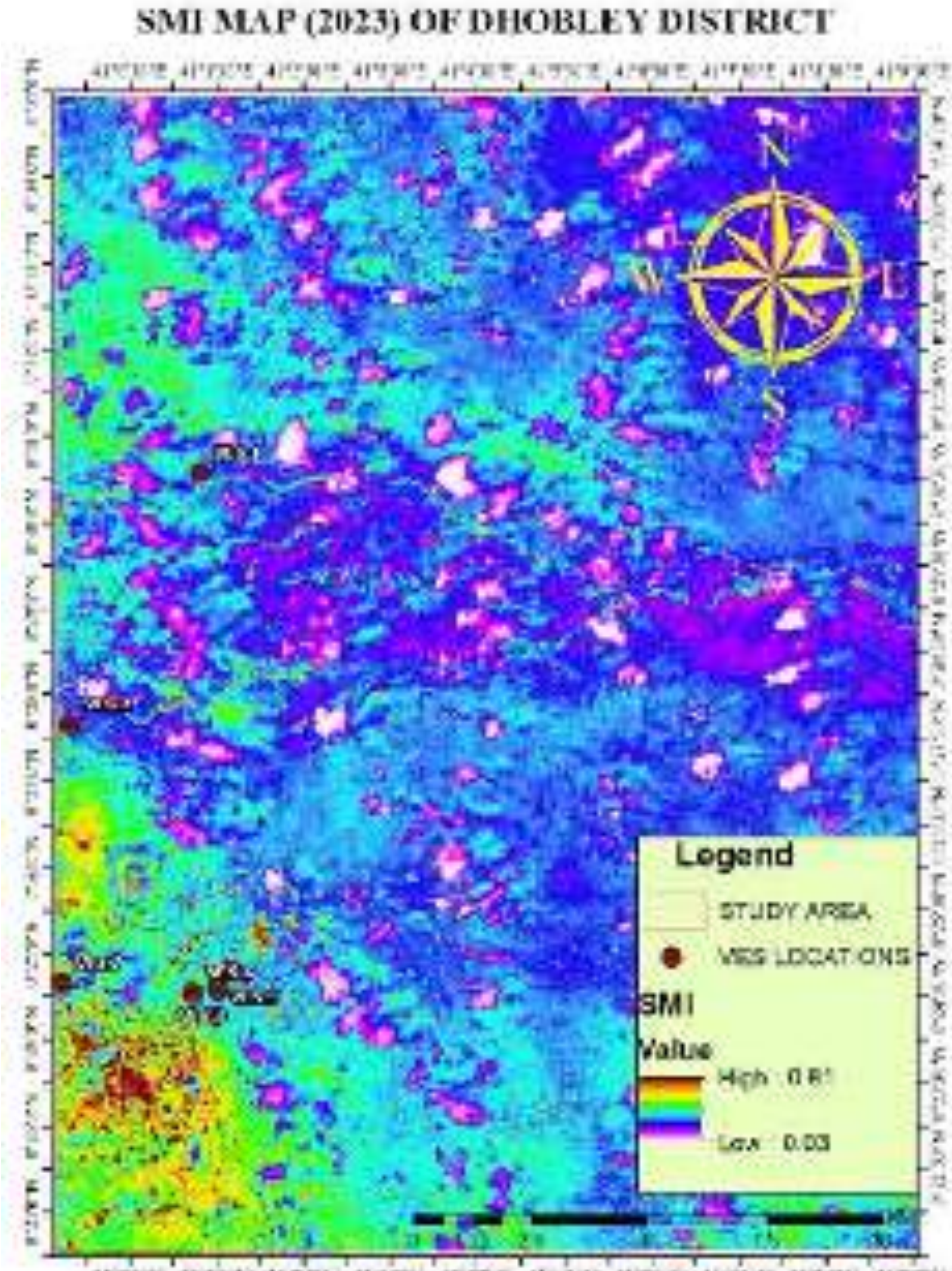

Figure 1.10 Soil moisture index map of Dhobley district on 10-Sep-2023

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Our investigation has recovered historical data that is available and collected valuable data on water and land resources over the past years to support our investigation of groundwater potential using the geophysical electrical resistivity method in Dhobley district, Jubaland State of Somalia.

Several investigations have been undertaken and discussed various aspects of geological, hydrological, and hydrogeological developments in the target area. For example, Faillace and Faillace (1964 - 1987), UNDP/FAO (1968), Hunting Service (1969), V. N. Kozerenko (1972), The UN "Mineral and Groundwater Survey" which was completed in 1973, divided Southern Somalia into the following hydrogeological provinces: the Cretaceous border belt, the Xuddur Bardheere Plateau, the lower Juba plain, the Shabelle and Juba valleys, the coastal plain, the coastal belt, and the Buur area. Also, Johnson (1978), Henry (1979), Pozzi, et al (1985), Hutchinson and Polishchouk (1988), Kammer (1989), MacDonald (1990), SWALIM (2007). The geology of the study area covered by this report is shown in the 1:500,000 scale geological map of Somalia. This map was compiled from various sources and was published by Abbate, et al in (1994) from the University of Florence.

2.2 International

MacDonald et al., (2001) have employed geophysical methods for locating groundwater in low permeability sedimentary rocks of Oju, southeast Nigeria. The geophysical techniques used to identify these groundwater targets comprise frequency domain conductivity using the Geonics EM34, Vertical Electrical Resistivity Sounding (VES) and magnetic profiling (using a proton precision magnetometer). In inter bedded shale and sandstone areas, sandstones were distinguished as low conductivity zones (< 20 mmhos m^{-1}) using electromagnetic and resistivity techniques.

Niwas et al., (2003) have attempted to estimate the aquifer hydraulic parameters using surface geoelectrical sounding data. In a mesoscopic framework, approximated analytical equations are developed separately for saline and fresh water saturations. A few existing useful aquifer models, both for clean and shale sandstones are discussed in terms of their electrical and hydraulic effects, along with the linkage between the two. These equations are derived for insight and physical understanding of the phenomenon.

Gholam et al., (2005) have assessed groundwater conditions in alluvial aquifer in the Shooro Basin in Southeast Iran using vertical electrical soundings by Schlumberger array maximum electrode spacing 200m to 600m. Sharma and Baranwal (2005) have delineated groundwater- bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data in Purulia district (West Bengal), India. A detailed survey of the area done by very low frequency (VLF) electromagnetic, Self-potential and resistivity profiling surveys. VLF survey and resistivity suggest the existence of deep groundwater sources in the southern part of the area.

Jinadasaet al., (2009) havecarried out the resistivity imaging and self-potential techniques to investigate groundwater accumulations in the hard rock terrain in Moneragala. The results obtained show areas of low resistivities and negative self-potential anomalies, which correlate well with the geological structures identified from maps or field observations. These are possibly areas with groundwater accumulations. However, this study shows that these simple methods show promise and may be used to improve accuracy to locate groundwater wells in the dry zone.

Musa et al., (2014) have conducted Vertical Electrical Sounding (VES) in Tudun Wada Kano State, Nigeria for groundwater exploration in the crystalline rocks. The study area is located within the sedimentary rocks, igneous, and metamorphic with alluvial as common types of rocks. The data acquired from six (6) VES stations using ABEM tetrameter (SAS 1000) and analyzed using computer software called IPI2win. The value for topsoil ranges from 16Ωm to 550Ωm with thickness varies from 1.45m to 6.05m. The weathered layer resistivity ranges from 14Ωm to 541Ωm and thickness of 5.70m to 33.00m. The fractured basement ranges in value from 189Ωm to 785Ωm with thickness ranges from 11m to 20m. The fresh or bedrock basement has a resistivity of 1011Ωm to 3006Ωm which move down infinitely. Therefore, the depth of the bedrock from the topsoil or earth's surface ranges from 2m to 45m.

Sultan Awadet.al. (2015), have done an Integrated geophysical interpretation for delineating the structural elements and groundwater aquifers in Sinai between Nakhl area and El Thamed area, central part of Sinai Peninsula, Egypt. Two hundred and eighty-eight magnetic and gravity stations were acquired by the EnviMag and Autograv CG3 instruments respectively. The magnetic data were processed by using Oasis Montaj.

Reductions to the pole and 2D magnetic modeling were established to construct basement relief map. The depth to the basement rocks in the study area is ranging from 1200 m to 7000 m. Besides, nine deep Vertical Electrical Sounding stations were measured to estimate the deep groundwater aquifer in the study area (Nubian Sandstone aquifer). The depth of upper surface of Nubian Sandstone aquifer is ranging between 975 m and 1100 m and affected by two major fault trends in the NE–SW and NW–SE directions.

Mohammed Adam Ginaya et al., (2017) Electrical measurements using the Vertical Electrical Sounding (VES) method was utilized in determining aquifer characteristics of Wad Hamid area. Three geologic units were recognized in the area; Quaternary deposits, Cretaceous Sandstone Formation and the Basement Complex rocks. 122 VES using the Schlumberger configuration were acquired for the study area. A maximum half electrode spacing of 900 m was utilized for data acquisition. All these soundings were processed using IX1Dsoftware. Geo-electric sections were constructed from which the aquifer us layers were delineated. Hydraulic parameters (hydraulic conductivity and transmissibility) were computed at the existing borehole and VES sites. SUST Journal of Engineering and Computer Science.

Evans Manu et al., (2019) The focus of this study is to delineate groundwater-bearing zones for the drilling of boreholes to ensure sustainable water supply in the Cape Coast municipality using the vertical electrical sounding (VES) technique. A total of 25 VES points was conducted of which thirteen (13) were test drilled. The VES survey was conducted using the ABEM SAS 1000 Tetrameter with the Schlumberger configuration and a maximum half current electrode spacing (AB/2) of 100 m. The VES data were processed and interpreted using the ZONDIP resistivity inversion software. Both qualitative and quantitative interpretations were used to ascertain the best points for drilling a successful borehole (yield > 13 l per minute). The criteria used in selecting a promising site for test drilling are as follows: the nature of the curve (observing the nature of the VES curves), the overburden thickness and the bedrock resistivity. The study revealed a drilling success rate of 90% with an average borehole yield of 118 lpm.

2.3 National

A number of studies have laid down a good base for further hydrogeological works. Numerous NGOs have also worked in Juba region and supported urban centers and local rural and semi urban communities by drilling water wells or conducting geophysical surveys. However, although many water projects have been implemented or supported in the region, water well drilling has commonly been conducted without adequate project feasibility studies, and to date, no systematic data collection has been carried on groundwater exploitation, capacity, and especially on groundwater level fluctuations. However, during the last few years, the FAO-SWALIM project (Somalia Water and Land InformationManagement) has done extensive work relating to water resources, including preparing more accurate and adequate hydrogeological maps but mainly in the northern part of Somalia, which are essential for planning any groundwater exploration and exploitation.

2.4 Geology of The Study Area

Geologically, the south-western part of Somalia is covered by sediment dating from the Cretaceous to the Recent period. The area has been described by Kozerenko (1972) and Pozzi et al. (1985), and several geological maps were created by Florence University (1973). The Faillace and Faillace Hydrogeology and Water Quality Reports (1986) were based on the aforementioned works. The area is covered by Cenozoic sediments and Tertiary-age limestone, which unconformably overlay the Cretaceous sandstone and limestone.

The uplifting of the basement complex in the Buur region has resulted in the division of the geological basin, which extends from southern Somalia to Ethiopia in the north and Kenya in the west. The northern sub-basin consists of Jurassic and Cretaceous rock suites, while the coastal sub-basin is composed of sediments spanning from the Lower Jurassic to the Quaternary **(Figure 2.1)**

Southern Somalia encompasses the Jurassic and Cretaceous sedimentary strata between the uplifting of the basement complex in the Buur area and the crystalline basement outcropping in the "Northern Frontier District" of Kenya. Previously known as the "Luuq-Mandera basin," the Xuddur-Bardheere Basin (Stefanini, 1931d; Barbieri, 1968; Beltrandi and Pyre, 1973; Angelucci et al., 1983; Canuti et al., 1983; Buscaglione et al., 1993) can be consulted for a more comprehensive list of fossil contents and a more detailed lithological description. Additionally, southern Somalia is primarily flat, except for the coastal belt which is hilly. The majority of the western lower Juba region and the inter-riverine territory between the Shabelle and Juba rivers consist of wide, gently sloping plains with shallow, broad-bottomed "Laaqs" that typically disperse their water in depressions.

