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DEVELOPING CHARACTERISTIC REGIONAL GROUNDWATER YIELD CURVES IN DIFFERENT GEOLOGICAL SETTINGS OF PADER, AGAGO AND KITGUM DISTRICTS IN NORTHERN UGANDA.

BY

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A RESEARCH REPORT SUBMITTED TO THE DIRECTORATE OF RESEARCH AND POST GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE MASTER OF SCIENCE IN WATER AND SANITATION OF UGANDA CHRISTIAN UNIVERSITY MUKONO.

SEPTEMBER, 2023

ABSTRACT

The main objective of this study was to develop characteristic regional groundwater yield curves in different geological settings of Pader, Agago and Kitgum Districts in Northern Uganda to act as references and guides during ground water prospecting. The specific research objectives were to: (i) identify the Vertical Electrical Soundings (VESes) for forty selected wells(Deep boreholes) drilled in Agago, Pader and Kitgum Districts and characterise the wells yields ranges, (ii)analyse geological and hydrogeological conditions for ground water exploration in the Districts and (iii) develop the characteristic regional groundwater yield curves that will be referred to during ground water investigations in the Districts. The identified VESes for forty selected wells drilled in Agago (08), Pader (04) and Kitgum (28) Districts under Orom Water Supply project respectively were used in this study. Resistivity curves (VES) used for each of the forty selected well sites was based on availability of supervised drilling data (lithological logs and Test pumping data) from the onsite supervisor and drilling contractor. The Total Depth of boreholes drilled in the study area was found to be highest with a mean of (130.6±3.0) m in Agago District, followed by (126.9±1.3) m in Kitgum district and lowest in Pader District with (121.0±0.5) m. On the other hand, mean water strike depth was found to be deepest in Kitgum (64.6±3.1) mbgl, followed by Pader (55.9±9.2) mbgl and shallowest in Agago District with (54.7±7.1) mbgl. However, the mean aquifer yield was highest in Pader district (19.0±4.1) m^3/hr, (17.8±2.5) m^3/hr in Kitgum district and (11.9±1.2) m^3/hr in Agago District. The mean Swing Angle of the resistivity curves in the three districts of Agago, Kitgum and Pader were respectively $(4.9\pm5.6)^o$, $(17.8\pm2.5)^o$, and $(19.0\pm4.1)^o$. Over all, as the distance within the region increases in the Eastern direction, the yield decreases from as high as over 26.0 m^3/hr to as low as below 2.0 m^3/hr. From a distance of

520000 mE to over 570000 mE, the yield is not spatially affected by shifting in the Northern direction, i.e., generally no change in yield from 340000 mN to 390000 mN. For distances between 335,000 mN to 360,000 mN, the Water Strikes are generally experienced at depths less than 60 mbgl, regardless of the eastern distance. This is a similar situation for distances between 490,000 mE to 530,000 mE where Water Strikes are achieved at depths less than 60mbgl, regardless of the distance along the Northern direction. The Total Depth (TD) of wells vary from 102 m to as high as 156 m, with half of the area having TD of less than 120 m and the other half having depths of 120 to 156 m. Spatially, there is a general similar TD of wells within the region, indicating that there are aquifers within the region at depths of 102 m to 156 m with an average value of 129 m. The Average Swinge Angle (ASA) of the Resistivity Curves typical of the area varies from as low as (-35)^o to as high as 40^o. Generally, the ASA varies relatively uniform over the area and therefore has no much effect on the groundwater exploration within the area. Below Total Depth (TD) of 115 m, regardless of the Water Strike depths, the Pump Test yield varies from as low as 18.0 m^3/hr to as high as greater than 38.0 m^3/hr. Above Total Depths of greater 140 m, the Pump Test Yield decreases from as high as 22.0 m^3/hr to as low as below 2.0 m^3/hr, regardless of the Water Strike depths. Between Total Depths of 120 m and 140 m, the Pump Test Yields are relatively higher, ranging from 18.0m^3/hr to as high as 30.0 m^3/hr. The best predictive model for Aquifer Yield (*Y*) within the region based on Total Depth (*TD*) and Water Strike Depths (*WSD*) for each lithological (geology)feature was found to have satisfactory Coefficient of Determination (R^2) of 66.8% and is of the form,

$$Y_i = \beta_0 + \beta_1 \ln(TD) + \beta_2 \ln(WSD)$$

Where Y_i= The Pump Test Yield for a borehole of Lithology 'i' in m^3/h; TD =Total Depth of the borehole in m; WSD= Water Strike Depth in m; β_0, β_1 and β_2 are the Regression coefficients determinable by Multiple Linear Regression method. These coefficients were determined for each of the eight (8) Lithologies in the region and summarized using matrix notation as:

$$\begin{pmatrix} Y_{AGG} \\ Y_{ASLD} \\ Y_{BGC} \\ Y_{IGSVDP} \\ Y_{KG} \\ Y_{MG} \\ Y_{MGG} \\ Y_{VDG} \end{pmatrix} = \begin{pmatrix} 175.7 & -32.67 & 0.712 \\ 174.7 & -32.67 & 0.712 \\ 176.2 & -32.67 & 0.712 \\ 160.5 & -32.67 & 0.712 \\ 169.0 & -32.67 & 0.712 \\ 176.0 & -32.67 & 0.712 \\ 167.5 & -32.67 & 0.712 \\ 165.8 & -32.67 & 0.712 \end{pmatrix} \begin{pmatrix} 1 \\ ln(TD) \\ ln\,(WSD) \end{pmatrix}$$

Therefore, this study major finding will guide groundwater exploration within the region by identifying and determining the Yield based on lithology. The approach used in the study can be applied during groundwater investigations to identify potential drilling points for groundwater supplies while minimizing cases of dry or low yielding wells. Application of this approach to groundwater investigation should take into account the factors that influence the occurrence and movement of groundwater in the study area. Geology and geological structures should be comprehensively investigated prior to application of this method.

This study has also revealed that the North Western (extended network of geological structures) and North Eastern regions (with direct connectivity with the main aquifer/alluvial sediments) specifically in Kitgum District constitute good groundwater potential for prospecting, while based on the data density, the Northern part of Pader and Agago constitute good potential areas.

DECLARATION

DECLARATION

I, Samuel Senfuma, declare that this is my original work and has not been submitted to any other institution for any award.

Samuel Senfuma

Signed..

Date.......September, 7th /2023

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APPROVAL

APPROVAL

This is to certify that this study has been carried out under our supervision and has been submitted for external examination with our approval as Uganda Christian University supervisors.

Signed..

Date....7th/09/2023....

Dr. Peter Mulamba

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DEDICATION

I dedicate this dissertation to almighty God who has given me life, health, protection and all my needs throughout my academic life, to Mr. Erisa Kyeyune whose encouragement, guidance and support inspired me in pursuit of further studies, to my most lovely wife Wolayo Jackline Senfuma, our beloved daughters Kirstin and Chloe, and son Malachi for their care, love, encouragement, support, endurance and financial sacrifice during the period of this study.

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Dr. Peter Mulamba and Mr. Willington Amanyire for their support, participation and contribution to ensure that this work is completed.

Thanks to all the lecturers at Uganda Christian University. These adequately guided and equipped me with both theoretical and practical skills. I would also like to acknowledge the contribution of the course participants for their work and availability.

I would like to express my gratitude to my aunt Mrs. Munaawa Suzan for the enormous sacrifices and encouragement she made to ensure that I obtain a quality Education, to Eng. Wesigomwe Jamil Mohammed for his tireless effort in supporting and, guiding me and bearing all my inconveniences throughout the period of doing this study, to Mr. Robert Naguyo, Mr. Waddamba Silver and Mr. Mutiibwa Robert Kirya for their input during the academic year and for their advice and encouragement during the project; and to all my course mates for their prayers and morale boosting to accomplish this study successfully. May God reward you abundantly

Finally, I would like to thank my colleagues at work for their help and standing in for me during the period of this project.

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LIST OF ACRYNOMS

AC	Alternating Current
ASA	Average Swing Angle
Bn	Billions
DC	Direct Current
DPs	Development Partners
EUTF	European Union Trust Fund
FWS	First Water Strike
FY	Financial year
G.O.U	Government of Uganda
GW	Groundwater
IP	Induced polarization
mamsl	metres above mean sea level
MCM	Million Cubic Meters
MWE	Ministry of Water and Environment
MWS	Main Water Strike
NRECCLWM	Natural Resources, Environment, Climate Change, Land and Water Management
NWRA	National Water Resources Assessment

RGC	Rural Growth Centre
RSWSS	Refugee Settlement Water Supply System
RWSSD	Rural Water Supply and Sanitation Department
SP	Self-Potential
SPR	Sector Performance Report
T/C	Town Council
TD	Total Depth
UGIFT	Uganda Intergovernmental Fiscal Transfers
UGX	Uganda Shillings
VES	Vertical Electrical Sounding
WATSUP	Water Supply
WMZ	Water Management Zone
WSDFs	Water and Sanitation Development Facilities
WSS	Water Supply System

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Groundwater which is defined as subsurface water stored in geological formations such as aquifers comprised of soil, sand, and rock fractures, plays a pivotal role in the water resource landscape (Freeze and Cherry, 1979; Fetter, 1994). Uganda possesses a substantial sustainable groundwater resource capacity estimated at around 5,670 million cubic meters per year (MCM/year) distributed across four key water management zones (WMZs) (NWRA, 2013), namely:

I. The Upper Nile WMZ, encompassing the entire Albert Nile and Kidepo catchments, most of the Aswa basin, and the north-eastern edge of the Kyoga basin (1,087 MCM/year), (Sali, et al., 2020);
II. The Kyoga WMZ, covering most of the Kyoga basin (2,476 MCM/year);
III. Lake Albert WMZ, including the drainage areas of Lakes George, Edward, and Albert (1,047 MCM/year) and;
IV. Victoria WMZ, which roughly aligns with basin 1, draining the Lake Victoria catchment in Uganda (1,060 MCM/year).

The total demand for groundwater in 2009, as determined by the Directorate of Water Development (DWD) design rule, was estimated at 225.3 MCM/year (4% of the available capacity). This demand was projected to increase to 462.8 MCM/year by the year 2030 (8% of the available capacity) (NWRA, 2013). Groundwater resources hold significant importance in Uganda, with over 80% of the rural population relying on groundwater for potable water supplies (MWE, 2013; Sserwada, et al., 2016). The Government of Uganda (GOU) and Development Partners (DPs) have been actively implementing groundwater-based piped water supply projects to cater to this substantial demand (MWE, 2013).

For instance, GOU-funded projects in Northern Uganda, such as the Agago RGC – Paimol T/C WSS, Kalongo WSS in Agago District, Omugo WSS in Maracha District, Yumbe Town WSS in Yumbe District, Adjumani Town WSS in Adjumani District, and Ntula RGC WSS in Moyo District, have focused on harnessing groundwater resources (MWE, 2013). Additionally, DPs, including the Japan International Cooperation Agency (JICA), have actively supported groundwater-based water supply systems in the region, such as the Unyama and Awere RGCs piped water supply systems in Gulu district, Kitgum – Matidi RGC system in Kitgum, Koch Goma RGC system in Nwoya, Adilang RGC System in Agago, and Corner Kilak RGC system in Pade District (JICA, 2020).

Also, KfW-funded projects have contributed to groundwater utilization, including the Moyo T/C in Moyo District, Padibe RGC, Atiak Town in Amuru District, and Odramacaku RGC WSS in Arua District (KfW, 2021). Furthermore, projects funded by the European Union Trust Fund (EUTF) have played a role in water supply systems in refugee settlements, such as Bidibidi RSWSS in Yumbe district, Nyumanzi, Ayiro II, and Alere RSWSS in Adjumani, Kiryandongo Ranch 1 RSWSS, and Ofua and Omugo 6 RSWSS in Arua District (EUTF, 2021).

Many Water and Sanitation Development Facilities (WSDFs) have implemented piped water supply systems based on groundwater resources (MWE, 2013). High-yield hand pump-equipped boreholes have been upgraded into solar mini-piped water supply schemes. Also new production wells have been drilled for micro-irrigation demonstration schemes in various regions, including Amogi scheme in Oyam District, Amoti scheme in Gulu District, and Ludel scheme in Pader District (MWE, 2013). Overall, numerous factories/industries, farms, and institutions have developed self-supply water systems utilizing groundwater (MWE, 2013).

In terms of technology options for rural water supply improvements serving a total population of 28,182,652 in Uganda (UBOS, 2020), the options are 44.7% deep boreholes, 23.1% shallow wells, and 20.8% protected springs (MWE, 2021). Boreholes remain the predominant rural water supply technology option though, it experienced a slight increase of 0.02%. from FY 2019/20 to FY 2020/21 (MWE, 2021).

As of June 2021, GOU and other DPs had constructed over 90,000 groundwater sources, primarily deep boreholes and shallow wells, serving approximately 19.1 million Ugandans (MWE, 2021). The trend in financing and investment in groundwater-based projects by both DPs and GOU indicates an increase of 41.4% from FY 2019/20 to FY 2020/21 and 58.1% from FY 2021/22 to FY 2022/23 (MWE, 2021).

The predominancy of deep borehole technology option to serving most RGCs and STs can be further traced from the MWE WATSUP Database for FY 2020/21 where the following observations are noted for the study area districts:

Agago district, with a population of 256,074 people (UBOS, 2020), had 1,372 domestic water points serving a total of 212,095 individuals. Among these, 83.7% were served by deep boreholes, and 12.1% by shallow wells. The predominant funding sources were NGOs (78.2%), followed by Local Governments (13.2%), and Central Government (6.8%) (MWE, 2021).

Kitgum district, with a population of 189,253 people (UBOS, 2020), had 1,335 domestic water points and 6 piped schemes serving a total of 179,790 individuals. Among these, 96.9% were served by deep boreholes, and 2.1% by shallow wells. The primary funding sources were NGOs (62.3%), Local Governments (22.1%), and Central Government (9.8%) (MWE, 2021).

Similarly, Pader district, with a population of 203,432 people (UBOS, 2020), had 1,253 domestic water points and 38 piped schemes serving a total of 178,745 individuals. Among these, 93.6% were served by deep boreholes, and 4.6% by shallow wells. The primary funding sources were NGOs (75.5%), Central Government (13.0%), and Local Government (7.5%) (MWE, 2021).

A simple analysis reveals that out of a total of 3,960 domestic water points in the three districts, 1,096 domestic water points (318 in Agago, 526 in Kitgum, and 252 in Pader), representing 30%, have been non-functional for a period of five years. These points are considered abandoned mainly due to poor yields, water quality issues, and technical breakdowns. This situation can be attributed to the limited or lack of knowledge to interpret geophysical survey results before source location and construction, thus affecting value for money and service delivery to the people (MWE, 2021; Sserwada, et al., 2016).

Given the unpredictable groundwater conditions at depth and occasional well failures, characterizing and quantifying subsurface conditions using geophysical methods has become an essential approach. The application of geophysics reduces uncertainties in borehole drilling and enhances the understanding of hydrogeology at various scales (Chandra, 2015; Macdonald, 2008). Geophysical methods are employed to measure spatial and temporal variations in the physical properties of the Earth and generate quantitative subsurface models, which are interpreted subjectively (Chandra, 2015).

The application of geophysical methods and techniques in groundwater falls within the domain of 'groundwater geophysics' or 'hydro geophysics.' It provides precise and comprehensive insights into subsurface hydrogeological conditions with minimal ambiguity (Chandra, 2015). Geophysical methods have been relatively new in groundwater applications compared to mineral and petroleum exploration (Chandra, 2015). However, they have been found effective and successful when thoughtfully implemented for specific groundwater problems (Macdonald, 2008). Surface geophysical investigations are non-invasive, reasonably economical, and can be employed from the early stages of drilling site selection and site characterization (Chandra, 2015).

While geophysical measurements may not directly predict well discharge, they can significantly reduce the cost of locating a successful or the best water well site within a given hydrogeological setting. This is achieved by sampling a larger volume for additional spatial insights and reducing the cost and time involved in drilling numerous boreholes to obtain close-grid information (Chandra, 2015).

Furthermore, geophysics can help optimize drilling depths for the highest chance of encountering productive fractures in the hydrogeological environment (Chandra, 2015).

In general, the most effective and economical geophysical methods for surface surveys are electrical or electromagnetic methods, which have been extensively used. Electrical resistivity and electromagnetic methods measure variations in the electrical conductivity of rock formations caused by changes in lithology, water content, porosity, and water salinity (Chandra, 2015).

The choice of the most appropriate geophysical method and technique, or combination of techniques, depends on objectives, hydrogeological conditions, the scale of the survey, required depth information, and available equipment, expertise, logistics, and financial resources. Overall, the choice should provide a clear response for the target with minimal ambiguity (Chandra, 2015).

Other geophysical methods commonly used include magnetic, gravity, and seismic methods. The magnetic method measures variations in the magnetic field caused by differences in magnetic susceptibility, while the gravity method measures variations in the gravity field caused by disparities in formation density (Chandra, 2015). The seismic method measures variations in seismic velocity due to differences in mechanical properties (Chandra, 2015).

Additionally, Induced Polarization (IP) and Self-Potential (SP) methods can also be used (Chandra, 2015). The IP technology measures variations in electrical polarizability or chargeability caused by differences in clay content, while the SP method measures variations in natural electrical potential resulting from changes in lithology, water quality, and water movement (Chandra, 2015).

1.2 Problem Statement

Despite substantial funding from the GOU and DPs for water supply projects based on groundwater resources, there remains a critical knowledge gap in groundwater exploration and geophysical data interpretation. This gap leads to poor site selection, inadequate yield, and, at times, dry wells. Site selection often relies on resistivity curves, among other factors, yet there are no established regional groundwater yield curves to reference over time.

Even when Groundwater Consultants are hired by Local Governments to conduct geophysical surveys, their output, including groundwater yield curves, cannot be compared to existing curves for quality assurance. This situation is particularly evident in the Acholi sub-region, encompassing Agago, Pader, and Kitgum Districts, where a low success rate or low groundwater yields have been consistently recorded (MWE, 2021).