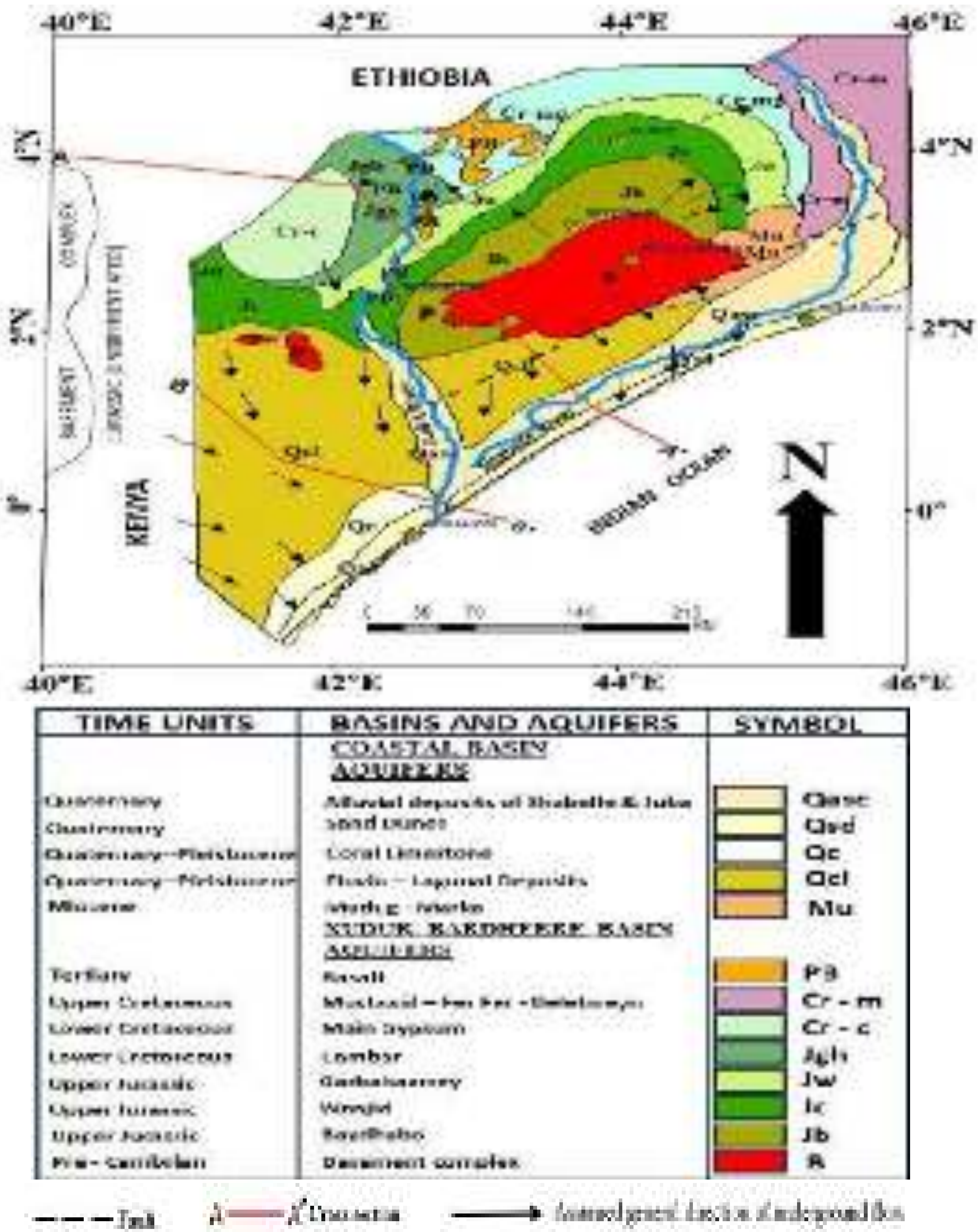

Figure 2.1 Modified from Generalized Hydrogeological Map of Southern Somalia by Beltrandi

Table 2.1 Table 2.1 1 Summary of the Stratigraphy of Southern Somalia.

ERA	PERIOD	EPOCH	SERIES	SYMBOL ON MAP	THICKNESS (M)	LITHOLOGICAL CHARACTERISTICS	DISTRIBUTION
Cenozoic	Paleogene	Miocene - Pliocene	Trap to series	PB	40-50	Basalts and tuffs.	Upper part of the Juba and Shabelle valleys.
Mesozoic	Cretaceous	Upper Cretaceous	Beledweyne formation	Cr-bel	200	Sandy limestone, Marls.	Eastern side of the Shabelle valley between [illegible] and [illegible].
			Fer fer formation	Cr-fr	60	Gypsum, anhydrite, Sandstone, marls.	North eastern side of Shabelle valley near the border with Ethiopia.
		Lower Cretaceous	Mustahil formation	Cr-m	200	[illegible]	West side of the upper part of the Shabelle valley
			Main Gypsum formation	CR-MG	500	Gypsum, Anhydrite, Limestone, Gypsiferous Clay, Marls, [illegible]	West side of the Shabelle valley along the Ethiopian border and the northern part of the Juba valley
			[illegible] formation	CR-C	450	[illegible] Gypsum.	Western part of Gedo region
	JURASSIC	UPPER JURASSIC	GARBAHAREY FORMATION	JGH	700	[illegible]	Widespread throughout the central part of Gedo region
			[illegible] FORMATION	JW	500	Oolitic limestone, Sandstone, Thin bedded Calcarenite [illegible]	Northern part of the Shabelle and Juba valleys.
			[illegible] FORMATION	JC	500	Argillaceous limestone, shales, marls.	Northern part of the Shabelle and Juba [illegible]
			[illegible] formation	JB	100 - 300	[illegible]	Western northern and eastern parts of the Buur area
PALEOZOIC	PRECAMBRIAN	PRECAMBRIAN		B		Granite, Granodiorite, Gneiss, Quartzite, Marble, and Amphibolite.	Buur area

C. Faillace and R. Faillace in their book "Hydrogeology and Water Quality of Southern Somalia" suggested that the coastal Basin is recharged by direct rainfall from the Shabelle and Juba rivers, as well as by underground flow from Kenya, run-off water from "Laaqs," and underground flow originating from the basement complex which follows the drainage pattern of the numerous Togag.

The oldest sediments outcropping in Central Somalia are the Cretaceous formations. The lithological characteristics of these formations indicate a shallow sea with extensive lagunal environments where evaporates were deposited. The Wadajir-Dhoobley area is predominantly an erosion plain covered by red sand, caliches, gypsiferous clay, hard limestone; concretionary rocks are quite common and are often covered by a thin veneer of aeolian red sands and terra rossa (red clay soil produced by the weathering of limestone). Limestone is often massive and karstified, and water quality in wells in this formation is good to fair. In a large part of the study area, the thick sequences of sub-surface basalt are a geological marker indicating that the sediments above the basalt are of Quaternary age. Generally, the land and water potential in southern Somalia is far better than in other parts of the country. (Ali Kassim M., 2002)

In the Lower Juba region, enclosed by the perimeter of Liboy, Bilis Qooqani, Hosingo, and south of Hosingo, there are good conditions for recharge. It is composed of sand sediments, generally fine to medium quartz sand, and dark-brown sandy clay is also present in large patches (R. Faillace, 1986). The area is characterized by gentle micro-relief with sand cover and hard caliche patches. Sloping gently towards the east, the area is covered by whitish sand, gypsum, and caliche sand. The area is covered by gypsiferous clay soils and gypsum; calcrete and caliche are common at the termination of the ancestral drainage systems. The bottom of these valleys is often covered by concretionary limestone. Large parts of the area are covered by varying thicknesses of whitish and pink sands overlying limestone, gypsiferous limestone, and caliche.

The geology of the area is poorly mapped, and published interpretations of the stratigraphic sequence are not always in agreement, as the main rock groups occur in Dhobley district as low-lying outcrops within the intervening alluvial sediment-covered plains and valleys deposits cover most of the area.

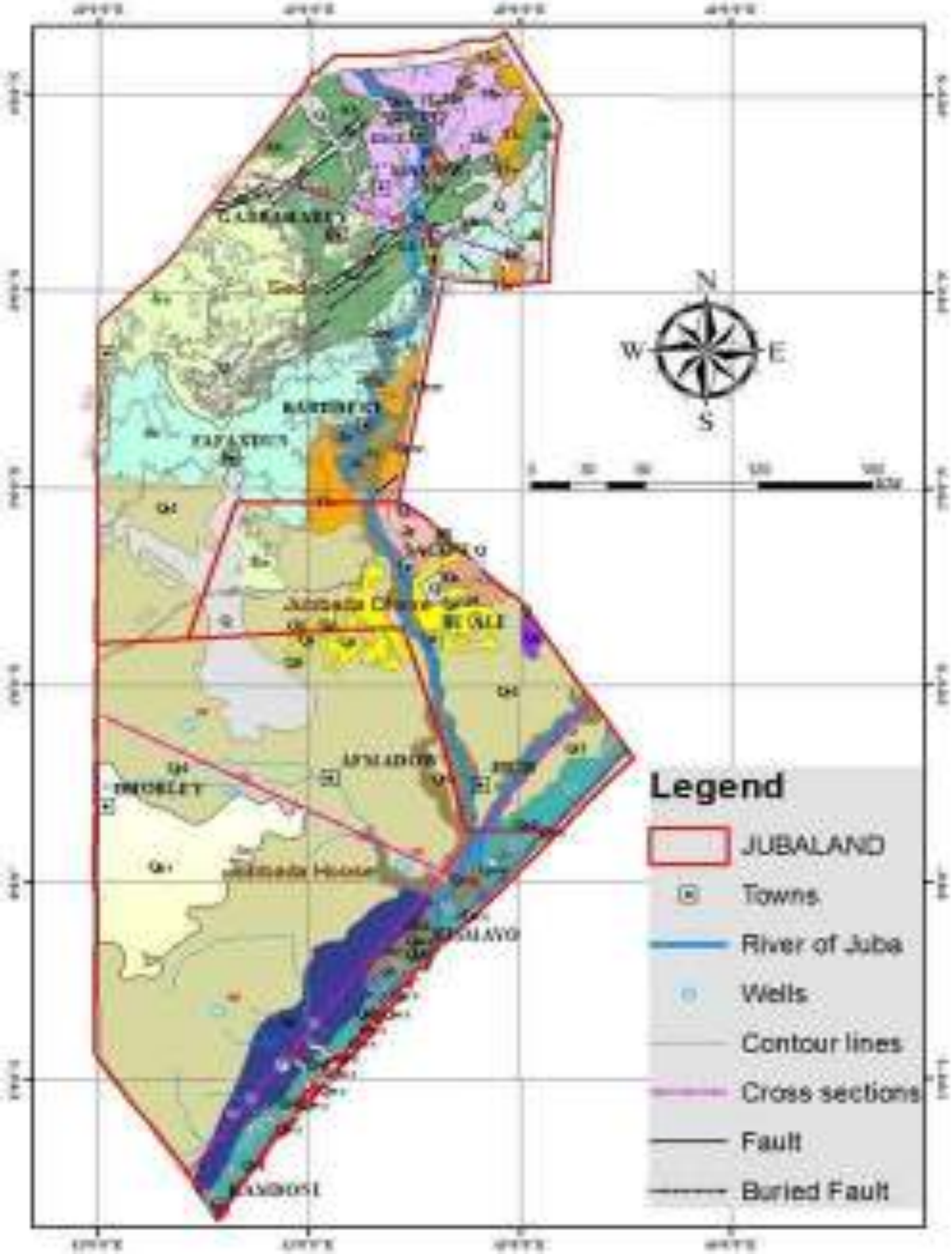

Figure 2.2 modified from Geological map of Somalia in 1994 by E. Abbate, M. Salgri and F.P. Sassi with collaboration of Ibrahim Hersi Adan, Mohamud Abdi Arush and Omar Shire Yusuf.

2.5 Structural Setting

This section provides a brief description of the main geological features of southern Somalia. For a more detailed discussion on the geodynamic evolution of eastern Africa, including (Norton and Sclater, 1979; Coffin and Rabinowitz, 1983; Rabinowitz et al., 1983; Bosellini, 1986; Piccoli et al., 1986; Coffin and Rabinowitz, 1987; Boccaletti et al., 1988; Coffin and Rabinowitz, 1988; Bosellini, 1989).

The structural setting of Somalia is not well understood. However, from a regional perspective, during the Triassic–Cretaceous period, Northern and East Africa experienced lithospheric extension, which was associated with the breakup of the South Atlantic and the separation of Gondwana. This extension resulted in NE-SW extension (Fairhead, 1988). As a result, NW-trending Mesozoic rift basins were formed, including those in Sudan, the Ogaden basin in Ethiopia, and the Anza rift basin in Kenya (Fig 3.4, McHargueet., et al. 1992; Binks and Fairhead, 1992). The architecture of the basins in southern Somalia is poorly understood, but it is believed that they formed during the Mesozoic breakup of Gondwana, similar to the NW-trending Mesozoic rifts found throughout Northern and Eastern Africa (Bosellini, 1991).

Geophysical surveys conducted for oil exploration in Somalia have identified three main faults. One major fault (or fault system), which runs approximately parallel to the coast due to the uplift of the basement complex and subsequent fracture along the Bandar-Jalalaqsi fault, separates the coastal Pliocene-Pleistocene sediments from the Oligocene-Miocene sediments, which have accumulated thousands of meters of sediment. The hydrogeological significance of these faults is not well understood, but they are likely to have some impact on the movement of groundwater within the deep aquifers.

Figure 2.3 Tectonic elements within and around the Blue Nile Basin (Modified after Fairhead 1988; Bosellini 1989; Guiraud and Maurin 1992; Binks and Fairhead 1992; Worku and Astin 1992).