This study aims to develop characteristic regional groundwater yield curves for yielding and non-yielding groundwater wells in the diverse geological settings of Agago, Pader, and Kitgum districts. These curves will guide decision-making regarding when and where to consider groundwater-based supply schemes in the planning process for Rural Growth Centers (RGCs) and small towns.

1.3 Objectives of the study

1.3.1 Main objective

The main objective of this study was to develop characteristic regional groundwater yield curves in different geological settings of Pader, Agago and Kitgum Districts in Northern Uganda to act as references and guides during ground water prospecting.

1.3.2 Specific Objectives

The specific research objectives were :

I. To identify the Vertical Electrical Soundings (VESes) for forty selected wells drilled in Agago, Pader and Kitgum Districts and characterise the wells yields ranges.

II. To analyse geological and hydrogeological conditions for ground water exploration in the districts.

III. To develop the characteristic regional groundwater yield curves that will be referred to during ground water investigations in the districts.

1.4 Research Questions and hypothesis

1.4.1 Research questions

The main research questions were :

I. What are the yield characteristics of the groundwater yield curves for the selected forty drilled boreholes in the three districts?

II. What is the effect of geological and hydro geological conditions on ground water well yields in the three districts in Northern Uganda?

III. What are the characteristic regional groundwater yield curves that aid ground water surveys interpretation in Acholi sub region covering the three districts?

1.4.2 Research Hypothesis

I. There are yield characteristics of the groundwater yield curves for the selected forty drilled boreholes in Acholi sub region covering the three districts.

II. Geological and hydrogeological conditions have an effect on ground water well yields in the three Districts in Northern Uganda.

III. There are no existing characteristic regional groundwater yield curves to guide ground water investigations in the three Districts.

1.5 Justification of the Study

Inspite of the fact that Government of Uganda and other DPs greatly fund ground water-based projects, there is still a knowledge gap in groundwater exploration therefore guaranteeing successful sites with good yields upon drilling is not accurate.

Annually, out of about 1,000 groundwater wells drilled in Uganda, approximately 200 (20%) end up being unsuccessful (dry) /low yielding. This translates into financial losses of about UGX 400 million and hence the intended overall objective of water supply as a service to the population is not wholly achieved.

The causes of dry or low yielding ground water wells are among other reasons attributed to:

I. Inadequate data for interpretation for example existing regional groundwater yield curves.

II. Lack of a standard tool in form of parameter checklist to which field data can be subjected for an impaired and unbiased analysis in the interpretation of subsurface ground conditions using geophysical methods, Vertical Electrical Sounding in particular.

III. Limited working knowledge on the analysis and interpretation of various field data collected.

The effect of dry or low-yielding groundwater wells is two-fold;

I. To the groundwater professionals, confidence levels in application and interpretation of geophysical investigation data is lost.
II. To the funding agencies, the low success rates may subsequently lead to Development Partners and Government suspend or abandon funding projects based on ground water supply.

The need for adequate, good quality water has increased extensively due to rapid population growth in Acholi sub region, water for irrigation requirement and the development of industries. The population projections in Acholi sub region between years 2015 and 2030 is estimated to be 282,500 people in Agago, 223,900 people in Pader and 248,600 people in Kitgum (UBOS, 2022) of which the largest percentage will depend on groundwater as source of clean and safe water supply.

There is increased awareness of the technology of groundwater as the source of supply country-wide, thus, many supply systems will rely on the exploration and exploitation of ground water resource.

UGIFT is a country wide World Bank project for micro scale irrigation schemes that will depend on groundwater to a larger extent. Developing of motorised piped water supply systems based on groundwater for RGCs and small towns will greatly support the program though it requires good groundwater studies to reduce multiple drillings.

1.6 Significance of the Study

This study focused on how best to develop characteristic regional groundwater yield curves for yielding and non-yielding ground water wells in the different geologic settings found in Agago, Pader and Kitgum Districts. Reference to these characteristic regional groundwater yield curves that are related to dry, low, medium, high and very high yielding boreholes shall guide on where to consider location of borehole sites with desired yields for water supply during the planning process for RGCs and Small Towns schemes.

Recommendations of the study may add to the body of knowledge for hydro geologists and contribute to the general change in approach of groundwater studies and exploration in the country to minimize wasteful investment in cases of dry or low yielding wells.

1.7 Scope of the Study

The study focused on secondary data of forty (40) production boreholes drilled in Agago (08 sites), Pader (04 sites) and Kitgum (28 sites) districts under the Orom Water Supply project which comprises of multi-satellite solar powered piped water supply schemes dependent on groundwater resource. It also focused and expound on the electrical resistivity method for site/geophysical investigations or ground water exploration. Existing data in terms of geological maps and hydro-census data of Uganda was useful in interpreting geological and hydrogeological conditions of the study area. Study findings are representative of only drilling attempts falling within the same conditions for the forty production wells.

Statistical analysis of the resistivity curves (VESes) resulting from the electrical resistivity survey method for the forty wells in correlation to wells yields in the different geological environments has been used for analysis in order to develop the characteristic regional groundwater yield curves for the study area.

1.8 Conceptual Framework

Groundwater world-wide is a broad research area and the knowledge gap is still wide. Geology, aquifer characteristics, hydrogeological conditions and depth to bedrock are the key factors affecting groundwater yield curve shapes and subsequently the yield during ground water investigations. For this research, the research variables were limited to those presented in the conceptual framework *Figure 1.*

The conceptual framework was designed to address the specific objectives, where characterization and spatial analysis of the independent variables which were Total Depth (TD), Lithology, Water Strike Depths (WSD) and Swing Angle (SA) were made from the forty borehole drilling datasets and the dependent variable Yield from the corresponding borehole pumping datasets. The forty deep boreholes used in the study were distributed as Agago (08), Kitgum (28) and Pader (04). The predicted as classified into five categories of Dry (0m^3/hr), low (1 -5m^3/hr), medium (6-15m^3/hr), High (16 -25m^3/hr) and Very High (>25m^3/hr) for decision making whether to develop a hand pump equipped borehole or develop production wells for mini piped water supply systems for larger towns and RGCs. Conceptually the predicted yield from the geophysical parameters is classified for decision making on GW exploration either as a point source or a mini piped.

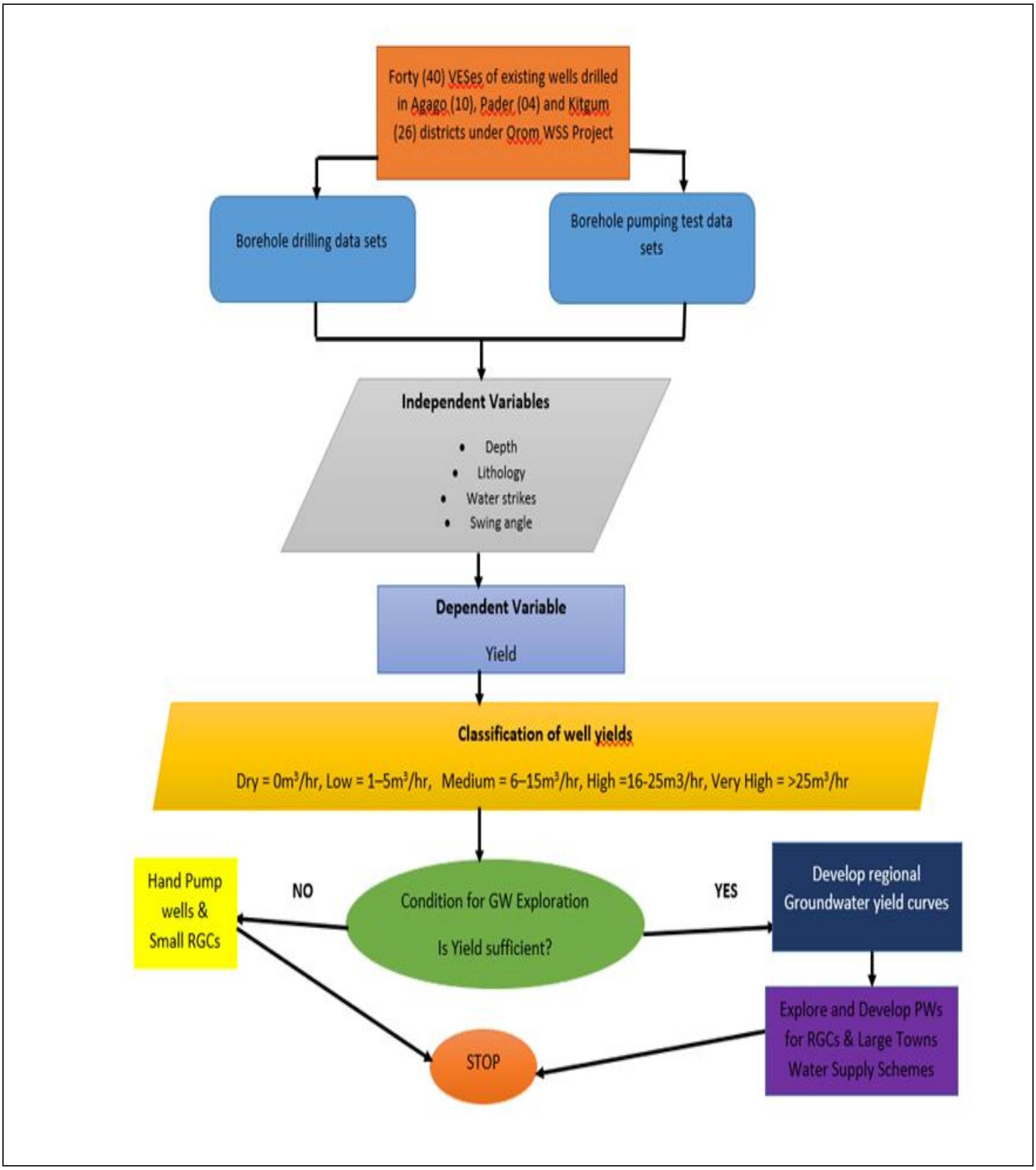


Figure 1: Flow chart showing developed conceptual framework to guide on the research

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

By undertaking a literature review, it enabled the researcher of this study to summarize knowledge required in developing characteristic regional GW yield curves for different geological settings of Pader, Agago and Kitgum districts that may act as references and guides during groundwater prospecting. It also enabled to identify the strengths and weaknesses in previous groundwater investigations work related to site selection that can give desired aquifer yields. During this research, potential weaknesses were eliminated, whilst bringing to the fore the potential strengths.

In this chapter, information on hydrogeology, geological formations, groundwater occurrence, groundwater potential, groundwater development in Uganda has been reviewed. The literature review focused on a conceptual framework in *Figure 1*, and the independent variables included:

i) Swing angle,

ii) Resistivity &

iii) Depth to bedrock conditions and lithology with the yield as the dependent variable, and objectives of the study.

2.2 Hydrogeology and Geological Formation

The availability of groundwater in a particular area mainly depends on its geology and possibilities of recharge. The amount of recharge usually influences how much groundwater can be replenished, which in turn determines the groundwater resource that is renewable. Geology greatly determines the recharge and storage characteristics as well as ground water flow dynamics within the rock (MWE, 2013).

The Hydrogeological conditions of Agago, Pader and Kitgum districts were reviewed in details during the study.

Groundwater is stored within the pore spaces and fractures in rocks and in situations where they are interconnected, groundwater can easily flow and these rocks are said to be permeable. Fractured or porous rocks therefore have a high potential for groundwater development provided they can be recharged with water.

The study area is mainly dominated by basement or crystalline basement, consisting of igneous and metamorphic rocks, that underly the sedimentary and volcanic rock sequences. The basement outcrops contain good aquifers, with conductive and storage functions which are to some extent spatially separated as shown in *Figure 2* below.

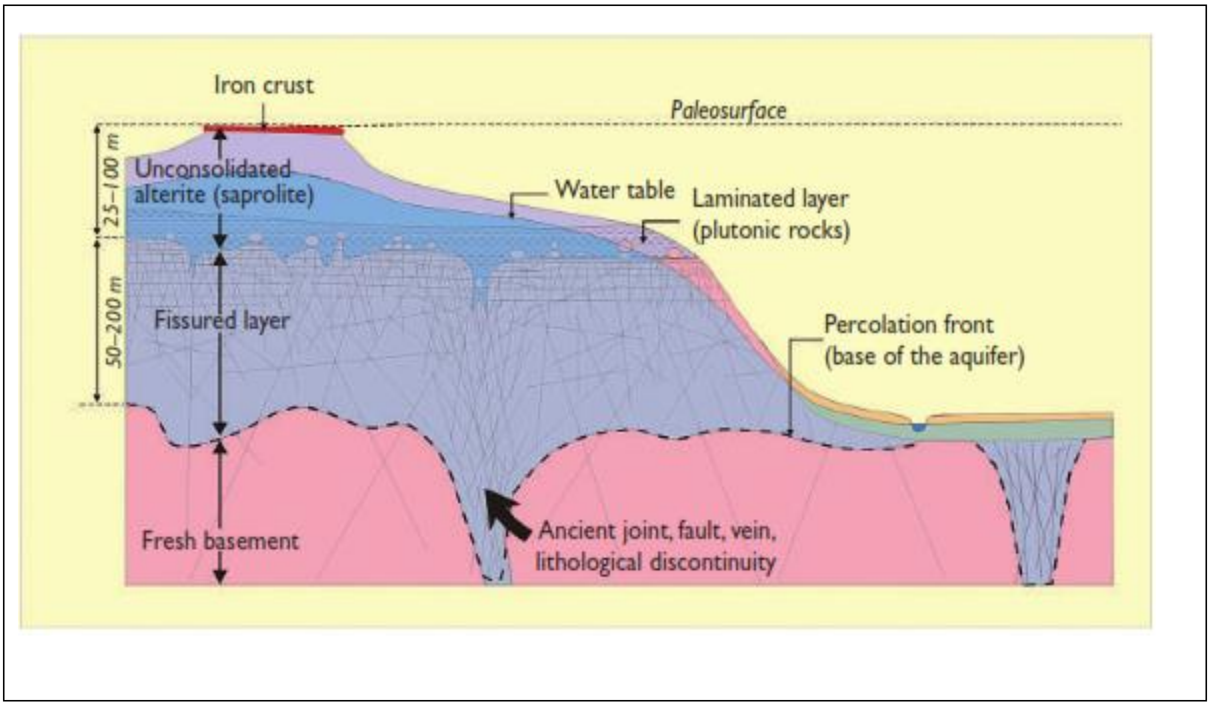


Figure 2: Basement aquifer consisting of residual regoliths and a fissured zone. (Source: (Lachassagne, 2005)).

Deeper parts in fresh rock with fractures to a certain depth forms discontinuous aquifer zones especially common in areas where recent tectonic evolution has produced fracturing. This part of the aquifer system is capable of transmitting groundwater locally, but the capacity to store groundwater is generally low. Properly planned drilled wells can have substantial productivity with yields of tens of cubic meters per hour.

The weathered shallow horizons (saprolite) of variable thickness depending on present and past climatic conditions is a less productive part of the aquifer system in terms of transmitting groundwater, but with a higher capacity to store water. Without this storage reservoir, wells in the underlying fractured rock would quickly run dry. Recharge varies according to climate.

The water-bearing saprolite and the fissured bedrock beneath it together form exploitable aquifer systems. These systems are generally of limited size and their boundaries are poorly defined. However, they are scattered widely over all basement rock systems, usually in patterns defined by the natural drainage networks. These aquifers provide widely distributed groundwater resources, used for rural domestic or animal water supply and even for small-scale irrigation. They also contribute to perennial flow in the often very dense stream networks found in the humid zone.

2.3 Groundwater Occurrence, Potential and Recharge.

The occurrence of aquifers in different parts of Uganda is related to the respective geological characteristics of different areas. The productive aquifers are mainly found in in-situ weathered bedrock, the regolith overlying the bedrock and in faults and fractures in the basement. High yielding wells are found in the weathered-fractured bedrock where permeability is high and where storage can be provided by the overlying regolith. Groundwater is the primary source of freshwater for drinking and irrigation in the world. In Africa alone, Groundwater supplies 75% of all safe sources of drinking water (Mileham, 2009)

Ground water in the basement type of rocks occurs in fractures which are thin and usually don't extend for long distances. The number and distribution of fractures, and the effective porosity in each geological formation control aquifer characteristics. The way Uganda was formed (rifting and uplift) has a significant impact on the water resources especially ground water formation, investigation and extraction methods.

The potential of groundwater in various areas in Uganda is evidenced by the presence old deep wells, shallow wells and springs which are reviewed by the parameters explained below.

Regolith Thickness: In Uganda, most of the regolith is clayey especially in the upper layers which are dominated by relatively low permeability dominates. Medium to high regolith thickness (>30m) leads to high groundwater potential through provision of storage in the deeper fractures (Nsubuga, 2014).This is represented by typical basement regolith aquifer system in <u>*Figure 3*</u> below.