Most of the study area is covered by a variety of continental Quaternary deposits consisting of caliche and related rocks, clay with sand, gypsiferous clay, aeolian red sands, and terra rossa (red clay soil produced by the weathering of limestone). The general land surface of the area covered by fluvio-lagunal deposits is a flat plain sloping gently towards the coastal belt. Several oil companies have contributed significantly to our understanding of the geology of southern Somalia during the past 30 years by conducting considerable geophysical and drilling exploratory work. (Ali Kassim M., 2002)

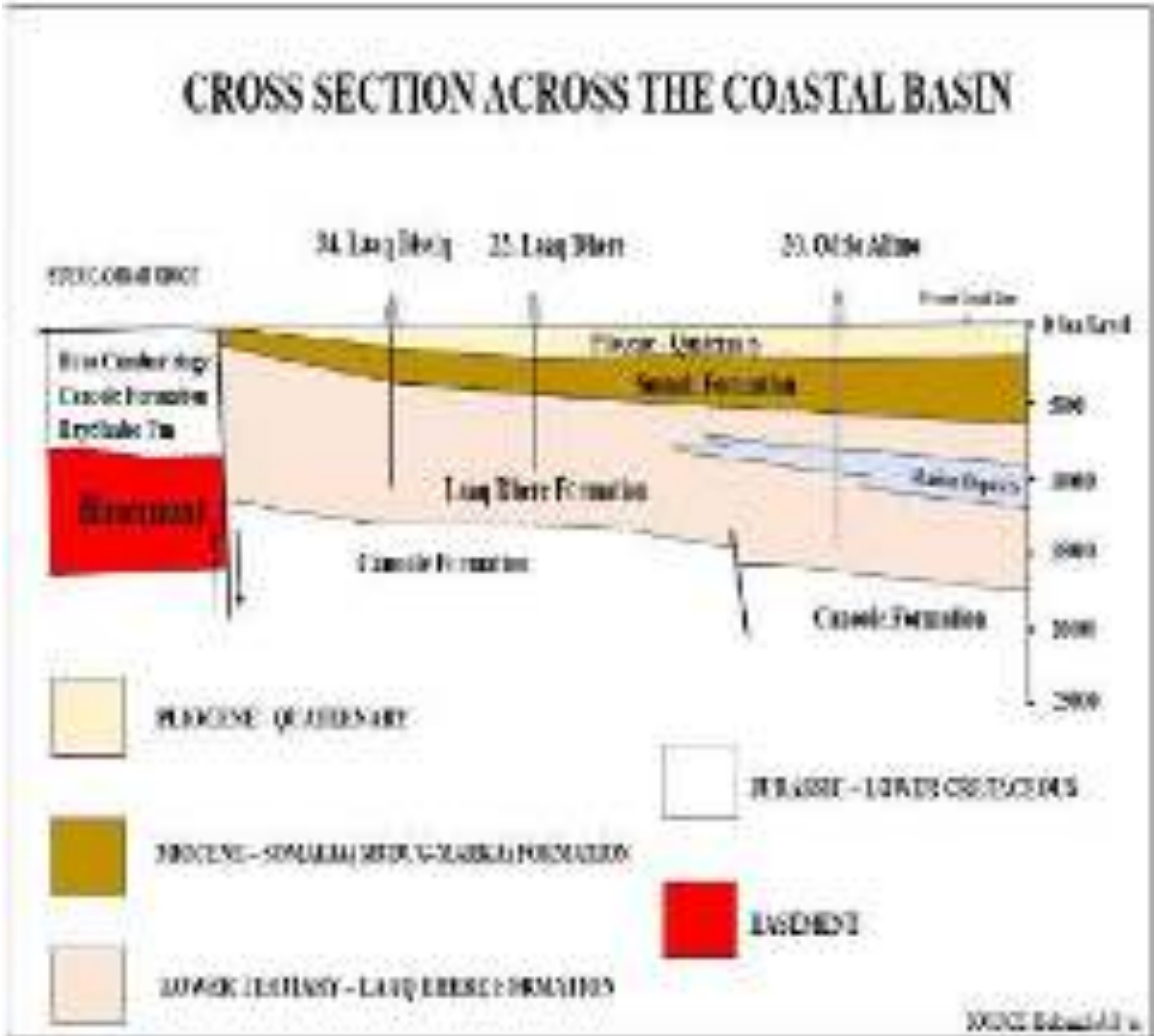

Figure 2.4 Modified Cross section across the Coastal Basin by Beltrandi & Pyre.

2.6 Hydrogeology Setting of Study Area

Detailed studies of the hydrological and hydrogeological condition have carried out in the three sites include information about lithology, surface water runoff and infiltration rates, well construction and hydraulics, water quality and all other data necessary to assess the groundwater conditions in these districts.

Surface water is limited in the target areas. Wars (also called bailey, water pan, ponds or dams) and Berkad for rain water harvesting are more common in Dhobley areas, Wars are large ground natural or mechanically scooped water catchments for surface water collection and storage, mostly unlined, also called bailey or water pan, ponds, dams. The main reasonfor this is the favorable soil type (clayey) for the construction of wars. War refers to unlined dug-out, mainly 2–3 m deep with a surface area of hundreds to thousands of square meters, built on clayey soils that retain water for approximately 3-4 months.

2.6.1 Groundwater Occurrence

The study area depends totally on the groundwater as main source for the water and they are only two types of groundwater recourses; shallow wells and deep boreholes. Due to that the survey curried out to assess the groundwater conditions of the area surrounding the towns. Little was known about the subsurface geology of target areas, to this end, integrated methods for field studies were used in selected areas around the villages with the primary goal of identify potentials of groundwater occurrence in the area, including traditional hydrogeological methods, remote sensing investigations (Landsat ETM+7 images and DEM images) and lineament mapping, structural analysis and geophysical studies through Vertical Electrical Sounding (VES techniques) with a moisture algorithm. most of the areas is covered by a variety of continental quaternary deposits consisting of clay sand, sandy clay, clay, caliche, gypsiferous clay, Aeolian red sands.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research design and methodology used in acquiring the necessary information and data in order to achieve the project's objectives. It outlines and specifies the research approach and techniques, as well as the research design.

3.2 Materials

ABEM Tarameter SAS 1000 is an extremely capable Resistivity IP system appropriate for a wide range of applications. It reduces costly field time by measuring resistivity and IP at the same time, and it may be expanded with a range of accessories.

3.2.1 Software

1) ArcMap is a vital component of geospatial process software suites such as Esri and ArcGIS. This software, which is regarded as open source, uses elements including topography, drainage and surface maps, contour maps, geology maps, location maps, and piezo metric maps to provide the pertinent maps.
2) IP12WIN Software is a program for 1D automatic and manual interpretation of VES curves. Interpretation mode. VES curves could be received with different arrays: Schlumberger, Wenner, dipole-dipole, pole - pole.

3.3 Remote Sensing Date Process

3.3.1 NDVI Estimation

The normalized difference vegetation index (NDVI) is calculated from spectrometric data at two specific bands: red and near-infrared. The spectrometric data is usually sourced from remote sensors, such as satellites. Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). The ratio of the reflectivity differences for the NIR and the red band is calculated to find (NDVI). The ratio of the reflectivity differences for the NIR and the red band to their sum (NDVI) is calculated using this Equation (3.1):

$$\mathbf{NDVI = (NIR - Red)/\ (NIR + Red)}$$

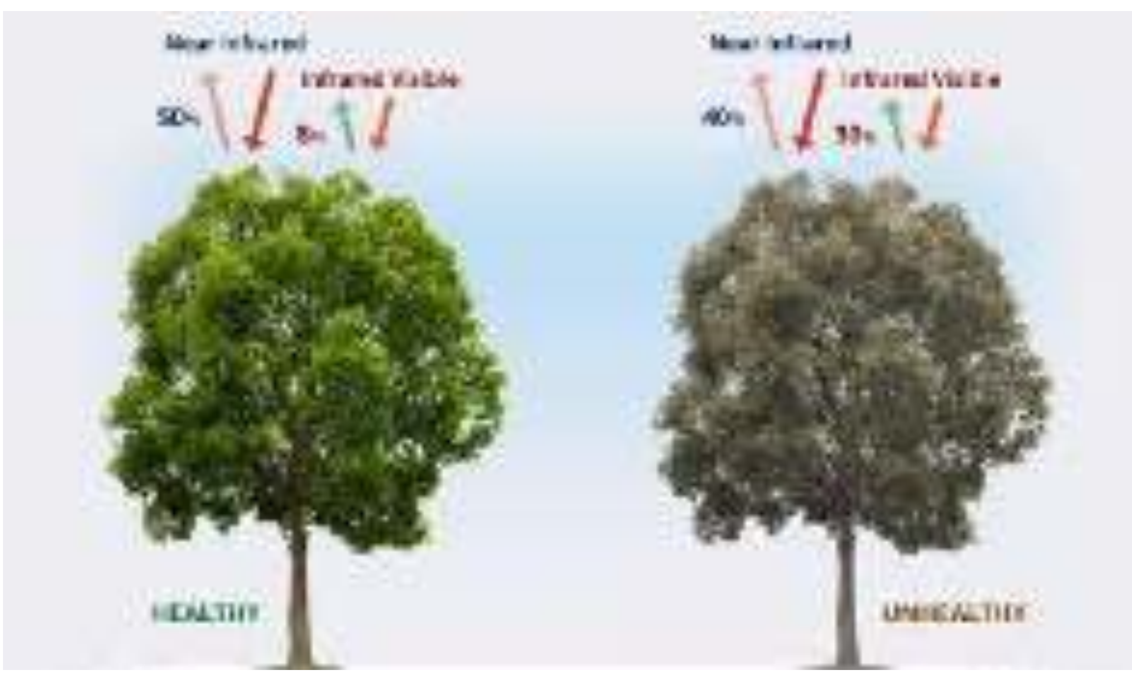

Figure 3.1 NDVI mapping in agriculture, index formula.

3.3.2 SMI Calculation

The soil moisture index is based on empirical parameterization of the relationship between land surface temperature (LST) and normalized difference vegetation index (NDVI). calculated using Equation (3.2):

$$SMI = (LSTmax - LST)/(LSTmax - LST\mathbf{min})$$

Where SMI is Soil Moisture Index, LST are the maximum, minimum and value of the retrieved LST respectively.

3.4 IDWA Analyst Tool

The Inverse Distance Weighted Averaging (IDWA) Interpolation Method has been used throughout this book to generate all climate maps we have made, based on CLIMWAT 2.0 for CROPWAT 8.0 software. the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. IDWA is an averaging procedure. Thus, closer stations have more weight in the averaging procedure than stations that are further away.

3.5 Principles of Electrical Method

The electrical resistivity approach takes advantage of the resistance differential between various ground materials. The level of resistance a material exhibits to the passage of electrical current through it is measured as resistivity. In general, resistivity is the opposite of conductivity and is measured in Ohm meters. According to Ohm's rule, which states that the current flowing through the ends of a linear conductor with a uniform cross section is proportionate to the applied voltage, theoretically all conductive materials must abide by this law therefore **V=IR** (Ogundana.A.K, 2022)**.** The resistivity survey is based on the principle that the distribution of electrical potential in the ground in the vicinity of an electrode array depends on the electrical resistivity distribution of the surrounding rocks. Ohm's law is the base of the resistivity method and it describes the change in the potential resulting from flow of the current through a resister.

The resistance (R) of certain material is directly proportional to its length (L) and cross-sectional area (A), which can be expressed as:

$$R = \rho * L/A \ (\Omega) \qquad (3.3)$$

Where: ρ is known as the specific resistivity, characteristic of material and independent of its shape or size. With Ohm’s Law:

$$R = \delta V/I \ (\Omega) \qquad (3.4)$$

Where: δV is the potential difference across the resistor and (I) is the electric current through the resistor, the specific resistivity may be determined by:

$$\rho = (A/L) * (\delta V/I) \ (\Omega m) \qquad (3.5)$$

$$\rho app = K * R \ (\Omega m) \qquad (3.6)$$

Where; K is constant or geometric factor which depends on the current and potential electrodes separation.

The usual practice in the field is to inject electrical current through two electrodes implanted in the ground (AB), and measure the difference in potential between two other electrodes (MN) (**Fig. 4.1**). Equi-potential surface are shells surrounding the current electrodes on which the electrical potential is everywhere equal. Current lines represent a sampling of the infinitely many paths followed by the current; these paths must be everywhere normal to the equipotential surface. The effect of an electrode pair (A the current source and B the current sink) can be found by superposition, such that the added effect of individual current electrodes yields of the final value of the potential field. In addition to the two current electrodes, a second pair of electrodes (M and N) is used, between which the potential difference ΔV is measured. The potential field decreases rapidly away from the current electrodes. The current and potential electrodes can be interchanged without affecting the results. The property is called reciprocity. (Shishaye, 2015)

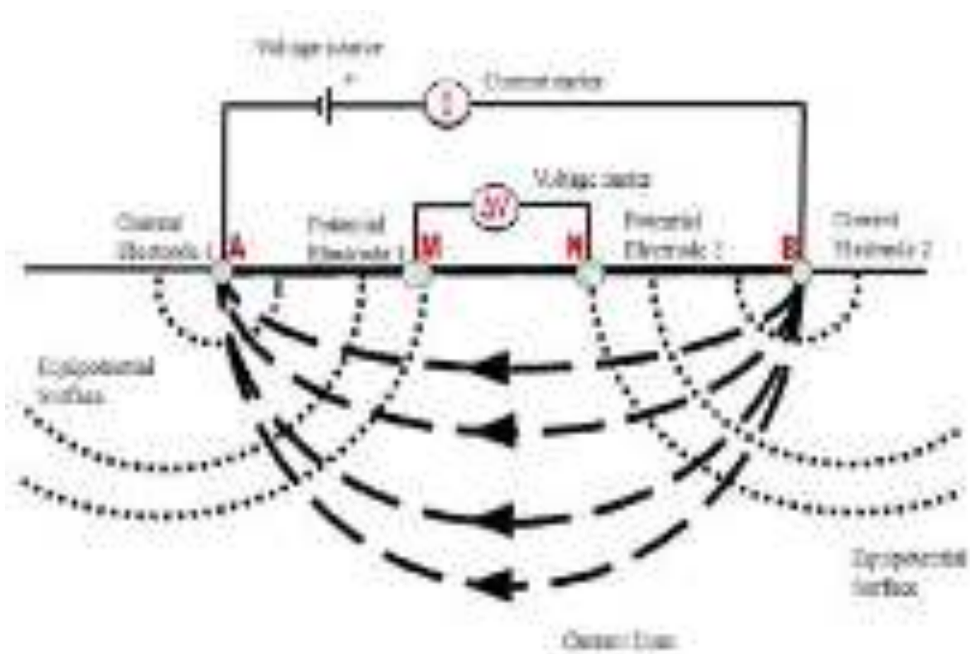

Figure 3.2 Equi-potential surface and associated current lines two current electrodes.

3.5.1 Electrical Properties of the Rocks

The electrical resistivity (or simply resistivity) of all materials governs the relationship between the current density and the gradient of the electrical potential. Variations of this resistivity of the subsurface materials both vertically or laterally, produce variations in the relationship between the applied current and the potential distribution as measured on the surface and thereby provides information on the composition, extent and physical properties of the subsurface materials.

In most earth materials, the conduction of the electric current take place almost entirely in the water occupying the pore spaces or joint openings, because most soil and rock forming minerals are essentially non-conductive. Since the conduction of the current in soil and rock is through the electrolyte (i.e. the ions in the water carry the current) contained in the pores, resistivity is governed largely by the porosity of the material and geometry of the pores. Pore space may be in the form of inter-granular voids, joint or fracture opening, and closed pores, such as bubbles in laves. Only the interconnected pores (effective porosity) contribute to electrical conductivity; the geometry of the interconnections also influences the conductivity. Saturation is another parameter that influence the resistivity of the rock, also increasing the temperature increases the conductivity of the electrolyte because the viscosity of the fluid decreases. There is no simple relation between resistivity and permeability, fine-grained clay or shale generally has lower resistivity than soils or rocks of bulk mineral grains. In massive metallic ores, when the metallic grains are connected, the current flows via the electrons contained in the metal. (Ali, 2023)

The range resistivity is very large. The values given in (**figure 3.3**) are only informative: the particular conditions of the site may change the resistivity values. For example, dry coarse sand or gravel may have a resistivity like that of igneous rock, whereas weathered rock may be more conductive than the soil that overlaying it. Since the resistivity of the soil or rock is controlled primarily by the pore water conditions, there are wide ranges in resistivity for any particular soil or rock, such that resistivity values cannot be directly interpreted in terms of soil type lithology. Commonly, however, zones of distinct resistivity can be associated with specific soil or rock units on the basis of local outcrops or borehole information. It is the enormous variations in rock and mineral electrical resistivity that makes resistivity techniques attractive.

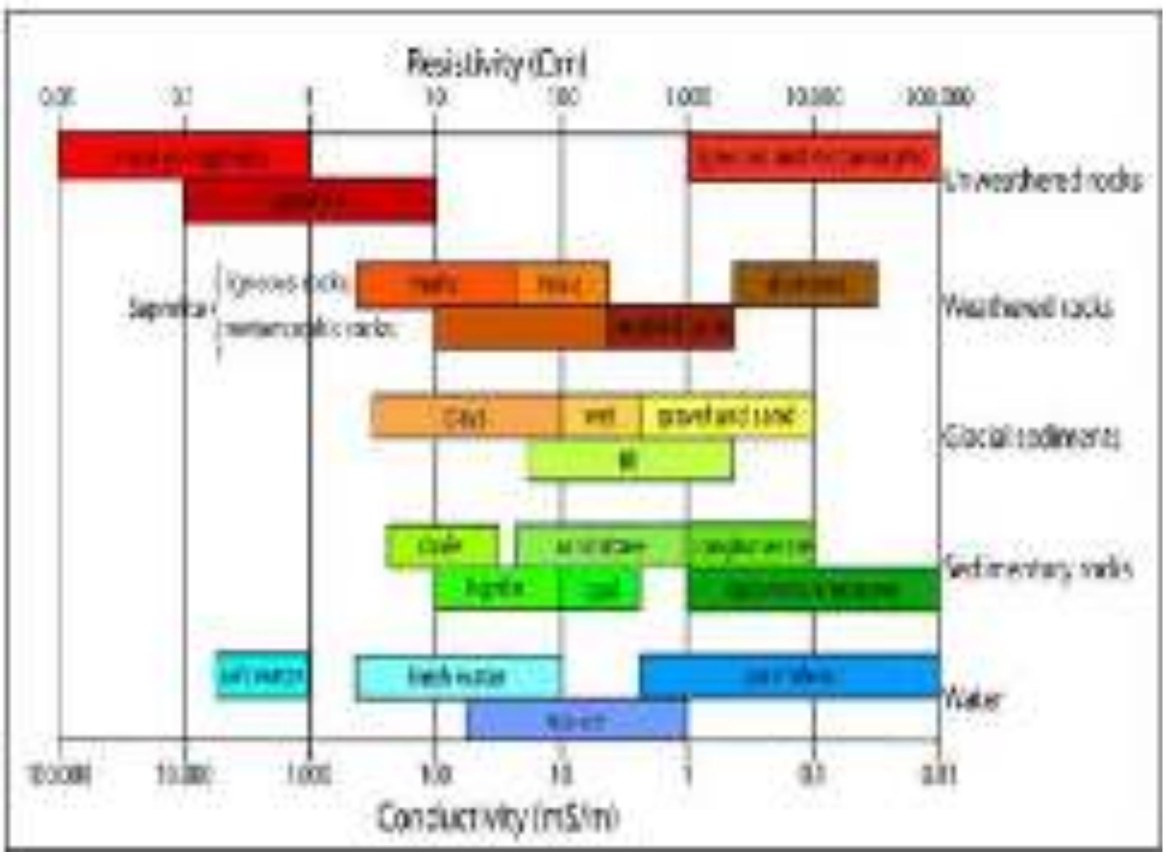

Figure 3.3 Electrical resistivity and conductivity of earth materials (Modified from Palacky, 1988).

3.5.2 Electrode Configurations

The measuring setup consists of resistivity meter (usually placed in the middle of the array), connected to two current electrodes (AB), and two potential electrodes (MN) towards the center. There are several electrical arrays used for resistivity survey (e.g. Wenner, Schlumberger, Pole-Dipole …etc.) most of them are laid a long straight line. However, the most widely used is 'Schlumberger and Wenner' arrays (**Figure. 3.4).**

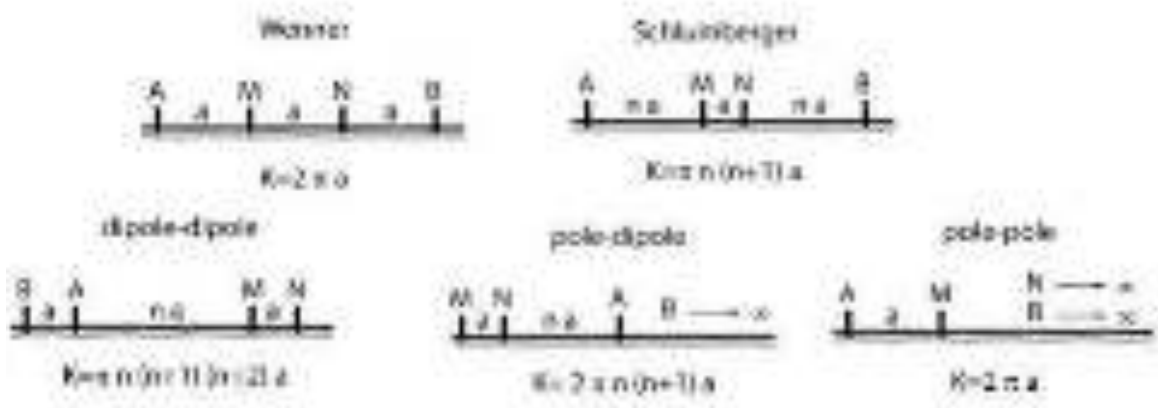

Figure 3.4 Electrode arrays frequently used in surface electrical prospecting (Modified from Telford et al., 1990).

In Schlumberger array measurement is made with an expanding array of current electrodes which allows the flow of current to penetrate progressively greater depths. The apparent resistivity as a function of the electrode separation AB provides information on the vertical variation in resistivity. Hence, the depth of penetration varies according to the electrode array. The point at which a change in earth layering is observed depends on the resistivity contrast, but is generally of the order of a quarter of the current electrode spacing AB. In Wenner array the electrodes are separated from each other by a constant distance (a) and the entire separation is moved with the same distance. (w.m.Telford, 2004)

Electrical resistivity techniques are primarily utilized through two basic methodology procedures: electrical profiling and vertical electrical sounding (VES). While profiling is used to identify lateral resistivity variations, the VES approach is used to identify vertical variations in resistivity readings.

3.6 Data Collection

The overall methodology for the study began with the collection of reliable data inputs and literature review. This research date unutilized from multiple different sources include open databases in the internet like satellite images from USGS and satellite date from Google Earth Pro. as well companies report like Mumtaz Engineering & General Services Company, as well previous studies of Books and maps.

3.6.1 Resistivity Surveys

Resistivity surveys serve as the primary method for investigating groundwater potential by Mumtaz Engineering & General Services Company 2023. The surveys were conducted using ABEM Tarameter SAS 1000, four cable reels and external 12-volt DC Battery covering Seven strategic locations within Dhobley District. The survey grid was designed to capture variations in subsurface resistivity, providing insights into potential aquifer locations.

Figure 3.5 ABEM Tarameter SAS 1000 with four cable reels

Schlumberger array is one of the most commonly used electrode arrays for determining the resistivity. In the present work, also Schlumberger configuration has been used for measuring apparent resistivity in the field by Mumtaz engineering company. The instruments used for resistance measurement and recording included the ABEM SAS 1000, four steel electrodes, field hammers, measuring tape and reels of wire, and a global positioning system (GPS). Vertical electrical soundings have conducted in 7 locations of study area using ABEM SAS 1000 Terrameter, four cable reels and external 12-volt DC Battery. The selected current electrode spacing (AB/2) and the potential electrode spacing (MN/2) from the center of the spread are illustrated in the table below:

Table 3.1 Schlumberger Electrode array configuration.

Current Electrode spacing (**AB/2**)	1-15	15-30	30-75	75-150	150-300	300-1000
Potential Electrode spacing (**MN/2**)	0.5	5	10	25	50	100

The Seven (7) geo-electrical soundings with a maximum half current electrode separation of 400m have been done by Mumtaz Engineering & General Services Company. All the VES's points have been conducted in Dhobley depending on the hydrogeological data. They have selected Schlumberger electrode array because of it is the most time effective in terms of field work. This company helped us geo-electrical sounding were covering the whole area while at the same time to be as close to the existing boreholes as possible in order to use them for calibration. Current was injected into the earth through a pair of current electrodes, and the potential difference was measured between a pair of potential electrodes. The current and potential electrodes were typically arranged in a linear array, but the spacing between them varied for each measurement. The centre of the electrode array, where the electrical potential was measured, remained constant. The electrodes were distributed along a line positioned at the midpoint of each profile, which was taken as the centre of the sounding. Furthermore, the two current electrodes and two potential electrodes were placed in line with each other.

3.6.2 Data Processing and Interpretation

Raw resistivity data collected during the surveys were processed using IP12WIN Software. The interpretation involved analyzing resistivity variations in correlation with geological features. The processed data aided in identifying potential groundwater-bearing formations and delineating subsurface structures.

The current electrodes were equidistant from the centre of the sounding at a distance of AB/2 = 1.5 m. Similarly, the potential electrodes were also equidistant from the centre of the sounding, but at a smaller distance of MN/2 = 0.5 m. This distance is much smaller than AB/2. Most interpretation software assumes that the spacing of the potential electrodes is negligible compared to the spacing between the current electrodes. If the distance between the current electrodes is larger, the distance between the potential electrodes is increased to ensure a measurable potential difference. The arrangement of the electrode configuration can vary, depending on the setup of current and potential electrodes. AB/2 was increased in steps up to a maximum value of 400 m, and MN/2 was increased to 100 m. The instrument was then moved to the next VES point, and the entire process was repeated. A total of 7 vertical electrical soundings were conducted across the study area, and the coordinates of the centre of each VES point were recorded.

All resistivity soundings were inverted using the IX1D, v. 2.06, software. This package performs an automated approximation of initial resistivity model using the observed data (Bobachev, 2002). It works in an iterative mode by calculating at the end of each step: (**A**) an updated model of layer thickness and resistivity and (**B**) the misfit function between observed and calculated data. All resulting models produced a low RMS relative error of the order of 4%. The starting model used during the inversion for each of the measured the VES locations, consisted of four layers over a half space and all depths were constrained again according to the nearest borehole information.