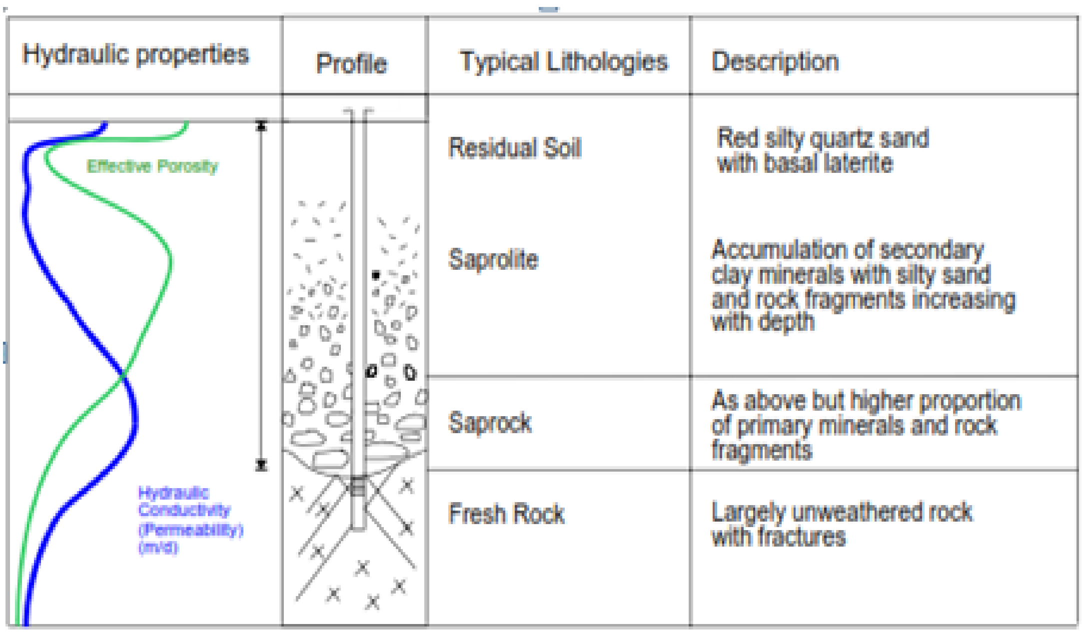


Figure 3: Showing schematic profile of a typical basement regolith aquifer system (Source: (DWD, 2005))

Aquifer Yields - The borehole yields in Uganda vary significantly according to the geological formation in which they are drilled and their degree of fracturing and weathering. Borehole yields vary from 0.5 - 10 m^3/hr, although recently wells of >100m^3/hr have also been encountered. High yielding boreholes are normally found in granites and gneisses which are highly fractured while low yielding boreholes are found in the phyllites and schists which exhibit a medium degree of metamorphism.

Rest Water Levels - Rest water levels also give an indication of the groundwater potential of an area. Shallow water levels (<20m) indicate that the aquifer has high potential for yielding groundwater while deeper water levels indicate low yields. In Uganda, rest or static water levels vary between 1m and 45m below ground level (Nsubuga, 2014).

Groundwater (GW) recharge plays an important role in evaluating groundwater resources but it is difficult to quantify (Alley, 2002). GW recharge can either be diffuse “recharge that take place from the land surface to the water table by infiltration and percolation through unsaturated zones over a large area or localised “where recharge is less uniform in space”. Recharge studies in Uganda have shown that upon reaching the land surface, most of the incoming rainfall (70 % to 90 %) is recycled to the atmosphere by evapotranspiration and the remainder stays at the surface which then contributes to surface flow through run off to recharge GW by infiltration into the unsaturated zone (Taylor, 1996), (Howard, 1992) (Tindimugaya, 2000)

The estimated annual GW recharge rates in Uganda with an average of 120mm/year are highly variable and amount to approximately 10% of annual rainfall in the zone of deep weathering in Central Uganda (Taylor, 1996) (Tindimugaya, 2000). In the zone of stripping in Western Uganda 1% of annual rainfall contributes to recharge (Taylor, 1996).

2.4 Extent of Groundwater Development in Uganda

Groundwater development has been identified as the most feasible source of water to develop in order to increase safe water coverage to over 95% in Uganda. However, shortcomings have been identified in:

- The nature and extent of aquifers,
- Their potential for large- and small-scale development,
- The quantity and quality of resources available, and
- The feasible water supply technologies in different parts of the country.

Groundwater is the major source of water supply in the rural, semi-arid and arid areas in Uganda (MWE WATSUP, F/Y 2022/22). Groundwater development has been on-going since the 1930s through construction of deep boreholes, shallow wells and protected springs.

Deep boreholes are diameter wells (5" to 8") that are deeper than 30m while shallow wells are wells that are shallower than 30m and constructed in the unconsolidated formation. The average depth of boreholes in Uganda is 60m while shallow wells are on average 15m deep. Boreholes and shallow wells are normally installed with hand-pumps with capacity of 1.0m^3/hour and their yields are usually low.

There has been an increase in groundwater development for town water supply since early 1990s due to the need to have water supply systems that can easily be operated and managed by the users. In addition, groundwater normally has good quality and requires little or no treatment unlike surface water. This therefore makes investment and operational costs of groundwater-based systems much lower than those of surface water-based systems. Boreholes with yields greater than 5m^3/hour are normally considered for installation with motorized pumps for piped water supply.

Under the Uganda Rural Water Supply Investment Plan, it was intended to improve significantly the safe water supply coverage in the whole country to at least 95% by 2015 (MWE, 2013). However, it stands at 68% as of June 2021 (MWE, 2021). The focus is on groundwater development using low-cost, simple water-supply technologies. In order to achieve construction of hand pumped boreholes and production wells for piped systems, knowledge in ground water resource must be addressed. The Uganda

Urban Water Supply Investment Plan aimed to supply piped water to over 250 small towns based on groundwater through deep boreholes.

Despite all the above planned developments, there is still very limited knowledge of the country's groundwater resources, making it difficult to guarantee sustainable groundwater development for the current and future needs. In order to address this issue, government-initiated groundwater assessment studies in 1996 to fully understand the nature, extent and reliability of the country's groundwater resources. Information so far obtained includes distribution and behaviour of aquifers, groundwater recharge, and aquifer vulnerability to pollution, impact of motorized abstraction on groundwater resources and conceptual model of groundwater dynamics. This information, though still scanty, forms the basis for the current groundwater resources planning and management in the country.

2.5 Applications of Electrical Resistivity in groundwater hydrology

The goal of geophysics is to determine properties and parameters of subsurface materials (usually rock or sometimes soils) from measurements made at the surface of the earth. A geophysical investigation often forms part of a larger study but has a large impact on the results and these are broadly classified into two groups;

i) Passive methods, which detect variations in the natural earth fields such as gravitational or magnetic, and
ii) Active methods, in which artificial signals are transmitted into the earth and subsequently recorded after passing through and being modified by earth materials (Reynolds, 1997).

A common limitation is the lack of sufficient contrast in earth properties (Burger, 1992). Still another limitation is resolution and noise. These methods are based on measurements and interpretations resulting from earth materials with different electric properties. The quantities measured are either conductivity which refers to the ability of a material to conduct current under an applied electric force, i.e., voltage) or resistivity which is a measure of resistance to current flow.

The most fundamental issue in undertaking a geophysical survey is detectability of the target which requires sufficient contrast in physical properties and suitable factors of scale, shape, and depth of the target (Greenhouse, 1998). The other factor that goes hand-in-hand with detectability is resolution. Detecting a target and resolving it are two different but complementary issues.

For this study, the Electrical Resistivity Method was undertaken using Geophysical investigations. Electrical methods generally fall into two categories:

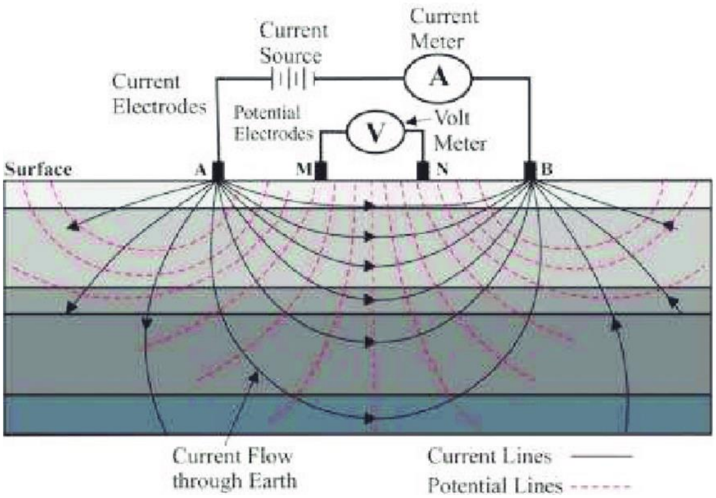
(i) Those in which current is applied to the earth and

(ii) Those using natural energy sources.

2.5.1 Applied electrical current methods.

For electrical resistivity (ER) methods, direct or low-frequency alternating current is applied at the ground surface and potential difference (voltage) is measured between two points using a geophysical equipment. For the raw data used for this study, an ABEM SAS 1000 was used during the field surveys.

When injecting a current from a point electrode into a homogeneous ground, the current flow outward in all directions forming equi-potential surfaces. The equipotential surfaces form half spheres in a homogeneous ground as illustrated in *Figure 4* below;



Schematic illustration of the basic measurements using electrical resistivity method (Modified after (Clark, 2011))

Figure 4: Schematic of electrical resistivity in a homogeneous ground.

The Injected electric current usually ranges from 1milli Amperes (1MA) to 2 Amperes(2A). A current lower than 10mA often produces noisy data and therefore, a resistivity imaging system is usually powered by a 12V battery to avoid lower current.

Similarly, the measured voltage ranges from sub milli-volts to 10 volts and therefore a measured voltage less than 0.1mV is often noisy, but marine data may be an exception due to its less noisy environment. Both positive and negative voltage values are acceptable.

Subsurface resistivity is a function of medium lithology, water content/saturation, porosity, pore fluid chemistry, temperature and many more underlying factors as illustrated in *Figure 5* below.

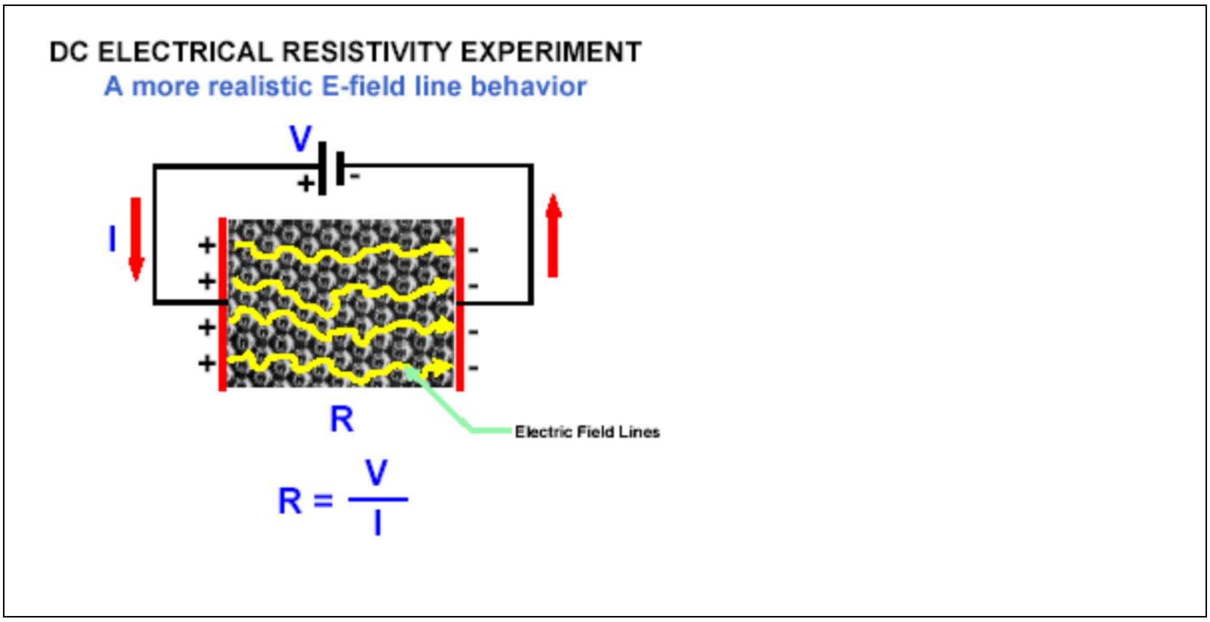


Figure 5: Shows behaviour of Electric field/sub surface resistivity.

The main relationship between the various properties is based on Ohms law as illustrated in the *Figure 6* below;

Electrical Units & Relationships:

Ohms law $R = \frac{V}{I}$ ohms

Conductivity is the reciprocal of resistivity $\sigma = \frac{1}{\rho}$

-Unit for resistance is Ohm
-Unit for resistivity is Ohmmeter
-Unit for conductivity is mho/m
1 Siemen (S) =1 mho

"Practically conductivity is expressed as millimhos/m = mS/m"

Apparent Resistivity

$$\rho = K\frac{\Delta V}{I}$$

ρ – Apparent resistivity (Ohm-m)
ΔV – Measured potential difference (V)
I – Injected electric current (A)
K – Geometric factor (m)

Geometric Factor – Surface Electrodes

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}}$$

$$K = \frac{4\pi}{\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN} + \frac{1}{A'M} - \frac{1}{A'N} - \frac{1}{B'M} + \frac{1}{B'N}}$$

- It is 4π full space instead of 2π half space
- A' is the mirror image of A
- B' is the mirror image of B

Arbitrary Electrode Location

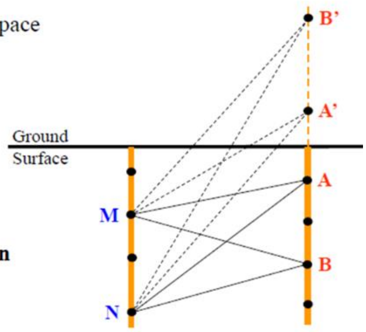


Figure 6: Electrical units and their relationships based on Ohms law

The other applied current methods are Induced polarization (IP) and Electromagnetic surveying (EM) which are based on measurements and interpretations resulting from earth materials with different electric properties.

When current is injected into the ground in an Electric Resistivity procedure using a pair of electrodes, the patterns of subsurface current flow reflect the resistivities of the subsurface which patterns can be inferred by measuring the variations in voltage at the surface using another pair of electrodes (Greenhouse, 1998).

Using the principle that the measured voltage or potential is proportional to the current density or else being equal, variations in current density (proportional to the spacing of current lines) near the surface will result in variations in apparent resistivity.

Apparent resistivity is a function of the measured potential difference, current injected into the surface, and the spacing's of the electrodes and is a weighted average of the resistivities under the four electrodes as illustrated in *Figure 7*. This apparent resistivity is dependent on the geometry of the electrode array, the true resistivity as well as other characteristics of the subsurface materials such as layer thickness and angle of dips (Zohdy, 1974).

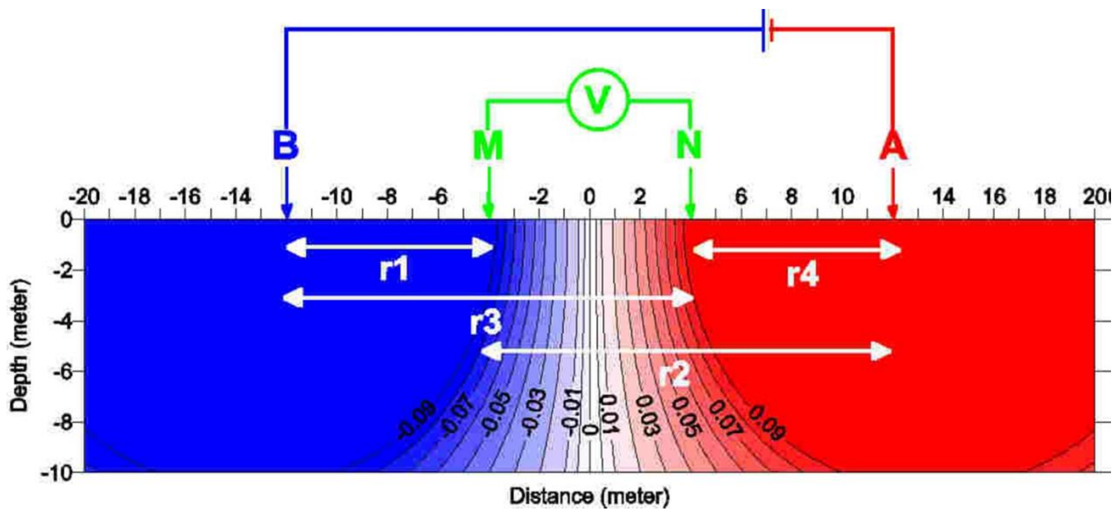


Figure 7: Variations of apparent resistivities with depth

Where the ground is homogenous, the apparent resistivity equals the true resistivity and the generalized formula for calculating Apparent Resistivity is based on the following relationship in *Equation 1* below;

$$\rho_a = \frac{2\pi\Delta V}{i}\left[\frac{1}{(\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4})}\right] \qquad \text{Equation 1}$$

Where; ρ_a= Apparent resistivity, ΔV= Change in voltage and r1, r2, r3 and r4 are resistivities

Also, to note is different rock types and soil exhibit different ranges of resistivity as shown in the *Table 1* below.

Table 1: Approximate resistivity ranges for various rock, mineral and water types in the basement complex area (Telford, 1976).