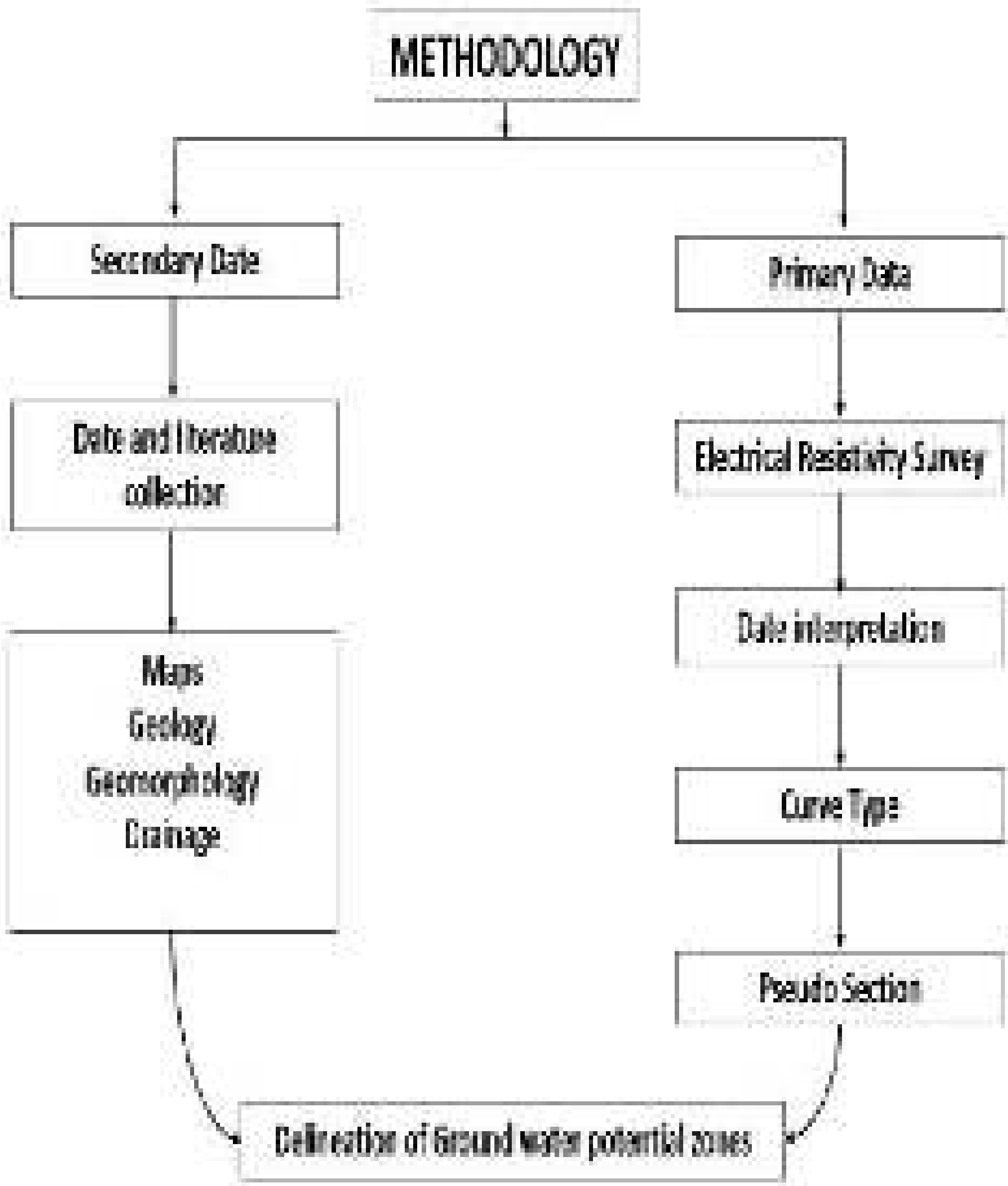

Figure 3.6 Flow chart of Methodology

3.7 Resistivity Measurement Techniques

3.7.1 Measuring by Vertical Electrical Sounding (VES)

The Vertical electrical sounding (VES) consist of a symmetric geoelectrical array can be used to determine the electrical resistivity of the subsurface. Increasing progressively the spacing between the current electrodes a and b, while keeping the potential electrodes m and n at the same position, provides a sounding curve corresponding to the apparent resistivity versus depth. Although the VES method is still widely used, nowadays VES is regarded as an outdated technique as there are alternative instrumentation and electrode configuration that can provide 2d and 3d images of the subsurface more time effectivelyInvalid source specified..

3.7.2 Apparent Resistivity Curve Types

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

1. Curve type (K): -a rise is displayed by this curve and when there is a drop in the curve, it indicates higher resistivity layers and between two low layers of resistivity they are found embedded.
2. Curve type (H): - as compared to the K type curve, this curve is totally opposite since at the time when there is a decline followed by rise this indicates the middle layer is having lower resistivity as compared to the bottom and top layers in the model of three layers.

3. Curve type (A): - there is a rise in resistivity in this case when the depth increases. The slightslowdown is exhibited by the rising curve and this is due to the depth and the layersencountered with it. With the depth, there is an increase in resistivity.
4. Curve type (Q): - As compared to A type curve, this is totally opposite curve and the curveis seen to fall sharply with change in gradient moderately and this is an indication ofsuccessive changes taking place in the layers as there is an increase in depth.

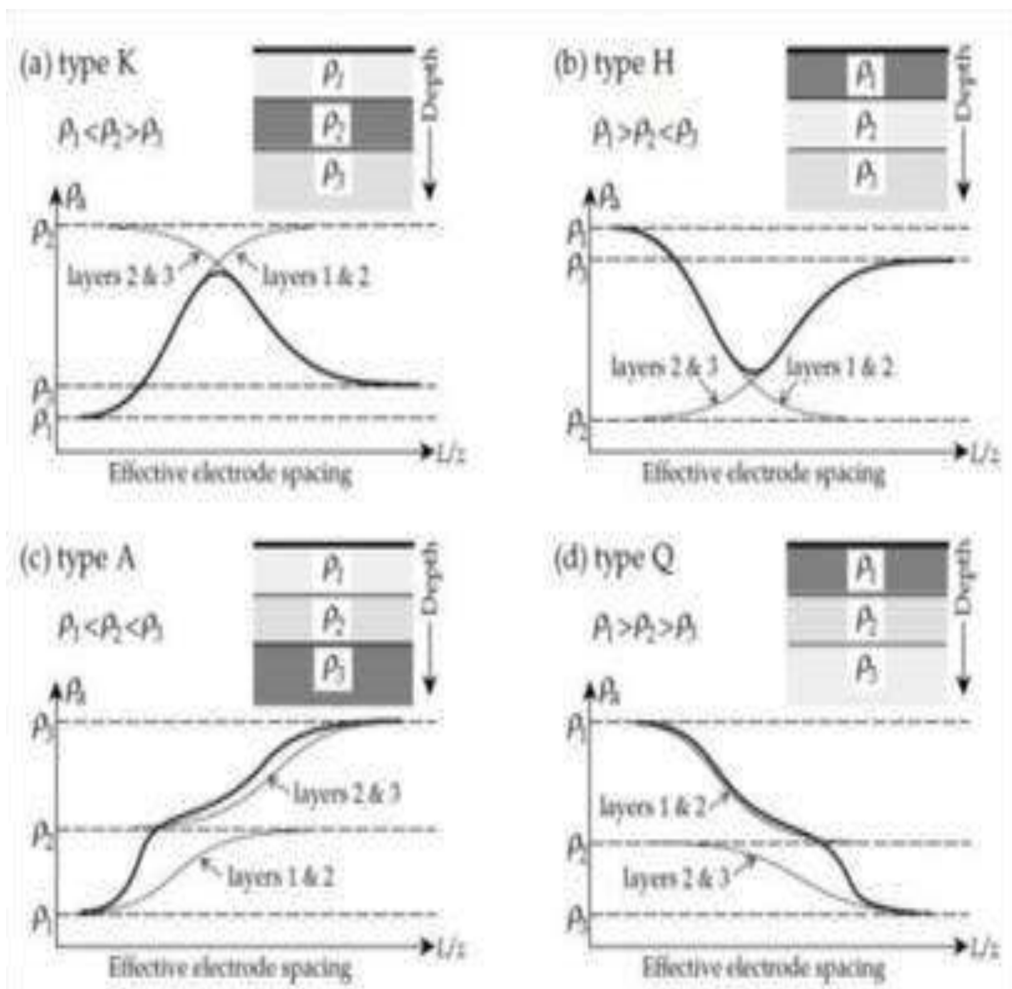

Figure 3.7 Apparent Resistivity Curve Types

3.7.3 Horizontal Electrical Profiling (HEP)

The Horizontal Electrical Profiling (HEP) also called the Electrical Resistivity Traverse (ERT) or the Constant Separation Traverse (CST) to determine the lateral variations in ground, the measurement is acquired along profiles using a large number of electrodes placed equidistantly, allowing the electrodes to be current and potential electrodes alternately. The procedure is repeated for as many combinations of source and receiver electrode position as is defined by the survey.

The CST is another name for the constant electrode separation technique and another name of this technique is electrical resistivity profiling. This technique has been launched to find out the resistivity lateral variability. In the end, this methodology can help us to trace the dipping contacts, geological mapping and mapping various soil related faults and fractures. To trace the variations in resistivity, any of the different arrays can be used and for each electrode a constant spacing or separation is adopted. For searching the ores and ore bodies, faults and zones at which faults are located, sand evaluation, deposits of gravels the method of electrical profiling is used. It also helps to determine delineating boundaries and to find out the contacts dipping for all the under-observation materials of Earth. (Nur, 2021)

Overall, this comprehensive methodology aims to provide a detailed understanding of the groundwater potential in Dhobley District, employing geophysical electrical resistivity methods alongside groundwater sampling and analysis. The integration of these techniques enhances the reliability and robustness of the investigation, laying the foundation for a thorough analysis in subsequent chapters.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This study report presents results of geophysical formations in Dhobley district area, in Lower juba region of Somalia. The present Geophysical survey using electrical resistivity method was used to investigate water bearing potentials and aquifer characterization was done. Electrical resistivity technique was done by Mumtaz Engineering & General Services Company. this interpretation of electrical conductivity in parts of study area providing us qualitative and quantitative data about the subsurface. Electrical resistivity method has advantage of mapping resistivity variations for layered formations and structures such as fractures within rocks and groundwater exploration. Low resistivity values signified potential zones for ground water.

Groundwater is not only essential but necessary substitute to surface water in every society. It’s no doubt a hidden; replenish able resource whose occurrence and distribution greatly varies according to the local as well as regional geological, hydrogeological setting and to an extent the nature of human activities on the land. Geophysical surveys can be useful in the study of most subsurface geologic problems. Geophysics also can contribute too many investigations that are concerned primarily with surface geology. However, geophysical surveys are not always the most effective method of obtaining the information needed. (Ali, 2023)

4.2 Interpreted Resistivity Layers

This apparent resistivity we have interpreted using IPI2Win v.2.0 software to obtain the true resistivity and layer thickness of the subsurface formation. The interpreted true resistivity and layer thickness is presented in **Table 4.9.** Besides, for better understanding the subsurface lithological variation and delineate potential groundwater zones, an attempt has been made to prepare resistivity pseudo sections considering all Seven (7) VES locations in the N – SE direction of the Dhobley town.

Electrical sounding curves of apparent resistivity against half current electrode separation AB/2 were shown on a log-log sheet using the computed apparent VES resistivity data for seven (7) VES soundings that were uploaded to the IP2WIN program. Plotting the theoretical and field curves on the same logarithmic graph with comparable axes, the software automatically superimposes the theoretical curves on top of the field curve. In the event that a match is discovered, the underlying structure and the theoretical structure are thought to be similar. The sounding curve windows for all the four VES soundings were represented as in (**figures 4.1)** On the right, next to the sounding curve window, is a **Table** indicating the error of approximation; the first Column indicates symbols N, ρ, h and where N is the number of geo-electric layers is the specific depth of a geo-electric layer and is cumulative depth of geo-electric layers.

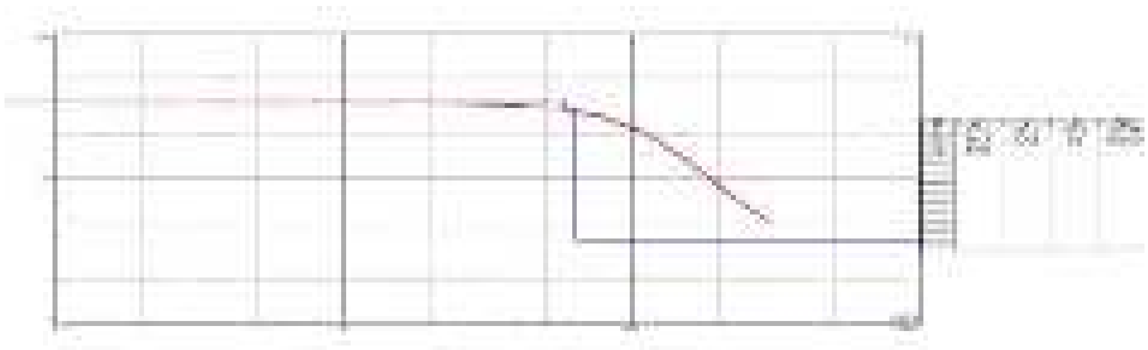

Figure 4.1 Resistivity (Ωm) against AB/2 (m), Transect 1 VES.1.

Table 4.1 Geo-Electric Parameters Transect 1 VES.1

Dhobley VES 1 (latitude 41.201944, Longitude 0.5097222)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	250	0.63	0.63
2	33.7	58.5	58.5
3	30.4	5.58	64
4	3.78	<<<<	>>>>

The first sounding curve (**Figure 4.1**) indicates a geo-electric section with four geo-electric-layers with the first, second, third and fourth layers having 250Ωm, 33.7Ωm, 30.4Ωm and 3.78Ωm respectively. The top layer has relatively high resistivity values, which could be due to unsaturated top soils while the second layer, which is imaged at 58.5 meters depth, could be a shallow aquifer followed by a deeper aquifer at a depth of 64m. The VES was conducted to confirm the presence of geological structure, thereby to pinpoint appropriate site for drilling. On the bases of the geophysical data, a well can be drilled at this point to a maximum depth of 64-74 meters. this is because of the maximum depth of drilling in such a case can be extended up to ten plus the total depth of the layers found from the interpreting packages.

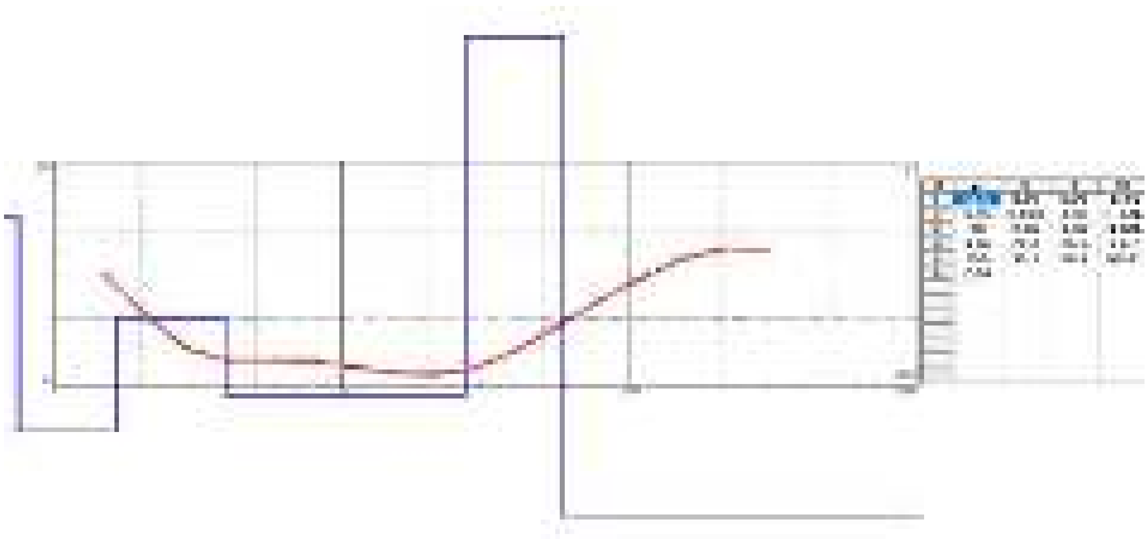

Figure 4.2 Resistivity (Ωm) against AB/2 (m), Transect 2 VES.2.

Table 4.2 Geo-Electric Parameters Transect 2 VES.2.

Dhobley VES 2 (latitude 40.996944, Longitude 0.461111)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	56.6	0.75	0.75
2	6.26	0.898	1.65
3	20	2.26	3.91
4	9.06	22.8	26.7
5	355	31.7	58.4

The second sounding curve **(Figure 4.2)** indicates a geo-electric section with Five geo-electric layers with resistivities 56.6 Ω m, 6.26 Ω m, 20 Ω m, 9.06 Ω m, and 355 Ω m respectively. The top two layers and the fifth have relatively high resistivity, while the second, third, and fourth layers, with an imaged cumulative depth of 27 meters, which is indicative of highly conductive infill within this layer. The layer four indicates very low resistivity value which indicates shallow aquifer while layer five at 58.4 m indicates deep aquifer in VES.2. The VES was conducted to confirm the presence of geological structure, thereby to pinpoint appropriate site for drilling. On the bases of the geophysical data, a well can be drilled at this point to a maximum depth of 59-69 meters. this is because of the maximum depth of drilling in such a case can be extended up to ten plus the total depth of the layers found from the interpreting packages. it thicknesses of the productive aquifer in this case is 31.7 m (**Figures 4.2**).

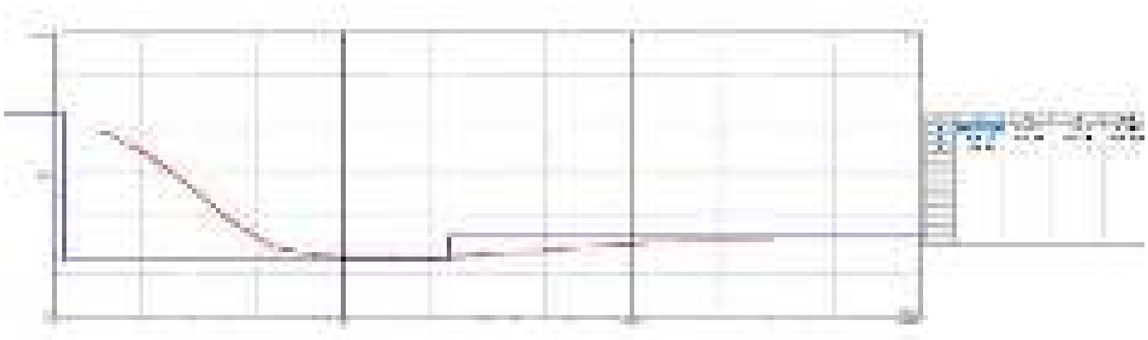

Figure 4.3 Resistivity (Ωm) against AB/2 (m), Transect 3 VES.3.

Table 4.3 Geo-electric parameters Transect 3 VES.3.

Dhobley VES 3 (latitude 41.025278, Longitude 0.4097222)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	266	1.07	1.07
2	25.3	21.8	22.7
3	36.8	<<<<	>>>>

The third sounding curve (**Figure 4.3**) show a geo-electric section with Three geo-electric-layers with the first, Second and third layers having 266 Ωm, 25.3 Ωm, and 36.8 Ωm. The first layer has high resistive layer. The second and third layers could be responsible for the relatively low resistivity which is imaged at 23 meters depth and could be signify highly conductive layer, signifying a shallow and a deeper aquifer at a depth of 23m. the geophysical signature displays three resistive layers, the most promising aquifer zone is located at the second layer. However, the thickness of the aquifer is 21.8 m. So, on the bases of geophysical data, the well in this site can be drilled to a maximum depth of 23-33 meters (**figure 4.3**).

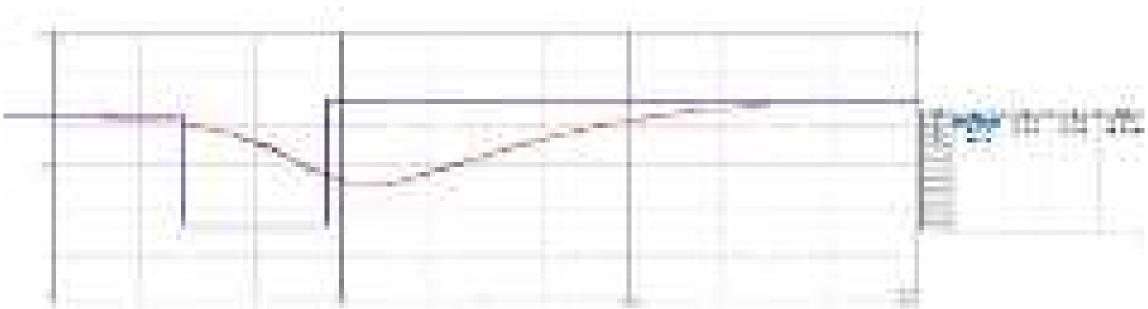

Figure 4.4 Resistivity (Ωm) against AB/2 (m), Transect 4 VES.4.

Table 4.4 Geo-electric parameters Transect 4 VES.4.

Dhobley VES 4 (latitude 41.027778, Longitude 0.4136111)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	23.4	2.81	2.81
2	3.57	5.93	8.74
3	30.4	<<<<	>>>>

The Fourth sounding curve (**Figure 4.4**) show a geo-electric section with three geo-electric-layers with the first, second and third layers having 23.4 Ωm, 3.57 Ωm, and 30.4 Ωm. The top saturated soils could be responsible for the relatively low resistivity on the first geo-electric layer also it could be shallow aquifer, in addition that the second, and third layers are signifying highly conductive layer, signifying a deeper aquifer. the geophysical signature displays three resistive layers; the most promising aquifer zone is located at the second layer. the thickness of the most promising layer is 5.93 m. thus, on the bases of geophysical data, the well at this site can be drilled to a maximum depth of 9-18 meters (**figure 4.4**).

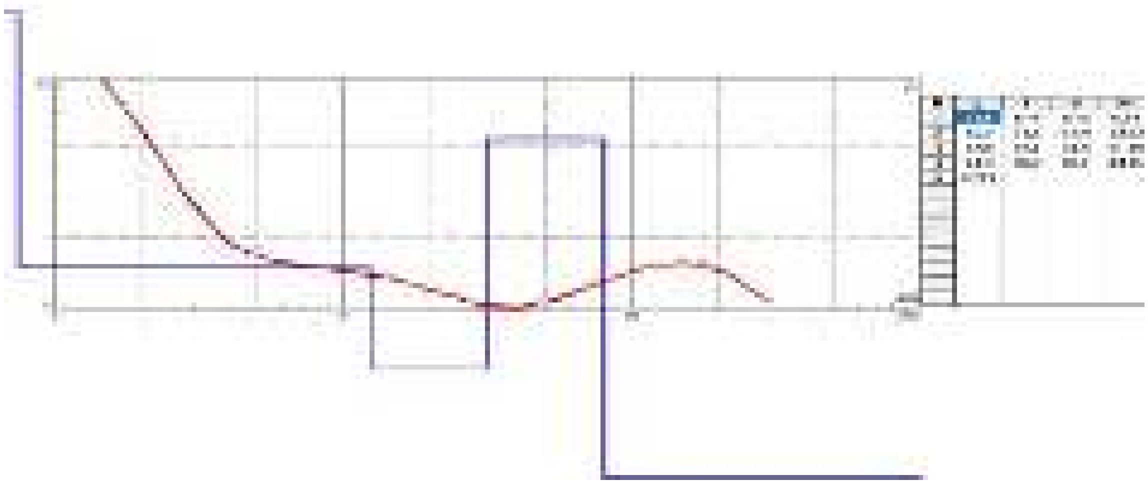

Figure 4.5 Resistivity (Ωm) against AB/2 (m), Transect 5 VES.5.

Table 4.5 Geo-electric parameters Transect 5 VES.5.

Dhobley VES 5 (latitude 41.025000, Longitude 0.40472222)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	190	0.75	0.75
2	15.2	11.6	12.4
3	5.54	19.1	31.9
4	54.3	48.7	80.1
5	0.285	<<<<	>>>>

The fifth sounding curve (**figure 4.5)** indicates a geo-electric section with five geo-electric-layers with the first, second, third, fourth and fifth layers having 190Ωm, 15.2Ωm, 5.54Ωm, 54.3 Ωm and 0.285 Ωm respectively. The top layer has relatively high resistivity values, which could be due to unsaturated top soils, also the Second, third and fourth layer could be a shallow aquifer followed by a deeper aquifer at a depth of 81m. while the deeper aquifer or fifth layer is a characterized salt water by very low of resistivity of 0.285 Ωm. the VES conducted to confirm the presence of geological structure, thereby to pinpoint appropriate site for drilling. this geophysical signature displays five resistive layers, the most promising aquifer zone is located at the fourth layer. However, the thickness of the aquifer is 48.7 m. So, on the bases of geophysical data, the well in this site can be drilled to a maximum depth of 81-90 meters (**Figure 4.5**).

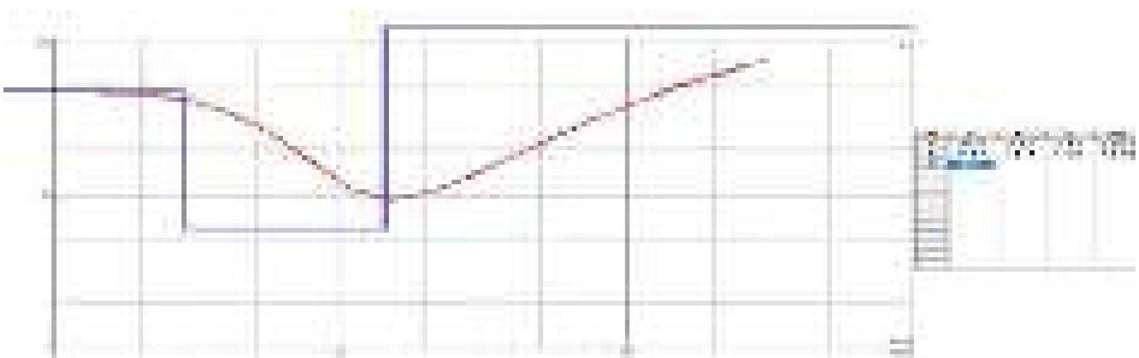

Figure 4.6 Geo-electric parameters Transect 6 VES.6.