Rock type	**Resistivity (Ωm)**
Clay and marl	1-67
Top soil	67-100
Clayey soil	100-133
Sandy soil	670-1330
Limestone	67-1000
Lignite	9-200
Sandstone	33-6700
Sand and gravel	100-180
Schist	10-1,000
Granite	25-1,500
Basalt	10^3-10^6
Quartzite	10^2 – 2 x 10^8
Surface water (in igneous rock)	30 – 500

Sea water	0.20
Saline water 3 %	0.15
Saline water 20 %	0.05
Groundwater (in igneous rock)	30 – 150
Weathered laterite	200 – 500
Fresh laterite	500 – 600
Weathered/fractured basement rock	100 – 500
Fresh basement rock	>1,000

The electrode patterns used in resistivity surveying are called arrays with the commonly used arrays being the Wenner, Schlumberger, and dipole-dipole (Keller, 1966), (Yadav, 1988). The basic equipment consists of a current source (generator or battery pack), transmitter/receiver (which may be in a single module), wire, and current/potential electrodes (Greenhouse, 1998). In practice, low-frequency Alternating Current (AC) is injected into the ground rather than Direct Current (DC). Different types of arrays are illustrated in the *Figure 8* below;

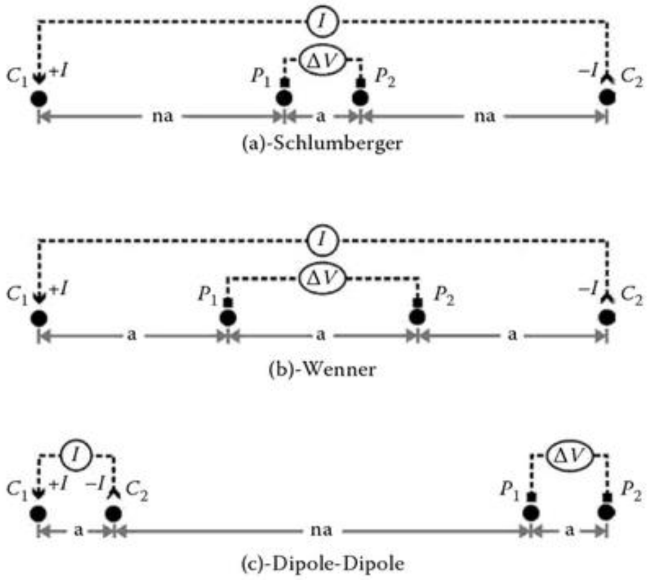


Figure 8: Arrangement and spacing current electrodes and potential electrodes for the three resistivity arrays commonly used (Barry, 2008)

Its best to keep the distance between potential electrodes as small as possible to avoid the effects of electrical potential noise resulting from naturally occurring electric elements (Dobrin, 1967) (Milsom, 2003)(Parasnis, 1986).

A summary of the various arrays and their effective use are outlined below after (Lokem, 2001) as follows;

a) If the survey is in a noisy area and a good vertical resolution is required with a limited survey then the Werner array will be the best option.
b) When a good horizontal resolution and data coverage is important with a resistivity meter sufficiently sensitive with a good ground contact, the dipole-dipole array will be the preferred choice.
c) If there is uncertainty whether both reasonably good horizontal and vertical resolution are required, the Wenner-Schlumberger array with overlapping data levels is the best option.

d) Survey with a system of a limited number of electrodes, the Pole-dipole array with measurements in both the forward and reverse directions might be a viable choice.

e) For surveys with small electrode spacing and where good horizontal coverage is required, the Pole-pole array might be a suitable choice.

Geologic control becomes critical in the interpretation phase when multiple geologic models can be found to fit the data. The next step is to decide the type of survey:

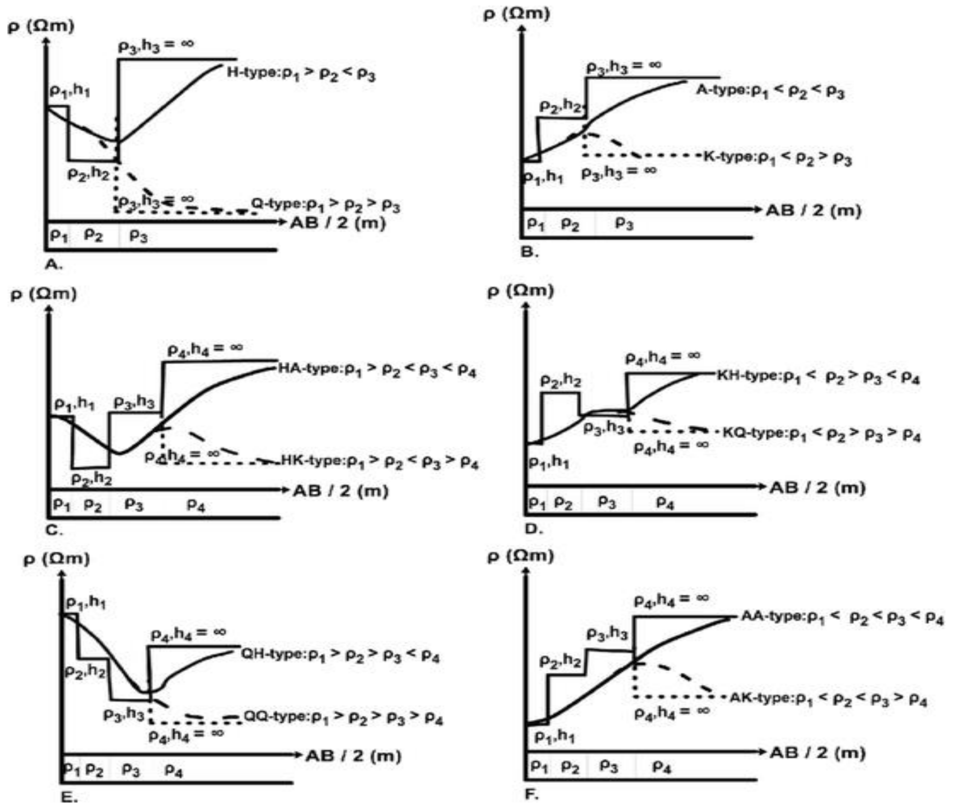
i) constant-spread (profiling)

ii) expanding-spread (sounding),

iii) a combination.

If the goal of the survey is to determine apparent resistivity information with depth, then two perpendicular soundings should be made to determine lateral variations in both directions (Burger, 1992). If the survey goal is to map lateral variations in resistivity, then a constant-spread survey or profiling is the correct choice. However, if multiple traverses are recorded and several electrode spacings are used at each location, then a contour map can be produced for each electrode spacing.

As a means of interpretation, Curve matching is a relatively straight forward approach to estimating the true resistivities of subsurface materials. *Figure 9* below illustrates the six types of resistivity curves that can be used for field apparent resistivities.



VES curve types. (a) H-and Q-type, (b) A-and K-type, (c) HA-and HK-type, (d) QH-and QQ-type, (e) KH-and KQ-type, (f) AA-and AK-type (after (Orellana, 1966) **and (Sunmonu, 2015)**

Figure 9: Showing the different types of resistivity curves.

This approach works best for the simple case of a single horizontal interface and expanding-spread traverse. The technique is a way to match field measurements of Apparent Resistivity and scaled electrode spacing to theoretical curves that have been calculated for various layer thicknesses and resistivities.

This study devised a means to improve on the former to decipher contrast and resolution in order to improve on the analysis and interpretation of the various resistivity signatures.

Groundwater potential varies across the country due to varying geological settings, recharge and precipitation. Due to inadequate data and tools for interpretation, knowledge on ground water is still limited. Investigation for ground water in Uganda is mainly by resistivity methods and is still not 100% accurate.

The lack of information on hydrogeological conditions, knowledge and groundwater potential of various areas across the country has hindered the development of groundwater sources, on which significant funds are spent by Government and Development Partners. This has led to significant financial losses due to development of unsuccessful water sources and implementation of expensive water supply technologies when cheaper and more sustainable alternatives are possible.

With rapid advances in software's and associated numerical modelling solutions, this knowledge gap can be filled. This study therefore developed an ideal formula which can be referred to in predicting yield in an area after rigorous analysis of the available secondary data with the main independent variables as lithology, number of water strikes and total depth especially during the planning phase of ground water-based supply projects.

Thus, there is need to thoroughly study and understand groundwater occurrence in the selected area in order to achieve the prime purpose of water supply based on groundwater resource.

2.6 Resistivity Curves and their Use in Groundwater Exploration

Application of the Electrical resistivity method in groundwater exploration by use of the Vertical Electrical Sounding (VES) technique is the most frequently used method due to its simple instrumentation that is easy to handle and its economical nature.

A number of studies have been undertaken by various researchers to predetermine the extent and nature of Aquifers using resistivity curves. Usually the resistivity of a water-bearing formation decreases as the quantity of water available increases (Olayinka, 1992).

A geophysical investigation was carried out in Oleh (Nigeria) to assess the groundwater condition of the area. The method employed in this study was the Vertical Electrical Sounding (VES) technique using the Schlumberger configuration. The data obtained were interpreted by computer iteration process and results when compared with lithologic log from existing borehole indicated a four-layered formation. Using the 1D VES surveys, only model layered structures of the subsurface in an effort to provide comprehensive information for interpreting the structure and extent of subsurface hydro-geological features (Anomohanran, 2011).

A study undertaken in Delta Central District of Nigeria to determine ground water potential and aquifer characteristics applied the electrical survey method, down hole logging and pump test data. Twenty VESes were performed and the geological data obtained interpreted with partial curve matching and computer iterations using RESIST software. The results showed the presence of four geoelectric layers (Anomohanran, 2011).

For a study in the central region of Cameroon in Bafia Sub Division, Fifty Schlumberger electrical soundings were undertaken in order to identify the vertical distribution of structures directly below the measurement stations. The field data were smoothened and interpreted using IP2WIN computer software to determine the depth and resistivity of the subsurface layers. The results from the interpretation of VES data revealed the presence of following terrains models' types: three layers (Q, A, H and K), four layers (KH, QH, AK and KQ) and five layers (KHK, HKH, KQH, and KHA) models. In addition, the relationship between discharge, hydraulic conductivity and transmissivity was used to determine zones with high yield potential for groundwater exploitation in the area (Enyegue, 2014).

Vertical Electrical Soundings were undertaken for 8 villages located in Kamuli District of Eastern Uganda and the results interpreted using Resound software models. The study enabled the interpretation of a relationship between the VES results and depth to competent rock. From the analysis of bed rock resistivities and borehole yields, the number of very low yielding and dry wells increased as the bedrock resistivities increased (Batte, 2008).

The primary advantage of vertical electrical sounding is that it is relatively easy to perform and provides good result when certain criteria for the survey are fulfilled. There are two critical limitations associated with VES. For the interpretation of the VES data to be accurate, the geological layers have to be horizontal, and each layer must have a consistent thickness across the surveyed area. In other words, the layers need to look like a layer cake. Of course, nature is not that exact in many instances. If the survey is on or beside a mountain range (or even a hill), the layers could be upturned or even flipped. They may even pinch out or expand at a certain point. At the same time each layer must be homogeneous in terms of resistivity yet, nature doesn’t always follow these rules. There could easily be caverns, boulders, or voids in the ground that interrupt homogeneity and create an issue with the VES resistivity solution. One final limitation of VES is that it is quite labour-intensive.

2.7 Summary of literature review

The researcher focused the literature review to the objectives of this study which looked at various research works providing empirical evidence on estimation of borehole yield, groundwater potential, geological layers and aquifer characteristics using electrical resistivity methods, vertical electrical sounding (VES) data in particular.

Some studies reviewed indicated a positive significant effect while other studies indicated a negative significant effect. Literature review further informed the extent of groundwater development in Uganda, applications of electrical resistivity in groundwater hydrology and various applied electrical current methods.

However, these studies were not in context of groundwater or yield estimation studies in Northern Uganda mainly Agago, Pader and Kitgum districts. Therefore, although the literature is insightful, it cannot be generic to development of characteristic regional groundwater yield curves in different geological settings Pader, Agago and Kitgum districts in Northern Uganda. Thus, this study intends to fill this gap.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology of the study that was conducted to establish main objective, respond to the research questions and prove the hypothesis. This chapter covered research design, study population, determinants of sample size, sampling techniques, and procedures, data collection methods, data collection instruments, validity and reliability, procedure of data collection, data analysis as well as measurement of variables.

(Patton, 1990) stated that the use of only one method is more vulnerable to errors linked to a particular method. Studies that use multiple methods in which different types of data provide cross-data validity checks minimise errors (Emmel, 2014). By implementing a proper desk study and use of existing or secondary data, resistivity profiling and sounding procedures, a site of high preference can be obtained.

3.2 Research Design

The study was cross sectional in nature and applied mainly quantitative approaches in data collection, qualitative approach being used for the issues that were not easily quantified (Mugenda, 1999) and a combination of numerical and written information was useful to enrich interpretation of the study findings.

3.3 Area of study

The study area is located in Northern Uganda, approximately 490kms from Kampala City. Kitgum, Pader and Agago districts particularly lie within UTM (WGS-84, 36N) coordinates that is; (a)(44180m E, 280295m N) (b) 441810m E, 418941m N) (c) 581058m E, 416456m N and (d) 581058m E, 280552m N).

Kitgum is located in Northern region, approximately 450 km, north of Kampala with an area of approximately 3,957 km^2 and a population of 248,600 (UBOS, 2022). 18 % of the district is classified as a protected area, comprising a Central Forest Reserve and a Hunting Area.

Agago District is located approximately 480 km north of Kampala with an area of approximately 3,495 km^2 and a population of 282,500 (UBOS, 2022). The topography of Agago District varies in elevation from a 975m amsl in the west of the district to 1,995m amsl in the east, where isolated hills rise abruptly from the surrounding area of gently sloping land. Over the remainder of the district, the elevation is below 1,100m amsl. The district lies within the Aswa catchment area and most of the district is drained by the River Agago that flows to the north-west into River Aswa.

Pader District is located approximately 430 km north of Kampala with an area of approximately 3,360 km^2 and a population of 223,900 (UBOS, 2022). The topography of Pader District shows ground levels varying between 725m amsl (in the north-west) and 1,100m amsl, rising sharply to a maximum elevation of over 1,400m along a north-south trending range of hills in the north-east of the district. The district lies entirely within the Aswa catchment. Achwa River flows north along the western district boundary. *Figure 10* below is of the map showing the location of the study area.

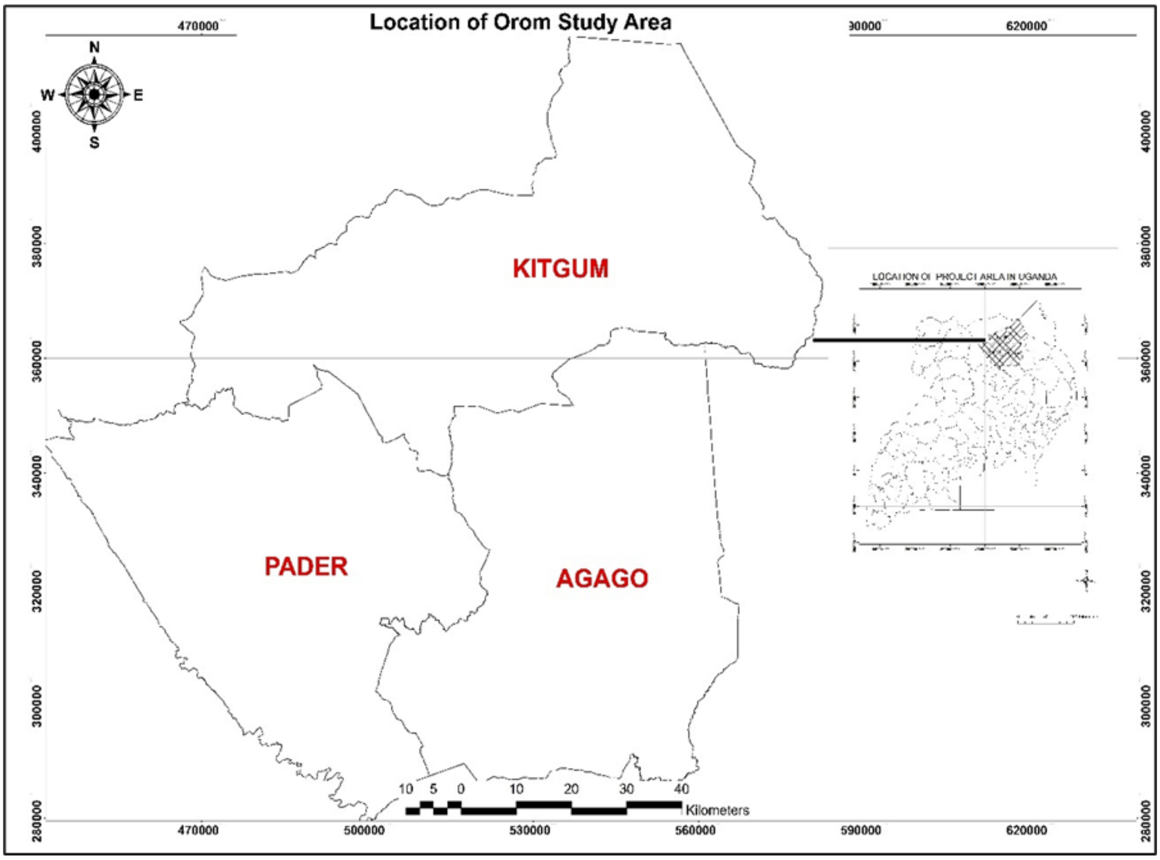


Figure 10 : A map showing location of the study area (Kitgum, Pader & Agago districts).

3.3.1 Topography and Drainage

3.3.1.1 Agago District

The topography of Agago varies in elevation from a low of 975m amsl to a high of 1,995m amsl. The high ground is found in the East of the district in the Sub-Counties of Parabongo, Paimol and Lapono, where isolated hills (termed inselbergs) rise abruptly from the surrounding area of gently sloping land. The highest points are Ogili (at 1,995m amsl), 20 km North-West of Kalongo Town; Parabongo (1,910m amsl), 5 km North-West of Kalongo and Napono Hill (1,957m amsl), 25 km South-East of Kalongo. Over the remainder of the district, the elevation is below 1100m amsl.

The district lies entirely within the Aswa catchment area and most of it is drained by the River Agago (*Figure 12*), which flows South-East to North-West across the southern half of the district into the River Aswa. A small area to the North of Kalongo drains Northwards into the River Pager.

3.3.1.2 Kitgum District

Ground levels across Kitgum are generally between about 870m amsl and 1,100m amsl with a few isolated hills rising abruptly from the surrounding area to elevations of around 1,500m amsl (*Figure 11*). Along the Eastern boundary with Kaabong District and within Nyapea Parish, the topography rises sharply to over 1,600m amsl forming a North West-South East trending range of hills known as the Nangeya Mountains, with peaks up to 2,380m amsl in Orom Parish.

Most of the district falls within the Aswa surface water catchment and its drainage is into the River Pager, which flows Westwards and eventually into the River Aswa on the border between Gulu and Pader Districts *(Figure 12*). The Northern parts of Kitgum (parishes Nyapea, Okuti, Akurumou and Northern parts of Kiteny fall into the Kidepo Catchment, which drains Northwards into South Sudan via the Rivers Lipan and Luyoro.

3.3.1.3 Pader District

Ground levels across Pader generally vary between 725m amsl and around 1,100m amsl, but rises sharply to a maximum elevation of over 1,400m amsl along a North-South-trending range of hills in the North East of the district (*Figure 11*). This range is approximately 12 km long and passes through the parishes of Ngekidi and Palenga.

The lowest ground levels can be found in the North-West of the district along the course of the River Pager.

The district lies entirely within the Aswa surface water catchment. The River Achwa flows from South to North along the Western boundary of the district. The southern half of the district is largely drained by tributaries of the River Agago, which flows from East to West into the River Achwa to the South East of Cwero. The northern half of the district is drained by tributaries of the River Pager, which flows from East to West along the northern boundary of the district and into the River Achwa just East of Palaro. *Figure 11* below shows ground elevation of the project area indicating the high and low elevations.

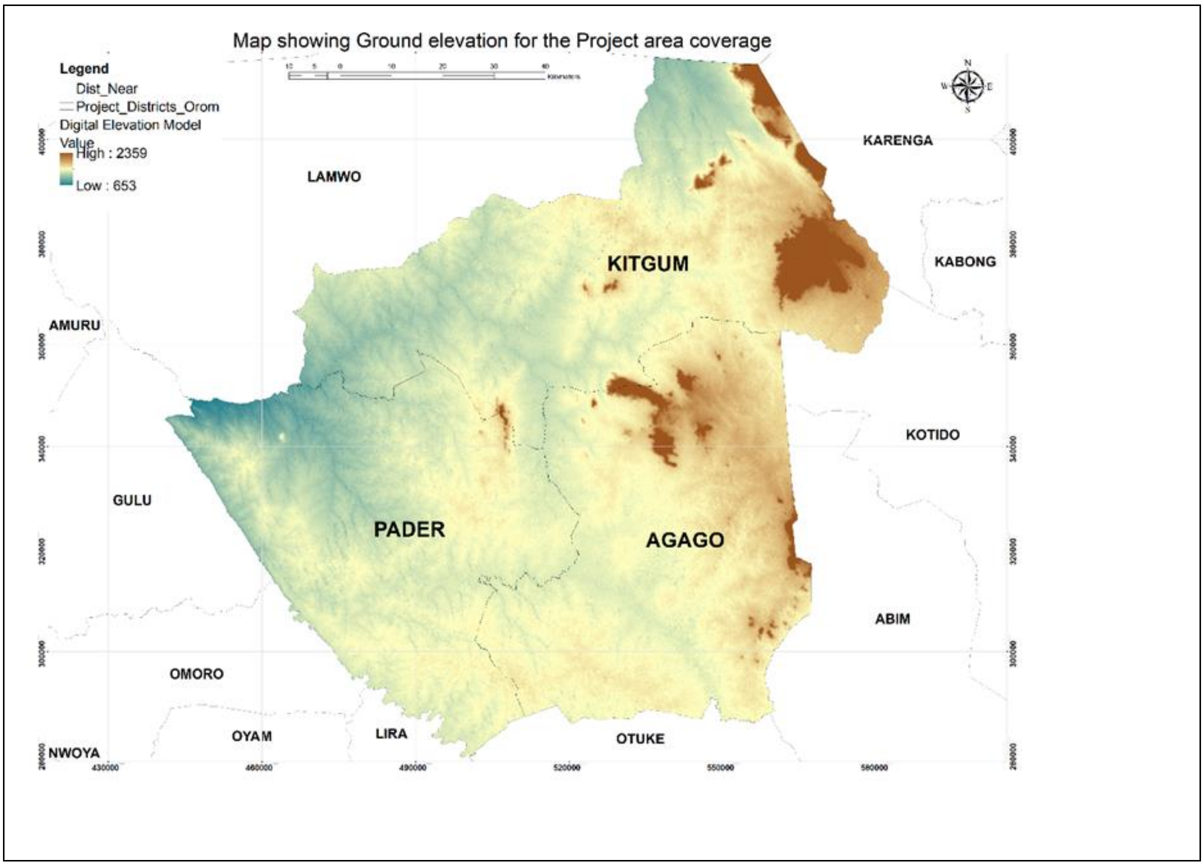


Figure 11: Prepared ground elevation map for the study area, covering through districts of Agago, Pader and Kitgum with elevation varying from as low as 653m amsl to 2,359m amsl.

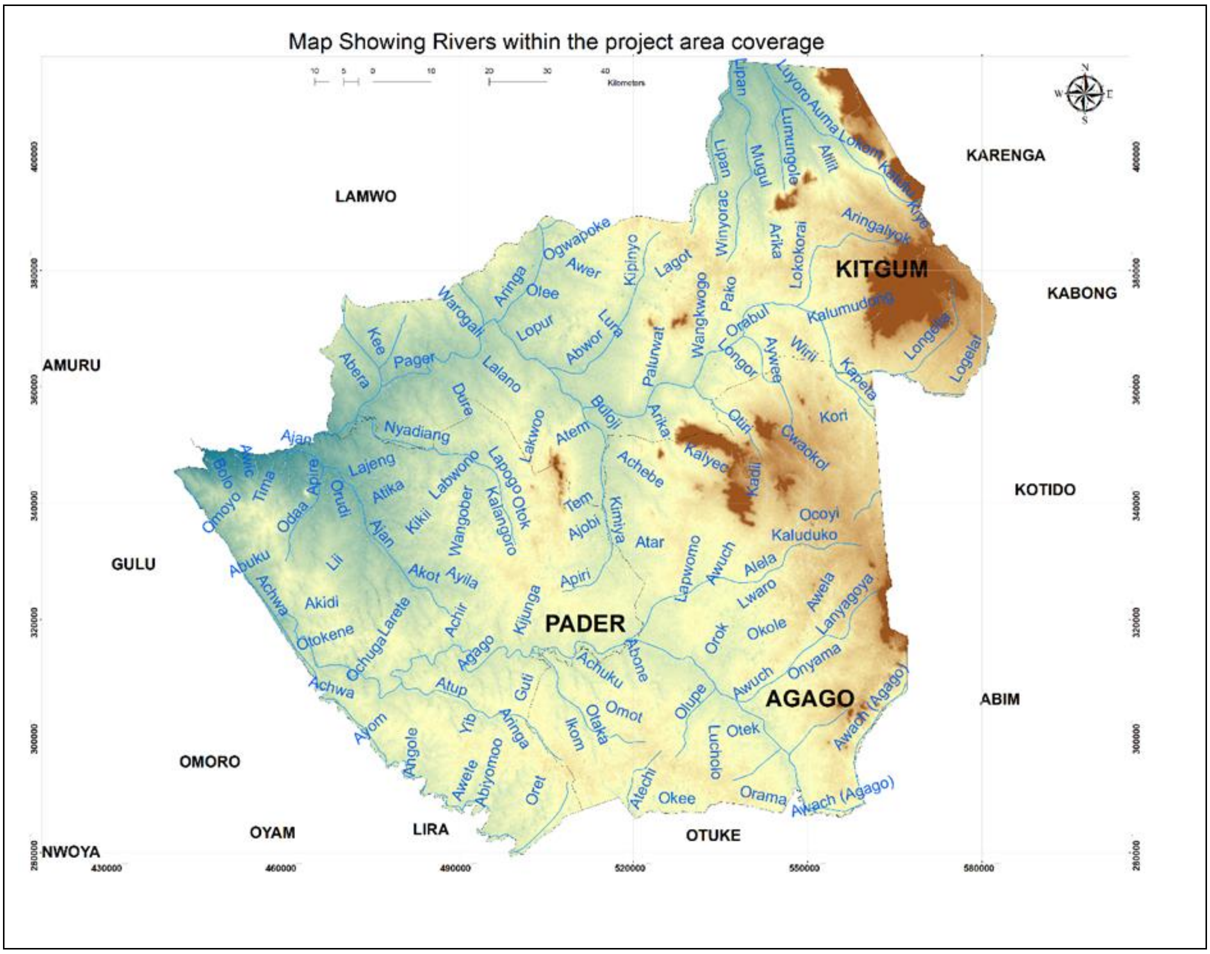


Figure 12: Drainage patterns within Agago, Pader and Kitgum Districts.

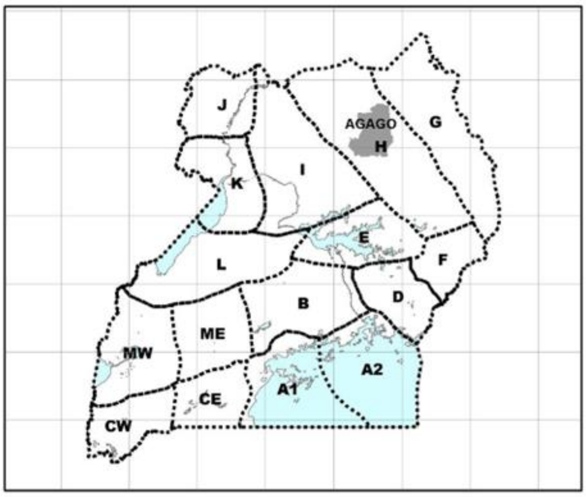
3.3.2 Rainfall

3.3.2.1 Agago District

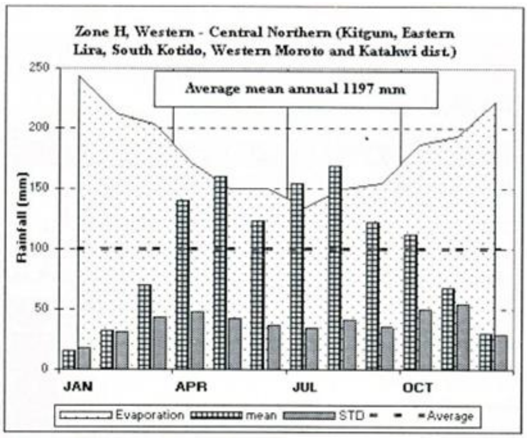
The climatic conditions in Agago have been described based on a Hydroclimatic study undertaken by (DWRM, 2007, unpublished report). The study was based on 14 climatological zones defined by (Basalirwa, 1999) using an analysis of monthly rainfall records at 102 rain gauges for the period 1940-75. The DWRM study subdivided three zones (C, M and A) to give a total of 17 climatological zones.

Agago lies in a Zone a with an average annual rainfall of 1,197 mm as shown in(*Figure 13*). Average rainfall varies from 1,000 mm in the North and North-East to

1,300 mm over the West and South. There is a single rainy season from April to October with the main peak rainfall occurring in July and August and a secondary peak in May. The single dry season lasts from mid-November to late March. Evaporation significantly exceeds rainfall in the dry season by a factor of 10 from December to February and slightly exceeds rainfall during the peak of the rainy season, May, July and August.



(a) Agago lies in Uganda Rainfall zone H

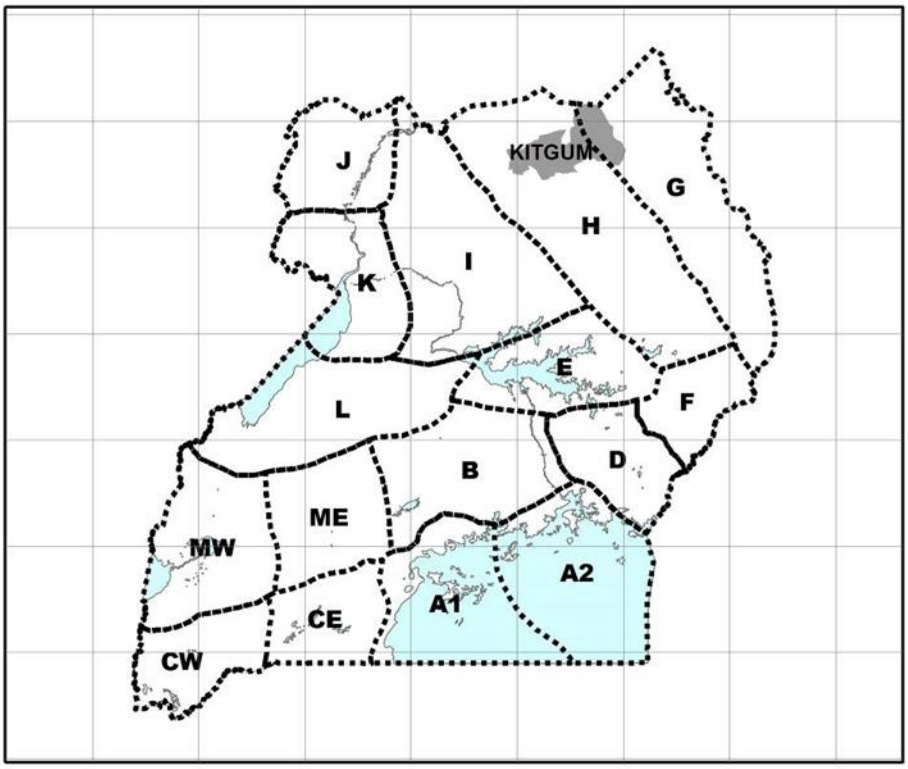


(a) Long-term average rainfall for Zone H (Source: (DRWM, 2012)

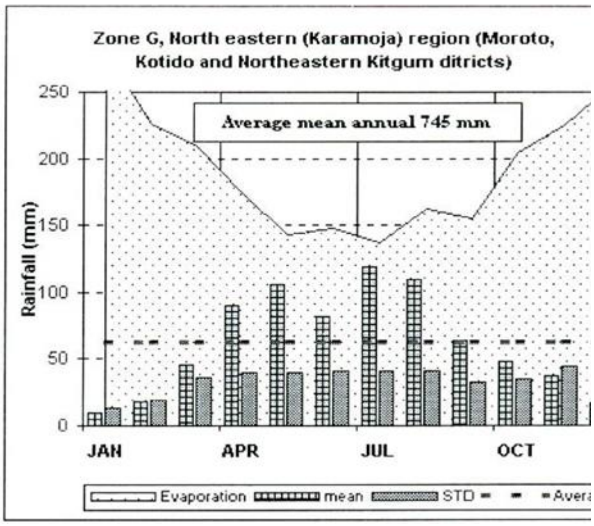
Figure 13: Uganda Rainfall zones and long-term average rainfall for Agago district

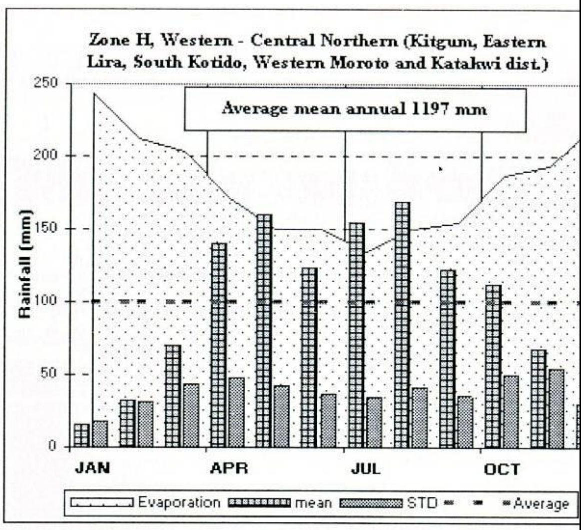
3.3.2.2 Kitgum District

Kitgum lies across two Climatological Zones, H and G (in the West, respectively East) as illustrated in *Figure 14.* It receives an estimated average annual rainfall in the zones is 1,197 mm and 745 mm respectively. However, the northern parts are much drier than the South. A single rainy season, from April to late October and from April to early September do occur. The main rainfall peak is in July/August with a secondary peak in May. The single dry season lasts from November to late March and from October to March. In the driest months, evaporation exceeds rainfall by a factor of 10, while in the rainy season evaporation only slightly exceeds rainfall.



(b) Kitgum lies in Uganda Rainfall zones H & G

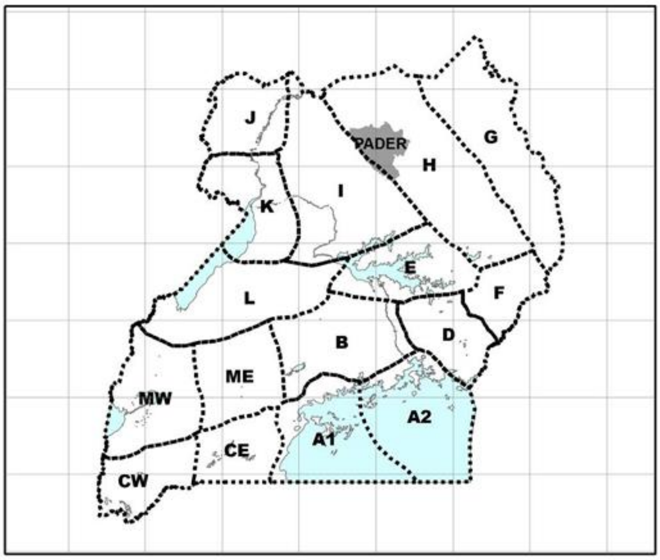




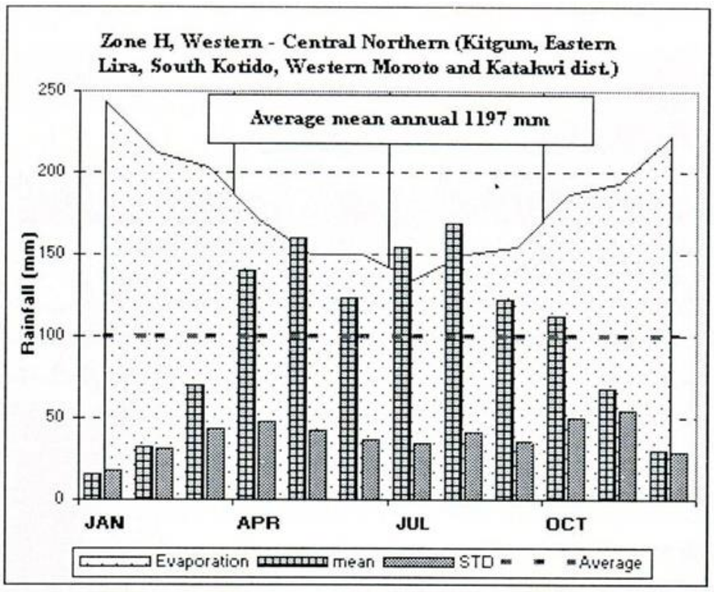
(b) Long-term average rainfall for Zones G and H. (Source: (DRWM, 2012))

Figure 14: Uganda Rainfall zones and long-term average rainfall for Kitgum district

Pader similarly lies in climatological zone H and receives an average annual rainfall of 1,197 mm with descriptions of the zone in *(Figure 15).* Average rainfall varies from 1,000 mm in the North and North-East to 1,300 mm over the West and South. There is a single rainy season from April to October with the main peak rainfall occurring in July and August and a secondary peak in May. The single dry season lasts from mid-November to late March. Evaporation significantly exceeds rainfall in the dry season by a factor of 10 from December to February and slightly exceeds rainfall during the peak of the rainy season, May, July and August.