Table 4.6 Geo-electric parameters Transect 6 VES.6.

Dhobley VES 6 (latitude 41.020556, Longitude 0.4091667)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	46.6	2.82	2.82
2	5.97	11.4	14.2
3	121	<<<<	>>>>

The Six sounding curve (**Figure 4.6**) show a geo-electric section with Three geo-electric-layers with the first, Second and third layers having 46.6Ωm, 5.97Ωm, and 121Ωm. The third layer has relatively high resistivity values, which could be due to unsaturated soils with a deeper aquifer around cumulative depth of 15 meters, it also indicates of highly conductive infill within this layer. while the second and top layers could be a shallow aquifer followed by a deeper aquifer at a depth of 15m. The VES conducted to confirm the presence of geological structure, thereby to pinpoint appropriate site for drilling. this geophysical signature in this case displays three resistive layers; the most promising aquifer zone is located at the second layer. the thickness of the promising aquifer is around 11.4 m. On the bases of geophysical data, a well at this site can be drilled to a maximum depth of 14-24 meters (**Figure 4.6**).

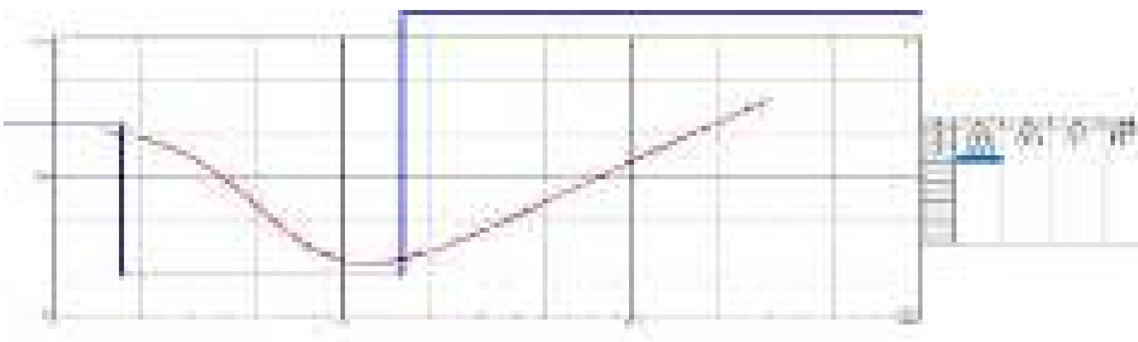

Figure 4.7 Resistivity (Ωm) against AB/2 (m), Transect 7 VES.7.

Table 4.7 Geo-electric parameters Transect 7 VES.7.

Dhobley VES 7 (latitude 40.992778 , Longitude 0.41111111)			
N	**P (Ohm.m)**	**H (m)**	**D (m)**
1	239	1.7	1.7
2	19.8	14.4	16.1
3	255	<<<<	>>>>

The Seven sounding curve (**Figure 4.7**) indicates a geo-electric section with thee geo-electric-layers with the first, second, and third layers having 239Ωm, 19.8Ωm and 255Ωm respectively. The top layer has relatively high resistivity values, which could be due to unsaturated top soils while the second layer, which is imaged at 16.5 meters depth, could be a shallow aquifer followed by a deeper aquifer of Saturated soil due to high resistivity 255Ωm at a depth bellow 16.5m. The VES conducted to confirm the presence of geological structure, thereby to pinpoint appropriate site for drilling. this geophysical signature in this case displays three resistive layers; the most promising aquifer zone is located at the second layer. the thickness of the promising aquifer is around 14.4 m. On the bases of geophysical data, a well at this site can be drilled to a maximum depth of 16-26 meters (**Figure 4.7**).

4.3 VES Curve Types

The VES curve types refer to the different patterns or shapes observed in the plot of apparent resistivity against electrode separation during a VES survey. The VES curve types are crucial for understanding the electrical resistivity distribution in the subsurface. They provide information about the vertical variation of resistivity, allowing geophysicists and hydrogeologists to infer geological structures, identify aquifer boundaries, and assess the potential for groundwater resources.

The different types of sounding curves are possible in the field. The nature of VES curve depends on the geological and hydrogeological situation and the maximum electrode spread is employed. The apparent resistivity data were interpreted using ipi2win software by curve matching technique. Interpreted Electrical Resistivity and Layer Thickness of the Study Area is presented in the **Table 4.9**.

The interpreted resistivity curve of the study area shows that One-layer curves have been observed in 5 locations and two layers curves was noticed 2 locations. The H curve type is found in 4 locations including VES.3,4,6 and 7, The Q curve type is found in 1 location which are VES.1, and HK for VES.2 also, QK curve type found in 1 location VES.5. The curve types of the study area are given in **Table 4.8**.

Table 4.8 VES Curve Types of the study area.

VES Locations	Apparent Resistivity	Curve Types
Ves 1	P1>P2>P3	Q Type
VES.2	P1>P2<P3>P4<P5>P6	HK Type
VES.3	P1>P2<P3	H Type
VES.4	P1>P2<P3	H Type
VES.5	P1>P2>P3<P4>P5	QK Type
VES.6	P1>P2<P3	H Type
VES.7	P1>P2<P3	H Type

Table 4.9 Summary of VES Data Interpretation

VES No.	Locations	Layers	Resistivity (Ωm)	Layer thickness (m)	Total depth (m)	Lithology	Curve type	Aquifer depth
1	41.2014444°E 0.5097222°N	1	250	0.63	0.63	[illegible]	Q	64
		2	37.7	58.5	58.5	Clay		
		3	30.4	[illegible]	64	Clay		
		4	3.78	-	-	Clay		
2	40.990941°E 0.4611111°N	1	56.6	0.75	0.75	Sand (topsoil)	HK	58.4
		2	6.26	0.898	1.65	Clay		
		3	20	2.26	3.91	Clay		
		4	9.06	22.8	26.7	Clay		
		5	353	31.7	58.4	Basal limestone		
3	41.025278°E 0.4097222°N	1	766	1.07	1.07	Sandy (topsoil)	H	22.7
		2	25.3	21.8	22.7	Clay		
		3	36.8	-	-	Clay		
4	41.027778°E 0.4136111°N	1	23.4	2.81	2.81	Clay (topsoil)	H	8.74
		2	3.57	5.93	8.74	Clay		
		3	30.4	-	-	Clay		
5	41.025000°E 0.4017222°N	1	190	0.75	0.75	Sandy clay (topsoil)	QK	80.1
		2	15.2	11.6	12.4	Clay		
		3	5.54	19.1	31.9	Clay		
		4	54.3	48.7	80.1	Clay		
		5	0.285			Clay		
6	41.020556°E 0.4091667°N	1	46.6	2.82	2.82	Clay (topsoil)	H	14.2
		2	5.97	11.4	14.2	Clay		
		3	121	-	-	Sandy clay		
7	40.992778°E 0.4111111°N	1	330	1.7	1.7	[illegible]	H	16.1
		2	19.8	14.4	16.1	Clay		
		3	255	-	-	[illegible]		

c

4.4 Pseudo Section

An attempt was made to generate a pseudo section of resistivity of the study area. The pseudo sections will helpful to understand the subsurface lithology variations and facilitate to delineate potential aquifer zones in the hard rock and sedimentary terrain. In order to make pseudo section, profile was constructed from VES.1 to VES.7 direction of Pseudo section station as shown in **Figure 4.8**. In the constructed profile, maximum number of electrical resistivity locations has been considered for the generation of possible better pseudo section.

Figure 4.8 Profile Direction of Pseudo section station.

The seven vertical electrical sounding which are VES.1, 2, 3, 4, 5, 6 and 7 are considered for construction of pseudo section as shown in **Figure 4.9** where the overall resistivity varied from less than 1 Ω-m to nearly 355 Ω-m. It is observed that resistivity is gradually decreased from the top layer to second and third layers. The top layer of all VES is different one another due to their locations from and it ranges 23.4 Ω-m to 266 Ω-m. in addition that the top layer noted up to 0.63m from the ground level in the north side VES.1 and increased to above 3 m in the south side of Dhobley VES.6. Below the top layer, resistivity range of 3.57 Ωm to 37.7 Ωm is observed as a second layer. The thickness of second layer is high VES.1 and lower VES.4, it varied from 0.898m in VES.2 up to 58.5m in VES.3 from the surface. the third layer found with resistivity range of 5.54 Ω-m in VES.5 to 255 Ω-m observed in VES.7 in SW of Dhobley and their thickness is varied from 2.5 to 19.5m. The resistivity of fourth layer found with 3.78 Ω-m to 54.3 Ω-m range, it increases from VES.1 to VES.5 in the south of study area and also, above 355Ω m is found as fifth layer in the VES.2 side with depth 58.4m from the surface. The high resistivity could be massive rock and low resistivity could be due to highly weathered or Sedimentary rock formation.

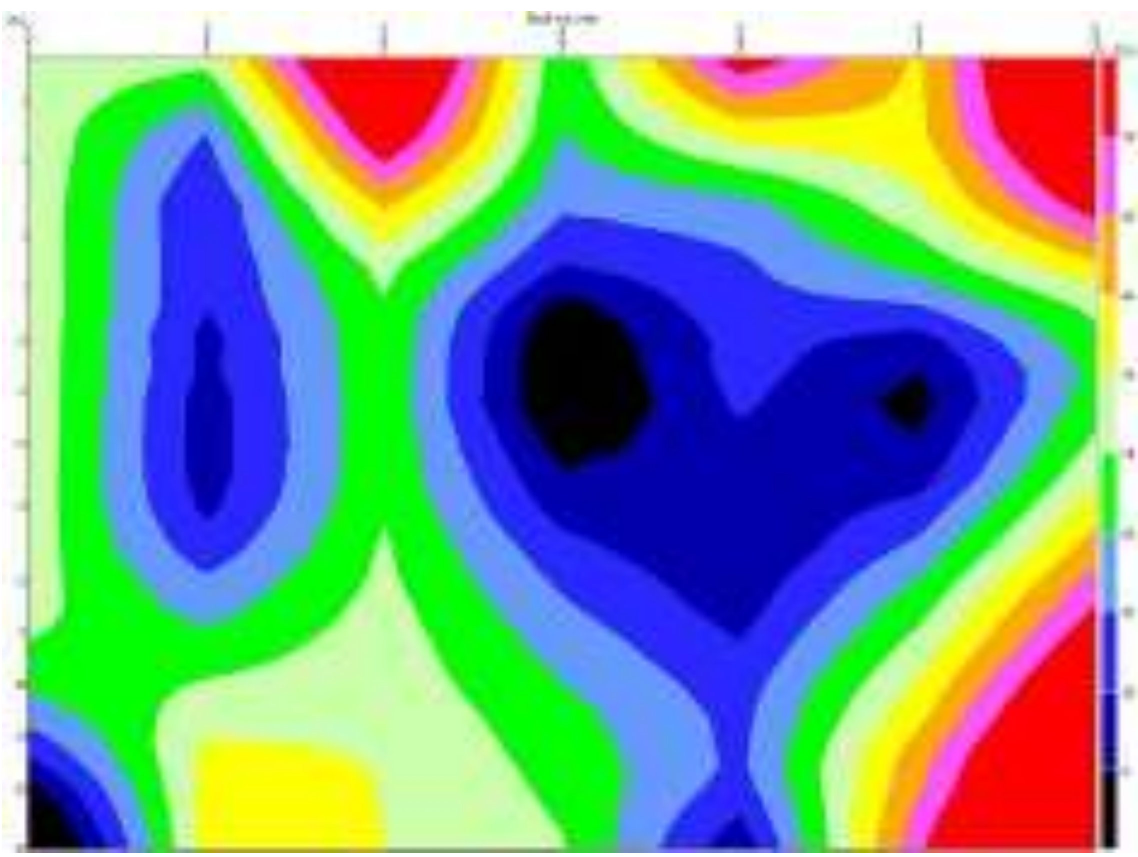

Figure 4.9 Pseudo section Profile.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Summary

The study area Dhobley is part of lower juba region of Somalia, it bounded north by Ceel Waaq and south by Laas Kamboni, while at East is found Afmadow District and also, in west side locate the boarder Somalia and Kenya. It extends to Longitude: 0.408799° and Latitude: 41.008975°, covering an area of approximately 21.66 km².

Somalia experiences two main rainy seasons, Gu and Deyr. Gu occurs between March and July, while Deyr occurs between August and November. The months with the heaviest rainfall are typically April to June and October to November. The dry seasons are called Jilaal (December to March) and Haggai (July to August). The Lower Juba region of Somalia's Dhobley District provides a varied landscape with a variety of sedimentary deposits as we show in **Figure (1.2).** Sands, silts, and gravels are among the deposits, together with dark gray clays and pink to white quartz sands. These different sediments' occurrence suggests that the area had a complicated geological past and groundwater.

The uplifting of the basement complex in the Buur region has resulted in the division of the geological basin, which extends from southern Somalia to Ethiopia in the north and Kenya in the west. The northern sub-basin consists of Jurassic and Cretaceous rock suites, while the coastal sub-basin is composed of sediments spanning from the Lower Jurassic to the Quaternary. While The Wadajir-Dhoobley area is predominantly an erosion plain covered by red sand, caliches, gypsiferous clay, hard limestone; concretionary rocks are quite common and are often covered by a thin veneer of aeolian red sands and terra rossa (red clay soil produced by the weathering of limestone).