(c) Pader lies Uganda Rainfall zone H



(c) Long-term average rainfall for Zone H (Source: (DRWM, 2012))

Figure 15: Uganda Rainfall zones and long-term average rainfall for Pader district

3.3.4 Geology of the study area

The Geology of Uganda is dominated by Archean also known as the 'Basement Complex' and Proterozoic rock system which underlie more than two thirds of the country in the Northern and Central regions (BjØrlykke, 1975), (Schlüter, 1997) as shown in *Figure 16* below showing different geological formations of Uganda.

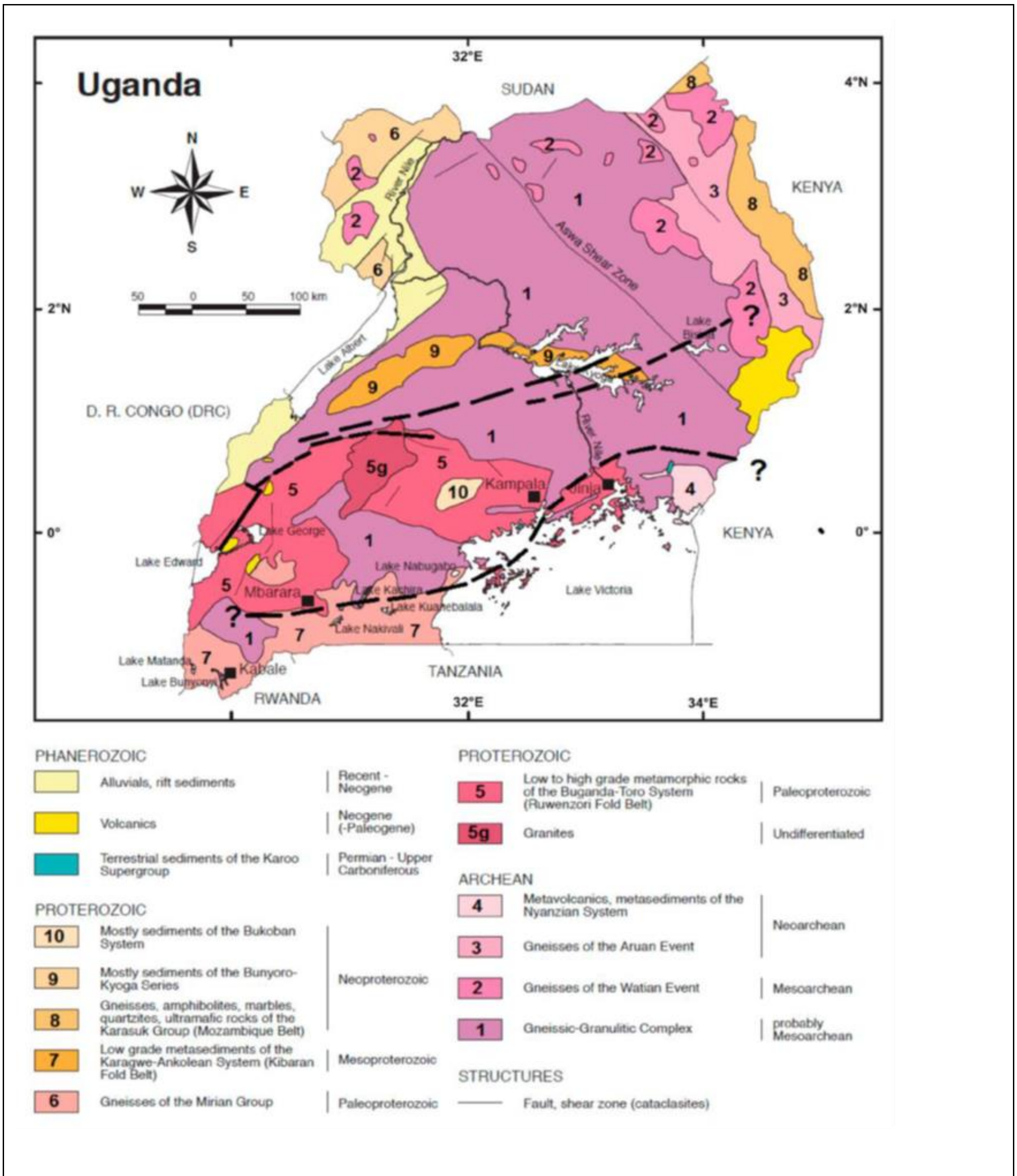


Figure 16: Major geological formations of Uganda based on Geological Survey and Mines Department (2017).

The study area is approximately 60% underlain by crystalline rocks, formerly attributed to the Archaean 'Basement Complex', except the granitoids and greenstones of the Lake Victoria Terrane, which had been attributed to the Tanzania Craton and so-called 'Watian' granulites, charnockites and 'Aruan' rocks (Hepworth, 1966), (MacDonald, 1964b), (Macdonald R. , 1964a).However, for purpose of this research, focus was on the geology of the study area as shown in <u>*Figure 17*</u> below and explained in details further;

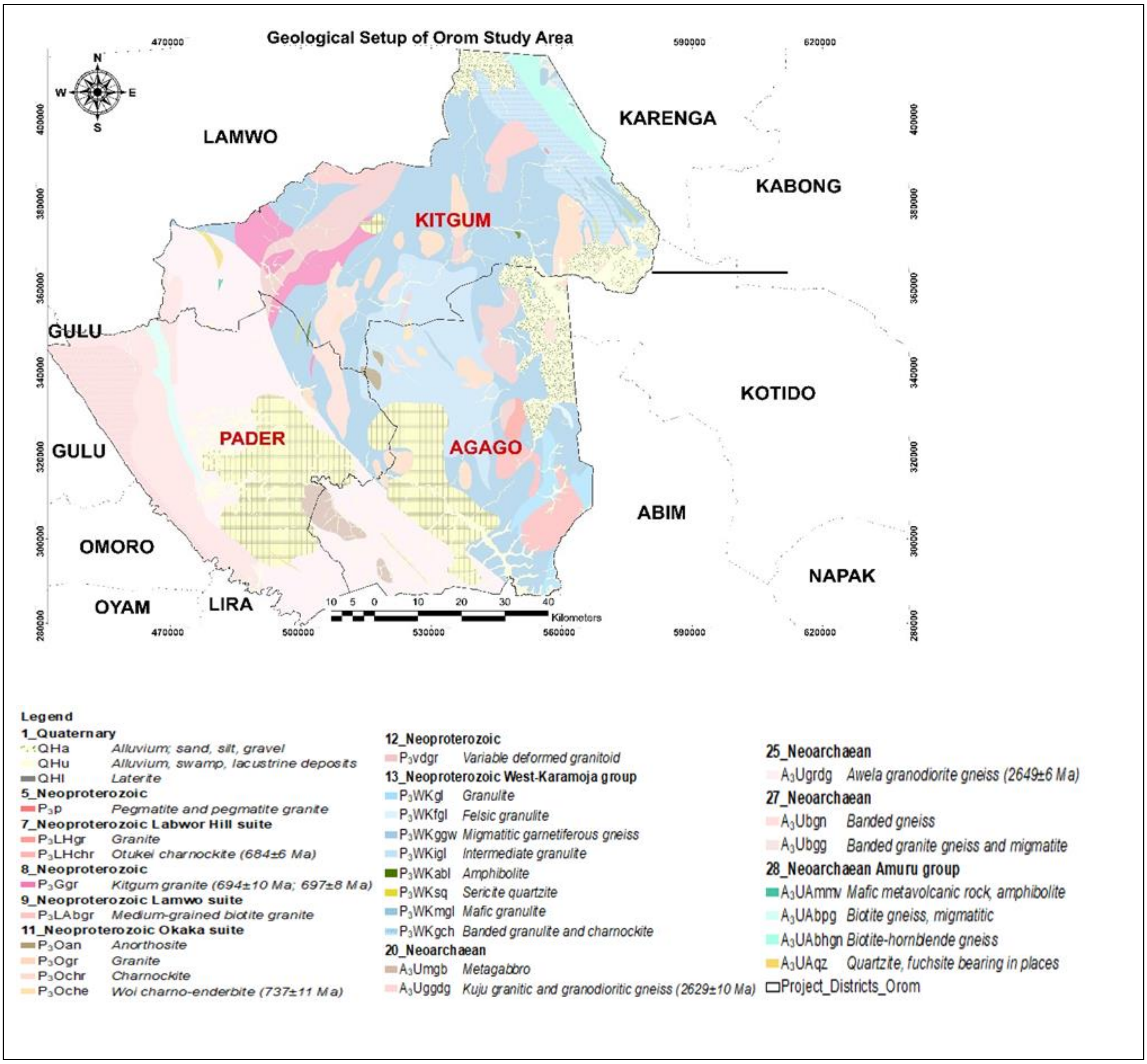


Figure 17:ARCGIS generated lithology or geological units in Pader, Kitgum and Pader(from the Geology Map of Uganda).

The many geological units within the study area further explain and confirm the complexity of geology of Uganda and these are described below and *Figure 18* showing the distribution of drilled wells yields in the different lithological formations across the study area.

3.3.4.1 Sericite quartzite (P3WKsq)

NE-trending quartzitic schists of the Lakwor formation, observed in the eastern sector of the Kitgum map sheet area which continues into the Kaabong area. They comprise narrow (<50 m), impure, intensively schistose and banded quartzitic rocks that show gentle to moderate dips towards the East. Their association with supracrustal amphibolites with a similar tectonic fabric suggests a sedimentary origin.

3.3.4.2 Amphibolite (P3WKab)

Small flat outcrops of concordant, banded and dark, fine- to medium grained amphibolitic rock of the Lakwor formation occur 10 km South of the Kitgum-Matidi and 10km East of the Nam-Okora trade center.

3.3.4.3 Migmatitic garnetiferous gneiss (P3WKggw)

The migmatitic gneisses of the Orom formation mostly occur in flat, scarce outcrops in large areas in the Kitgum, Patongo and Kotido Districts. In the study area, they occur to the East of Madi Opei trading Centre, and is underlain by supracrustals, mainly comprising migmatitic garnetiferous gneisses. This assemblage of paragneisses reflects deposition in slightly different sedimentary environments.

3.3.4.4 Quartzite, fuchsite-bearing in places (A3UAqz)

Despite strong deformation, quartzites in the Kinaga formation generally show an obscure banding, interpreted as sedimentary bedding. The yellowish brown, fine-grained quartzite forms low ridges, e.g. parallel to the Aswa Shear Zone in the central sector of the Northern Uganda Terrane, where strongly foliated and jointed, pure, steeply west-dipping quartzite is over 250 m thick. Micaceous quartzite is further exposed in a number of aggregate quarries about 6 km NW of Kitgum town.

3.3.4.5 Mafic metavolcanic rock, amphibolites (A3UAmmv)

These occur as a long, elongated or curvilinear belt, in the central part of the Kitgum-Gulu area. The main lithological units, are the quartz dioritic gneiss, banded TTG gneiss and garnetiferous amphibolites.

3.4.4.6 Awela granodiorite gneiss (A3Ugrdg)

The Awela granodiorite gneiss covers extensive areas in the central and northern segment of the Northern Uganda Terrane, mostly east of the Aswa Shear Zone, although partly overlapping with it and NW–SE-trending zone reaching from the Kitgum and Gulu areas in the NW to the Aloi area in the SE. Awela granodiorite gneiss east of the Aswa Shear Zone shows that the degree of metamorphic differentiation decreases away from this major dislocation. Strongly banded and differentiated gneiss can, however, be found throughout the large granodiorite gneiss.

3.4.4.7 Migmatitic garnetiferous gneiss (P3WKggw)

The migmatitic gneisses of the Orom Formation mostly occur in flat, scarce outcrops in large areas in the Kitgum, Patongo and Kotido Districts.In the study area, specifically occurring 25 km east of Madi Opei trade Centre, and is underlain by supracrustals, mainly comprising migmatitic garnetiferous gneisses.

3.3.4.8 Variable deformed granitoids (P3vdgr)

The best exposures of these rocks can be found NE of Kalongo village, where they form large hills and ridges up to tens of metres high.

3.3.4.9 Charnockite (P3Ochr)

Charnockitic rocks of the Okaka Suite are well exposed in hills and ridges, the largest being the 30 km long, N-S-trending Okaka mountain range north of Pader town. Although charnockites are the dominant rock type, some granitic sub-types free of orthopyroxene, have also been encountered.

3.3.4.10 Banded granulite and charnockite (P3WKgch)

Banded granulites and charnockites of the Napararo Formation occur in in the study area (Williams, 1966).

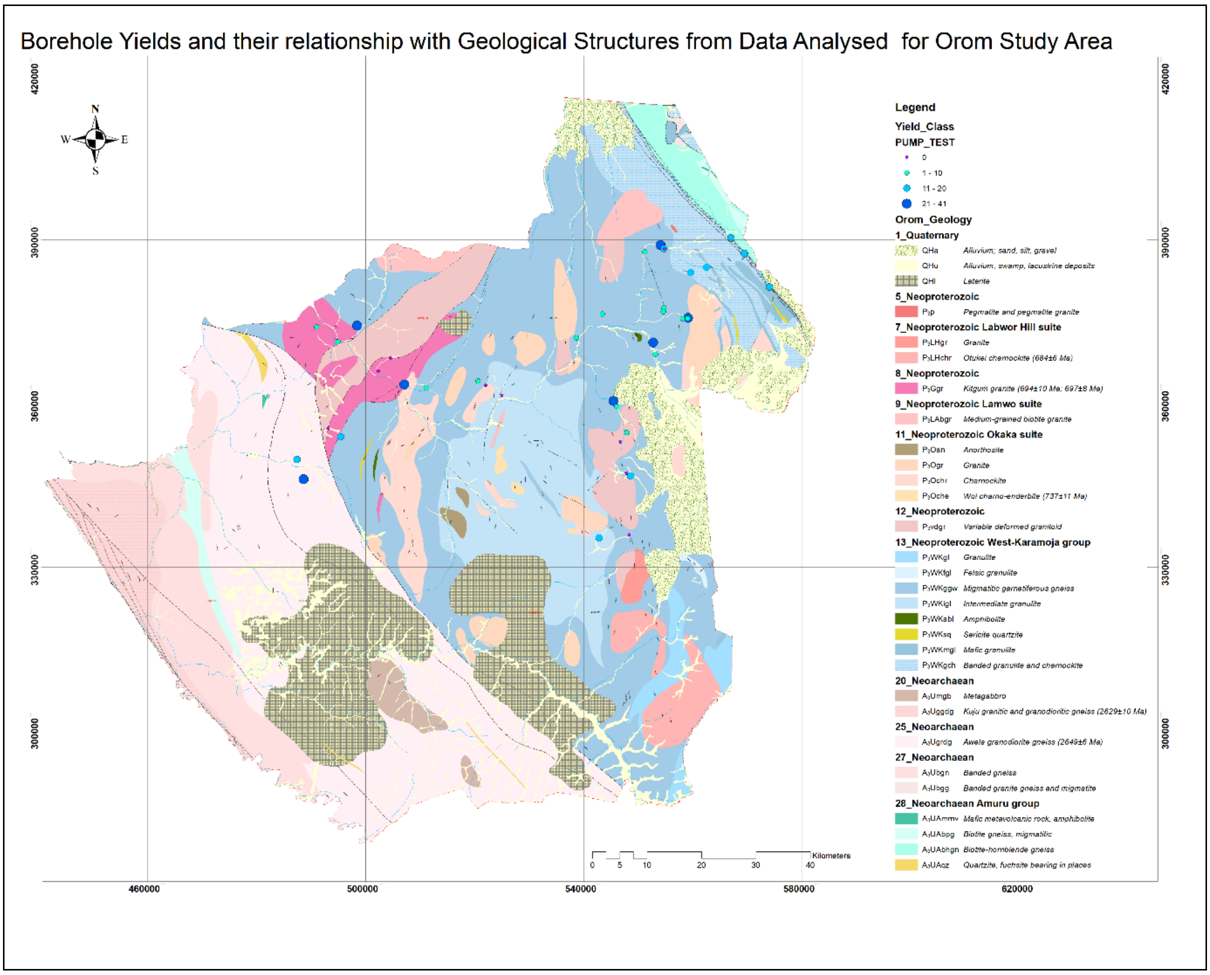


Figure 18: Overlay of deep borehole yields and locations on the geological map of Pader, Agago and Kitgum Districts.

3.3.5 Hydrogeology and Soils of the study area

3.3.5.1 Kitgum

District Groundwater Reports, Hydrocensus data and previous map products enabled a generalized understanding of the Hydrogeology in the study area.

Most of Kitgum district falls within the Aswa surface water catchment which drains westwards with the northern parts of district falling into the Kidepo Catchment, which drains northwards into South Sudan. Precambrian basement rocks underlying the entire district comprise of mainly undifferentiated gneisses. Granulite facies rocks and banded gneiss cover about 13.4 % of the district area while Pleistocene to Recent sediments overlie in over 18.0 % of the district Precambrian rocks.

The depth to bedrock greater than 25m in extensive areas, with the deepest (> 40 m) in the East and Southern parts of the district and it ranges from 0.1 to 94.0 mbgl with an average of 28.5 mbgl. An overburden thickness of 0 to 25 metres are found scattered in some small areas over the district. Kitgum lies within the zone of active stripping therefore aquifers present within the weathered zone may be of limited lateral extent. Only in the North of the district is within the zone of deep weathering.

Deep boreholes (i.e. > 30 metres deep) may be used in extensive areas of Kitgum, especially in the western part of the district. Shallow boreholes (< 15 m deep) may also be constructed in a few places in the district especially near the river valleys. The district has no potential for springs.

The Overburden thickness throughout the district generally greater than 15m, with the deepest (> 40 m) in the eastern region. The areas located North generally have an overburden thickness of 0 – 15 metres while other parts of the District have an overburden thickness of 15 – 25 metres. The Central and western areas have overburden thickness ranging between 25 and 40 mbgl.

The FWS groundwater levels in most areas in the east, centre and some parts in the south exceed 40 mbgl. In the west, areas with FWSs are found between 25 and 30 mbgl. In almost 95 % of the district, the MWS levels exceed 40 mbgl. A few small areas scattered over the district show MWSs ranging between 30 and 40 mbgl. The SWL levels in Kitgum district in extensive areas in western and southern regions range between 15 and 30 mbgl. Areas in the centre and east SWL exceed 40 mbgl. Small areas in the north and west have SWLs of less than 15 m.

Generally, Kitgum District has good quality water (below Guide Line and Maximum Acceptable Values for Total Iron, Total Hardness, Sulphate and Total Dissolved Solids (TDS)), except in parts of Namokora Sub-county in the centre of the district and some small areas in the west (Kitgum T/C), where water quality is poor due high total Iron values exceeding the MAV. In Labongo-Amida Sub-county (south-west) the water quality is marginal (between GV and MAV).

Groundwater potential in most of the District is considered good (Success rates between 50 to 75 % and yield > 0.5 m^3/h). The south-west of the District has very good groundwater potential with success rates greater than 75 % and yields > 0.5 m^3/hr. Areas with poor groundwater quality, are considered as having a poor groundwater potential.

3.3.5.2 Pader District

Pader District is underlain by Undifferentiated Gneisses and Granulitic Facies Rocks (95 % of the district area); Granulite facies rocks and associated rocks (mainly in the north-west). Cataclasites are found in the Aswa Shear Zone (western district border). Pleistocene to Recent Sediments (alluvium and black soils) are distributed along Agago river valley, running east - west in the district centre.

The Depth to bedrock ranges from 1.5 metres below ground level (mbgl) to 78 mbgl, with an average depth to bedrock is 30.3 mbgl. With some exisitng wells intersecting the top of the bedrock at depths of less than 15 m, this suggests that shallow hand dug wells do not have much potential, although potential for shallow borehole technology may exist.

The most viable water supply option in the district is the deep borehole for about 60 % of the district. Shallow wells (< 15 metres depth) are restricted to areas in the South and North-West about 5 % of the district area.

Generally, the overburden thickness throughout the district is deeper than 15 m, with the deepest (> 40 m) in the east and south-west; 15 – 25 metres in the north-west, west and in various other, smaller areas.

FWS groundwater levels in extensive areas in the north-west, north-east and south-east exceed 30 mbgl. While SWL levels ranging from 15 - 30 mbgl are found in the centre and north-west.

In a large part of the district, the MWS levels exceed 30 mbgl. MWSs of 15 - 30 m are found in the centre, east and in small areas in the south. In the western half and south of the district, the SWL levels are less than 10 m.

The district generally has good quality water (below maximum acceptable values), except in a few pockets here and there with Total Iron values above the maximum acceptable values. The areas with poor water quality mainly occur in the north, west and south.

The largest part of the district has good groundwater potential of > 75 per cent (> 0.5 m^3/hr) and good water quality. Well yields of over 1.0 m^3/hr are found all over the district. In some parts of the centre and north, the groundwater potential is moderate because of a high proportion of failed boreholes (success rates of 50 to 75 %: yield > 0.5 m^3/hr).

3.3.5.3 Agago District

Geological formations in Agago district are comprised of mainly; Basement Complex rocks (Undifferentiated gneisses and Granulitic facies rocks in 67 % of the district area); Granulite facies rocks and associated rocks (mainly in the south-east – 11 %) and Banded gneisses. In about 22 % of the district, the Precambrian strata are overlain by sediments of Pleistocene to Recent age.

The Depth to bedrock ranges from 3.0 metres below ground level (mbgl) to 70 mbgl, with an average depth to bedrock is 30.3 mbgl. 70 % of the district area represents a deep aquifer zone (> 30 m depth), 5 - 25 % is shallow aquifer zone (i.e. 15 – 30 metres depth). In the north, the west and the south some areas are found with Depth to Bedrock over 40m. The central part of the district has thicknesses of 30 to 40 m, however, most of the District overburden thicknesses are within the range of 10 to 25 m.

The FWS and MWS range between 15 to over 40 mbgl with Shallow FWSs (15 – 25 m) occurring mostly in the East, North-West and South-West. Areas with MWS greater than 40 m are mainly found in the north, the centre and the south. SWLs are generally less than 10 m in an extensive area in the south-west and in the east. For areas in the north, north-west, west, centre and south-east, the SWL mainly ranges between 15 and 30m. In a few small areas, the SWL exceeds 40 mbgl. In general, the water quality in Agago District is good.

General information about soils in the study area.

FAO (Food and Agriculture Organization of the United Nations) provides guidelines for soil description that help users to collect and record reliable soil data in the field. The guidelines cover aspects of soil description including; (i)Registration information (observation number, author, date, description status), (ii) Location information (coordinates, elevation), (iii) Soil forming factors (climate, landform, parent material, land use/cover, vegetation, landscape age and history), (iv) Soil profile description (boundaries, horizons, layers, surface characteristics), (v) Soil horizon description (color, mottling, texture, coarse fragments, structure, consistency, stickiness, plasticity, porosity, cementation, nodules, roots, biological activity, organic matter content, carbonates, gypsum, soluble salts and pH) and (vi) Soil classification (using the World Reference Base for Soil Resources)

The FAO also provides a soil map of the world that shows the distribution of different soil types according to the FAO–UNESCO Legend for the Soil Map of the World. The soils in Pader, Agago and Kitgum districts as shown in Figure 17 below, belong to the following soil units:

Eutric Regosols: Regosols are soils that have little profile development and are characterized by a lack of horizons. They are usually found in areas with low rainfall and high temperatures. The infiltration rate of regosols is generally high due to their coarse texture and low organic matter content. The recharge of groundwater is influenced by the infiltration rate of the soil. The higher the infiltration rate, the higher the recharge rate. The flow of groundwater is also influenced by the soil type and structure. Regosols have a low water-holding capacity and therefore do not retain water for long periods of time. Boreholes located within this Red sandy clay over laterite (often eroded) exhibited high yields ranging from 6 cubic meters per hour to 40 cubic meters per hour.

Gleyic Arenosols: Arenosols are soils that are dominated by sand and have little profile development. They are usually found in arid and semi-arid regions. The infiltration rate of Arenosols is generally high due to their coarse texture and low organic matter content. Arenosols have a low water-holding capacity and therefore do not retain water for long periods of time. Gleysols are soils with signs of waterlogging and reduction. They are found in wetlands and poorly drained areas. Gleysols are formed under waterlogged conditions produced by rising groundwater. Groundwater gleysoils develop where drainage is poor because the water table (phreatic surface) is high.

Leptosols: Leptosols are soils that are shallow and have little profile development. They are usually found in steep areas and have a high rock content. The infiltration rate of leptosols is generally low due to their shallow depth and high rock content. The flow of groundwater is also influenced by the soil type and structure. Leptosols have a low water-holding capacity and therefore do not retain water for long periods of time thus influenced low yields encountered in some areas.

Plinthosols: Plinthosols are soils that are characterized by a subsurface layer containing an iron-rich mixture of clay minerals and silica that hardens on exposure into ironstone concretions known as plinthite. The infiltration rate of Plinthosols is generally low due to the presence of plinthite. Plinthosols have a low water-holding capacity and therefore do not retain water for long periods of time. Boreholes located within these Shallow grey, brown sandy loams over laterite exhibited the lowest Yields.

Vertisols: Vertisols are cracking clayey, arable soils that often overlay groundwater reservoirs. The soil cracks enable flow that bypasses soil blocks, which results in both relatively fresh recharge of the underlying groundwater and contamination with reactive contaminants. The infiltration rate of Vertisols is generally high due to the presence of cracks. Vertisols have a high water-holding capacity and therefore retain water for long periods of time. Boreholes located within these Grey clays and occasionally sandy clays yielded highly ranging from 6 cubic meters per hour to 40cubic meters per hour.

Lithic Ferralsols: These are soils that are rich in iron and aluminum oxides. They have a low infiltration rate due to their high clay content and low porosity. Boreholes located within these Brown loams, that were sometimes lateralized yielded from 6 cubic meters per hour to 41 cubic meters per hour. The high yields within these soils could be attributed to Structure (Sinistral strike-slip fault zone Aswa and Auma) that enhanced recharge within this area.

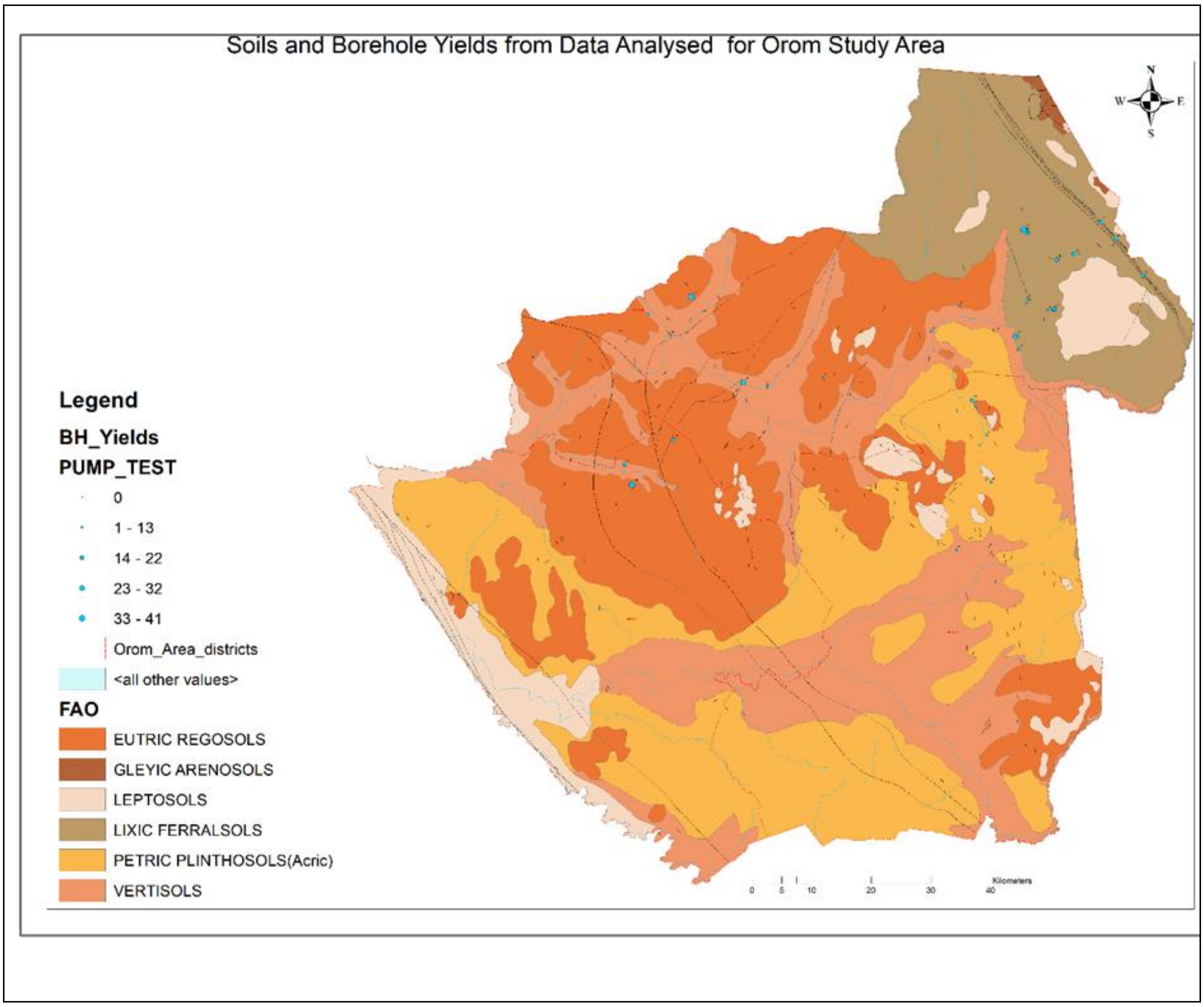


Figure 19: ARCGIS developed Soil map based on FAO Soil classifications within the study area (Agago, Pader and Kitgum).

3.4 Determination of the Sample size

Geophysical methods are increasingly being used for subsurface characterization since they offer the potential to derive basic characteristics, state variables and properties of the geological formations(Vereecken, 2005). The Vertical Electrical Sounding(VES) has proved very popular with groundwater prospecting due to the simplicity of the technique.

A lot of secondary data gaps do exist in the availabe hydrocensus data sets and the level of the accuracy of the existing data sets from previous drilling programs specifically didnt target high yielding wells. A controlled drilling program aimed at providing production well sites for forty drilling points was specifically targeted for this study. The sample size selected was representative of the existing conditions of the region, since the drilling sites are located in different hydrogeological environments.The selected districts (Agago, Kitgum and Pader) for this study located in Northern Uganda for some time have been classified as low to medium ground water potential areas.

Furthermore, the sample size was determined based on (Amin, 2005) and (Krejcie, 1970). Emphasis was put on identifying potential sites within the study area that were indicative of the most reliable data collection procedures in due consideration of accessibility to data. Basing on (Krejcie, 1970) who came up with a table for determining sample size for a given data set, that would be easier to reference, three (03) raw data (Vertical Electrical soundings (VESes) per site and One (01) drilling attempt were selected. Table 2 below shows the sample size used by the researcher.

Table 2: Sample size determination

Category (Lithology)	Population (Raw Data VESes)	Sample (Drilled VES)	Sample Technique
Alluvium swamp lascustrine deposits	3	1	Clustered
Awela granodiorite gneiss	6	2	Clustered

Banded Granulite & Charnockite	15	5	Clustered
Intermediate granulite Sediments	3	1	Clustered
Kitgum granite	9	3	Clustered
Mafic granulite	3	1	Clustered
Migmatic garnetiferous gnesis	69	23	Clustered
Variable deformed granitoid	12	4	Clustered

Source: Sample adopted using (Krejcie, 1970) table.

3.5 Data collection methods and Tools

This research started with a thorough desk study of the Orom water supply water project for mainly Agago, Pader and Kitgum districts. This provided detailed information on the geology, groundwater conditions, the aquifer system and the selection criteria of sites for the running of the electrical resistivity survey leading to drilling.

Selection of geophysical data from a well supervised drilling programme was undertaken through identification and characterisation well yields of forty Selected drilled wells in Acholi Sub-Region particularly Agago, Pader and Kitgum Districts in order to analyse geological and hydrogeological conditions as well as developing the characteristic regional groundwater yield curves. Analysis of Geological and Hydrogeological conditions for groundwater exploration in the study area using geophysical data, Satellite images, Topographic maps incuding drainage data and recent geological maps, hydrocensus data, lithological data, test pumping data were used to further characterise the existing groundwater conditions, and some of these are presented in form of maps at appropriate scale within the confines of the targeted area.

Vertical Electrical Soundings (secondary data - VESes) for each of the forty wells drilled in Agago, Pader and Kitgum Districts have been selected based on availability of supervised drilling data(lithological logs and testpumping data) from the onsite supervisor and drilling contractors.

3.5.1 Satellite Data

Satellite Remote Sensing processed data has been used to enable observation and systematic analysis of geomorphic units, lineament features using overlay analysis and Geographic information system (Arc GIS 10.2) in order to analyse Groundwater Conditions and possible flow direction and *Figure 20* below shows distribution of wells on the prepared satellite map of the study area.