The NDVI map indicates that the area is predominantly characterized by sparse vegetation, shrubland, grassland, and pockets of healthy (dense) vegetation. The vegetation acts as a reliable indicator of potential groundwater availability. Areas with healthier vegetation often signal higher groundwater tables, as the roots of plants reach down to access moisture.

The Soil texture of Dhobley District in Lower Juba, Somalia, are composed of a range of sediments, In and around Dhobley area is largely covered by loam soil, clay loam and sandy clay loam soil. With Different soil classifications react differently to the infiltration of water. The results of the soil moisture index map of September 2023 indicate the soil moisture index was in the range of 0.03 to 0.81 as classified in four color gradients.

The vertical electrical soundings were conducted in 7 different locations using SSR-MP-AT-ME model resistivity meter. The interpreted resistivity curve of the study area shows that one-layer curves have been observed in 6 locations and two layers curves was noticed 1 location.

The first layer or top soil consists of sandy soil with resistivity range from 23Ωm to 266Ωm and thickness of range from 0.63m to 2.82m (VES 1 to VES 7). The second layer composed of clay its value ranges from 3.57Ωm to 37.7Ωm with thickness varies from 0.898m to 58.5 m (VES 1 to VES 7).

The third layer composed of sandy clay with resistivity ranges from 5.54Ωm to 121Ωm with thickness varies from 2.26m to 19.1m (VES 1, VES 2, VES 5 and VES 7). The fourth layer composed of clay its value ranges from 3.78Ωm to 54.3Ωm with thickness varies from 22.8m to 48.7m (VES 2 and VES 5). The fifth layer of VES 2 indicates the presence of weathered limestone with a resistivity value of 355Ωm and a thickness of 31.7m.

5.2 Conclusion

The main goal of the study was to select potential well locations for water supply purposes. Among the several disciplines the pre-construction study, i.e., site investigation, which includes geological, Hydrogeological and Geophysical investigations need special attention that helps to minimize the project cost and increase quality and quantity of water.

The present study revealed the hydrogeological control of the area with reference in groundwater potential. The area has resulted with 5-layer case in maximum VES locations and shows a wide range resistivity variation.

The low resistivity values are due to the presence of wet laterite soil in the top layer and in the second layer could be sandy clay formation with water saturation. In the third layer, low resistivity attributed by clay with water saturation. The fourth and fifth-layer low resistivity attributed by weathered coarse sand and sandstone with water saturation.

The high resistivity noticed in the top layer is due to dry laterite soil and sandy soil followed by rock formation. The pseudo section has clearly exposed the sub surface lithology variation and possible groundwater potential zones. In overall, the study locations are favorable for deep groundwater development and limited zones are represented at shallow level.

5.3 Recommendation

The present study area provided good knowledge about groundwater. Therefore, the following recommendations are suggested and consider in future investigations:

1) Establishing drilling test boreholes at the areas of proposed high groundwater potentiality and should be consider more geophysical and hydrogeological investigation in the area in order to determine depth, thickness, and extension of highly potential groundwater aquifer and the interface between saline and fresh water.
2) Increasing the population and expanding the city and surrounding areas demanding more water it necessary to make regular monitoring of subsurface water resources and its quality in the area for effective management.
3) We suggesting the good locations for sitting boreholes are VES 3, 4, 6 and VES 7 because of they have potential zones for groundwater exploration which is indicative of their low resistivity with low cost, and closer the district.
4) The activating climate stations in order to find acquire data that can be used from different purpose. Also, we suggest to do more study in soil tests in order to determine Mineral content, PH level, Soil moisture, salinity, pesticides and chemical contamination, structure and texture, etc
5) We are recommending for the government of Somalia and local companies to do further geophysical electrical resistivity surveys in different seasons to improve the accuracy of groundwater potential surround at Dhobley district.
6) We suggest for geology researchers to do more extensive information on the tectonic setting of Somalia which is the key to any geological research.

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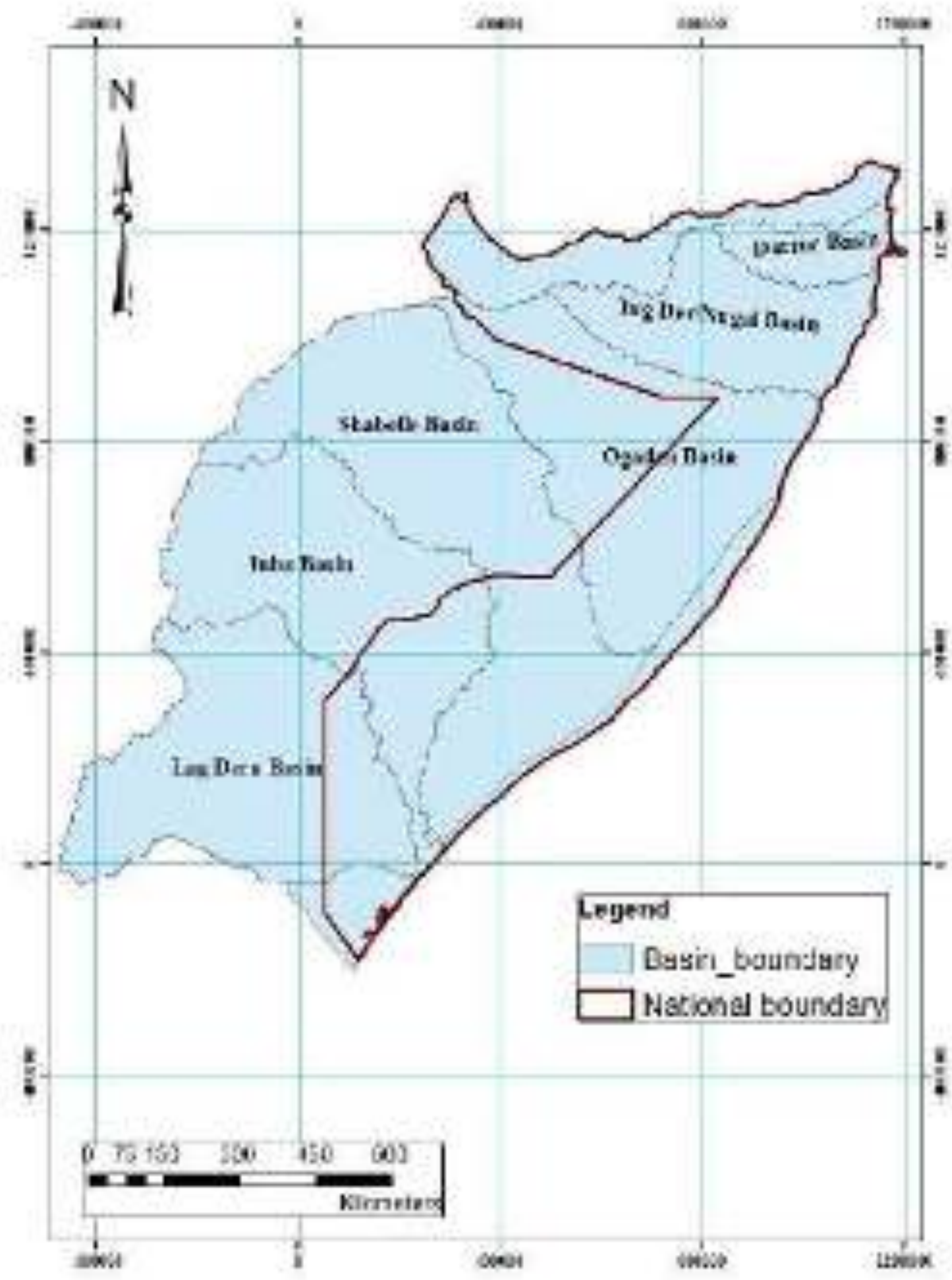
APPENDICES

Appendix 1 Topographic map of Somalia

Appendix 2 Somalia major Drainage Basins



Appendix 3 Mean monthly Rainfall in Somalia (1963-1990) by FAO

CLIMATE STATION	Lat	Lon	Alt	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Bosaso	11.20	49.18	5	0	0	3	4	1	0	0	0	1	2	3	0	11
Berbera	10.43	45.03	69	6	0	0	11	0	0	1	5	1	11	1	6	30
Scusciuban	10.3	50.23	345	0	0	3	22	24	2	0	5	2	6	5	1	72
[illegible]	9.5	49.08	9.5	0	1	7	35	43	4	0	4	4	35	5	0	137
Djibouti	11.55	43.16	15	10	18.8	20.5	28.0	18.3	3.1	8.2	5.6	3.5	22.2	22.4	11.2	160.5
Galkayo	6.85	47.46	302	0	0	4	37	50	8	3	1	2	46	15	2	168
El Bur	4.68	46.61	175	5	1	13	54	47	3	3	1	1	43	33	6	205
Obbia	5.38	48.52	10	10	1	4	47	41	8	0	0	5	24	33	25	206
Mandera	3.93	41.86	231	1	7	18	83	35	2	1	1	2	46	48	5	247
[illegible]	1.71	44.76	12	0	0	0	57	38	70	18	21	20	13	29	0	261
[illegible]	5.4	48.50	285	0	3	16	89	68	1	0	0	4	48	35	4	266
Lugh Ganana	3.58	42.55	193	1	1	18	82	53	2	1	1	3	48	48	16	275
[illegible]	7.46	47.71	1041	6	9	25	81	107	13	1	1	15	57	51	2	310
Wajir	1.75	40.06	244	5	5	42	93	35	3	2	2	4	23	61	27	310
Bulo Burti	3.85	45.56	150	1	3	11	33	64	5	5	5	8	50	61	1	318
Belet Uen	4.7	45.21	173	0	0	9	72	66	15	0	1	13	86	41	7	330
Degehabur	8.15	43.55	1000	6	1	24	79	68	28	5	12	43	64	12	1	350
Huddur	4.16	43.9	500	0	0	5	107	75	8	0	0	46	108	32	2	358
Brava	1.1	44.03	5	0	0	3	45	91	96	66	22	17	31	33	30	376
[illegible]	[illegible]	42.86	8	0	0	0	42	174	30	57	15	8	6	24	26	403
Hargeisa	9.5	44.09	1334	2	11	25	85	65	30	89	55	65	28	8	1	418
Kismayo	-0.36	42.45	8	0	1	6	45	95	117	93	42	39	31	34	1	419
[illegible]	5.88	44.3	450	2	12	4	141	100	5	0	0	15	114	53	8	467
[illegible]	-1.1	40.05	100	15	15	34	95	30	20	21	11	45	38	54	31	470
Bardera	2.35	42.3	106	3	6	27	117	73	10	11	5	8	82	116	37	473
Mogadisho	2.03	45.35	9	0	2	4	60	75	86	77	33	17	24	73	8	474
Genale	1.83	44.75	69	2	0	3	87	67	71	69	53	16	24	80	25	487
Giohar	2.78	45.5	108	0	1	14	100	67	41	29	12	8	69	75	28	460
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	3.13	43.64	487	6	3	23	155	95	20	25	6	13	135	84	6	577
Afgoi	2.13	45.13	79	2	7	10	93	94	64	58	26	15	62	77	19	584
[illegible]	0.5	42.7	25	1	3	4	131	136	74	50	24	22	51	80	37	600
[illegible]	6.75	42.11	1428	14	23	46	72	92	87	80	83	101	64	13	4	668
[illegible]	9.33	42.71	1644	9	31	50	114	103	58	78	118	101	50	23	3	771
Harar	9.30	42.05	2125	13	30	58	87	126	96	145	151	94	42	28	5	858
[illegible]	9.40	42.06	2135	9	38	71	82	100	88	115	150	124	45	23	7	[illegible]
[illegible]	9.13	41.83	2250	16	26	53	111	108	95	115	159	95	46	39	6	[illegible]
Lamu	-2.26	40.91	6	6	4	95	129	295	187	86	45	56	44	57	81	[illegible]

Appendix 4 Mean monthly Temperatures in Somalia (1963-1990) by FAO

CLIMATE STATIONS	LAT	LON	ALT	JAN	FEB	MAR	APR	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVRAGE TEM
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Appendix 1 Mean Climate Date in Afmadow Station (1963-1990) BY SWALIM Latitude 0.051 and Longitude 42.06

Month	Min Tempe °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day	Rain mm	Eff rain mm
January	21.5	38.1	59	190	7.8	20.8	6	5	5
February	21.7	39.3	58	164	7.6	21.1	6.04	12	11.8
March	22.5	39.6	57	156	7.2	20.7	6.02	32	30.4
April	22.6	37.1	65	112	5.6	17.8	4.75	102	85.4
May	21.8	34.5	75	138	5.7	17.1	4.32	81	70.5
June	20.2	32.6	73	190	6.3	17.2	4.36	23	22.2
July	19.5	32	75	216	6	17.1	4.28	30	28.6
August	19.5	33	72	242	6	17.9	4.75	13	12.7
September	19.5	35	68	233	6.6	19.5	5.30	18	17.5
October	21	35.8	70	164	5.7	18.2	4.83	84	72.7
November	21.5	35.5	73	112	6.8	19.3	4.58	97	81.9
December	21.5	35.8	69	121	7.1	19.4	4.71	53	48.5