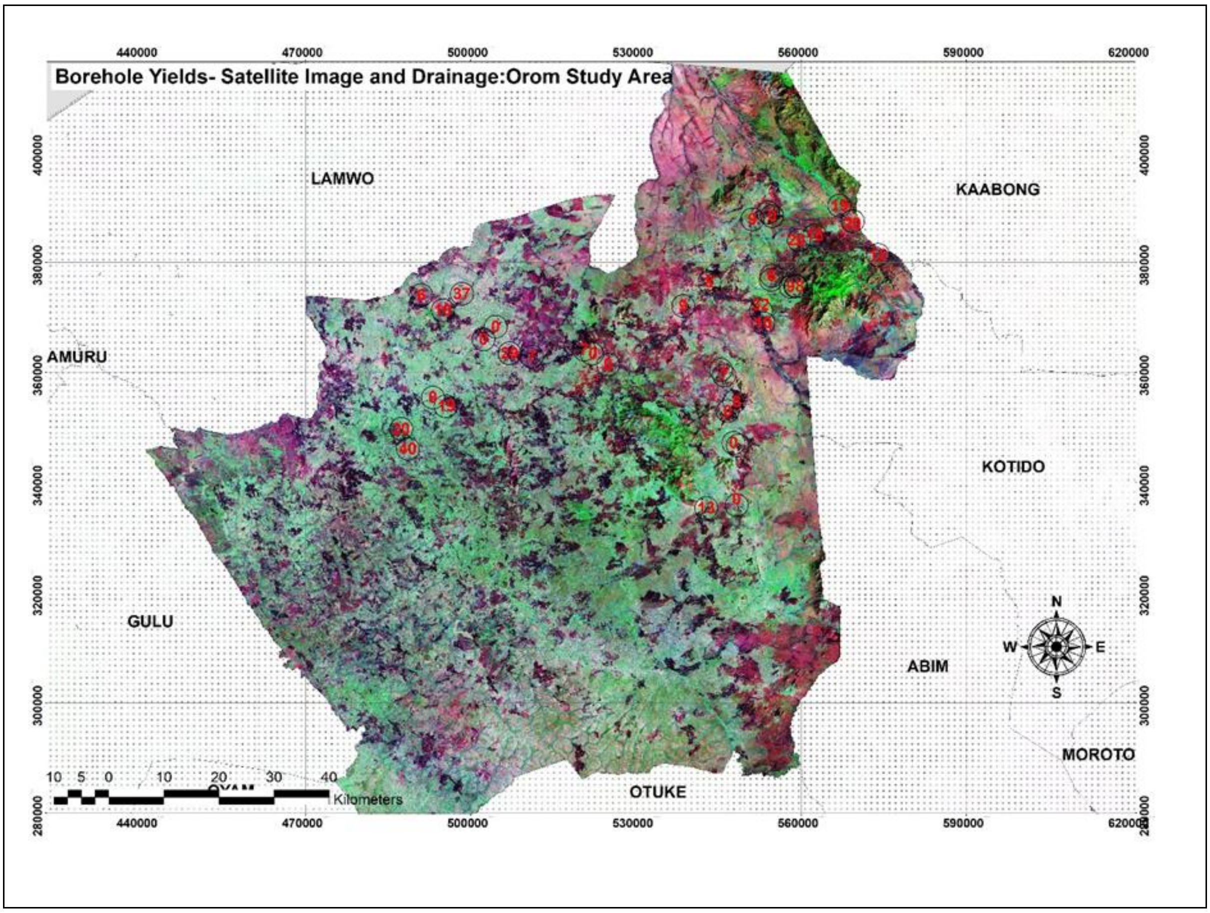


Figure 20: ARCGIS developed geophysical map of Pader, Agago and Kitgum showing distribution of deep boreholes on the prepared satellite map.

3.5.2 Topographical and Geologic Structural Data

Topographical maps (Scale 1:50000) obtained from the Directorate of Land and surveys, Entebbe enabled to further discern geological structures, springs, drainage and to establish a relationship of geology to topographic features using overlay analysis and Geographic information system (Arc GIS 10.2). Figure 21 below shows structures which greatly influenced boreholes yields in the study area.

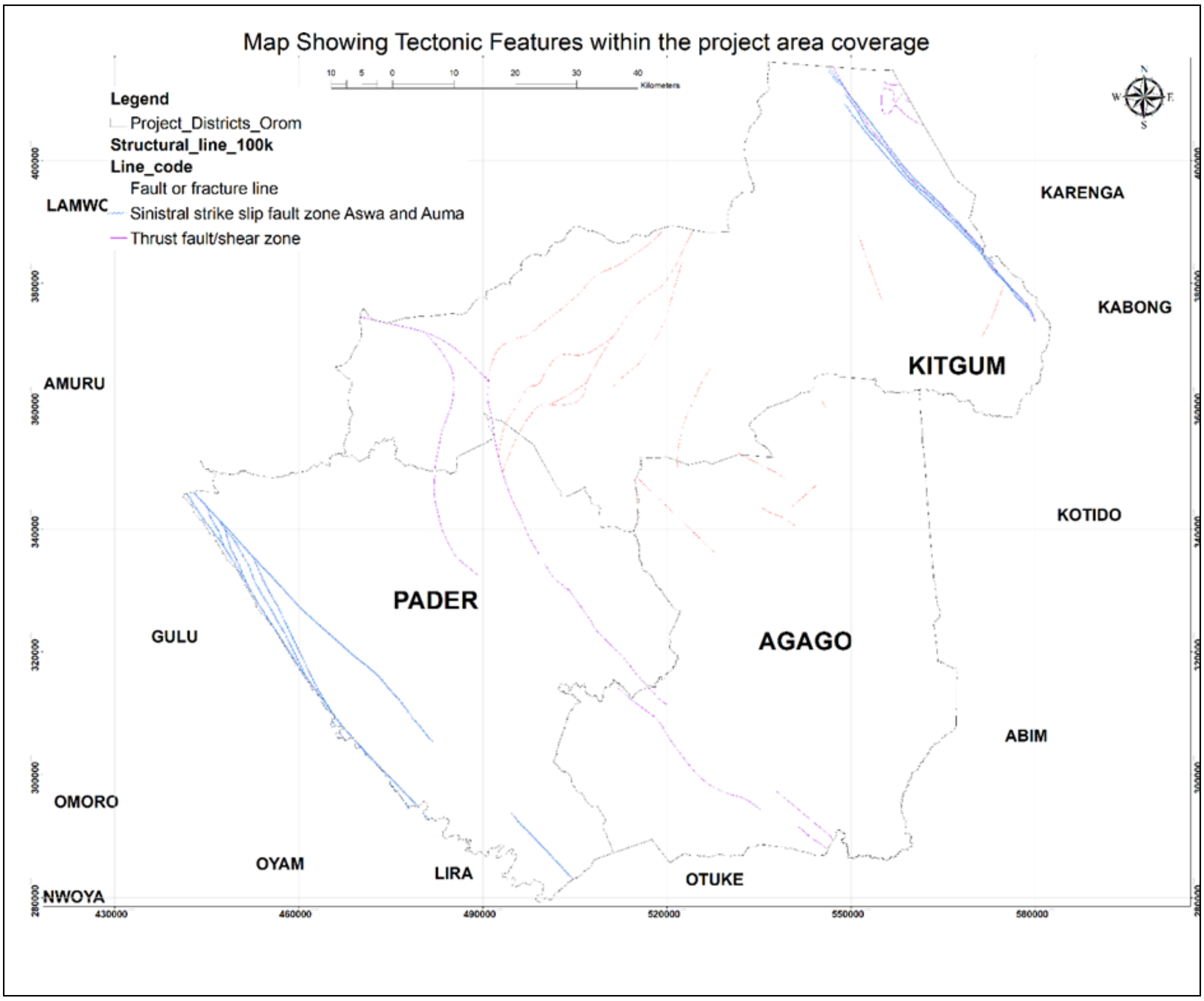


Figure 21: ARCGIS developed geophysical map of Pader, Agago and Kitgum showing structures which greatly influenced boreholes yields in the study area.

3.5.3 Geological Data

Geological maps (Scale 1:100000) were obtained from the Directorate Geological Surveys and Mines, Entebbe to aid understanding of geological units within the study area and how it influences the occurrence, movement of Groundwater and to further understand the depth to bedrock conditions, quantity and quality in relation to geological structures/ signatures through the use of overlay analysis using Geographic information system (Arc GIS 10.2) and correlation with the results of the lithological drilling data.

3.5.4 Hydro census Data

Hydro census data from the Directorate of Water Resources Management (DWRM) managing the National Groundwater Database was used to further the analysis of the groundwater potential of the study area as well as to improve on aquifer characterisation. Specifically, data for the 40 drilled sites with controlled construction supervision have been used for the analysis of Depth to Bedrock Conditions and Well Yields in relation to the resistivity curves (VES).

3.5.5 Geophysical Data

Secondary data mainly consisting of electrical resistivity data totalling to 120 data sets were obtained from Groundwater unit, Ministry of Water and Environment was used for the study. Orom water supply project was done in phases; the first phase being geophysical surveys undertaken in Kitgum, Agago and Pader districts to determine the most preferred groundwater sites and the phase two was drilling of the selected points for water supply. The secondary data obtained was for both phases.

3.5.6 Yield Distribution Map

Borehole yield data from the forty (40) boreholes were used in generating the yield distribution map of the study area. Nine (09) of these boreholes were dry(0m^3/hr), Zero (0) had low yields(1-5m^3/hr), seventeen (17) had moderate yields(6-15m^3/hr), eight (08) had high yields (16-25m^3/hr) and six (06) were Very high yielding (>25m^3/hr) based on the classification adopted for this study. The yield distribution map was prepared in order to understand of groundwater yield distribution in the study area. This was done by arranging the data in Microsoft Excel with their respective coordinates and inputting the data into ArcGIS.

Using ArcGIS, the area maps were imported and the coordinates of both datasets were set in conformity with the geographical location of the study area. The yield distribution map was then generated using Inverse Distance Weight (IDW) interpolation method. *Figure 22* below shows the yield distribution map of the forty sites drilled in Kitgum, Pader and Agago Districts.

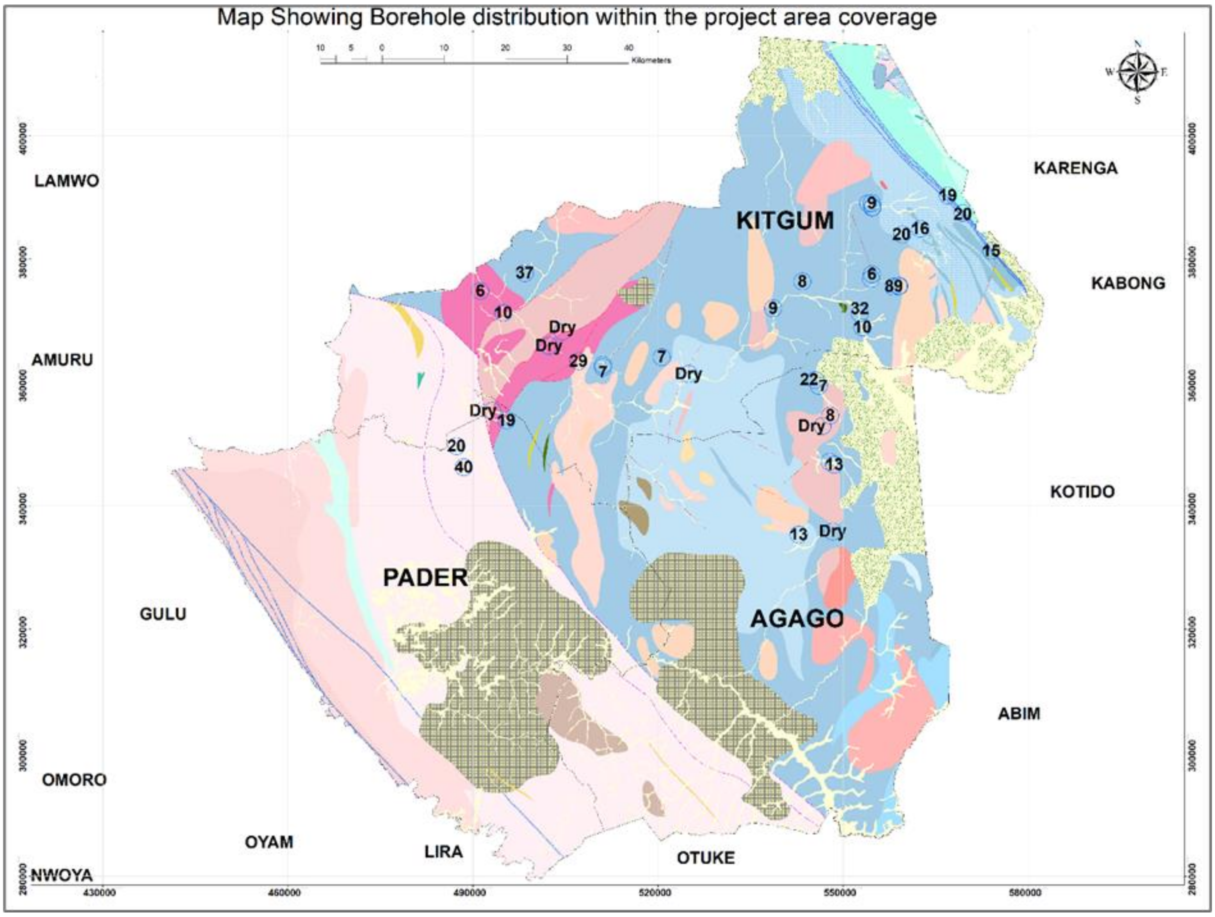


Figure 22: Shows the yield distribution across the study area.

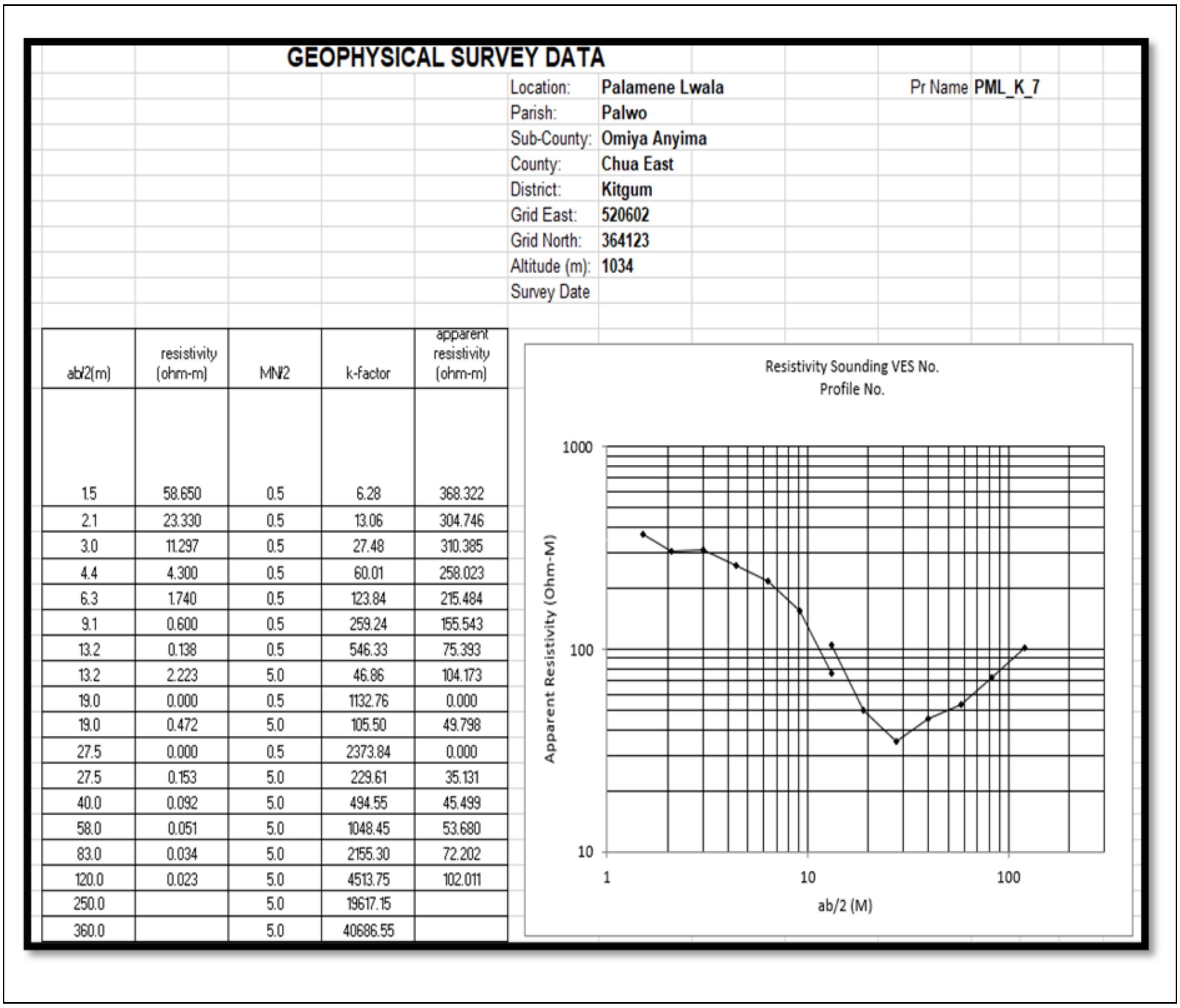
3.6 Data Analysis

Data analysis refers to the processes and procedures that were used to examine the data & provide some level of explanation, understanding or interpretation. Information obtained from all the secondary data included but not limited to;

- Schlumberger array sounding data detailing how siting was conducted, maximum depth investigated and variation of subsurface resistivities with depth.
- Location coordinates (UTM WGS 84 system) of the drilled borehole sites.

Borehole construction details including completion drilled depths, drilling penetration rates, design adopted (location of screens and UPVC plane casings), different lithologies encountered, airlift yields and pumping test yields. Pump test yields were considered for analysis in this study.

Resistivity measurements from field work conducted in different villages in Agago, Pader and Kitgum districts and the data used was Vertical Electrical Sounding (VES) survey obtained using the Schlumberger array type with investigation depth up to 120m. All the VES measurements were conducted such that the depth of investigation started from 1.5m beneath the ground surface. A sample VES field data sheets as shown in *Figure 23* below and contained information such as:


GEOPHYSICAL SURVEY DATA

Location: Palamene Lwala
Pr Name PML_K_7
Parish: Palwo
Sub-County: Omiya Anyima
County: Chua East
District: Kitgum
Grid East: 520602
Grid North: 364123
Altitude (m): 1034
Survey Date

ab/2(m)	resistivity (ohm-m)	MN/2	k-factor	apparent resistivity (ohm-m)
1.5	58.650	0.5	6.28	368.322
2.1	23.330	0.5	13.06	304.746
3.0	11.297	0.5	27.48	310.385
4.4	4.300	0.5	60.01	258.023
6.3	1.740	0.5	123.84	215.484
9.1	0.600	0.5	259.24	155.543
13.2	0.138	0.5	546.33	75.393
13.2	2.223	5.0	46.86	104.173
19.0	0.000	0.5	1132.76	0.000
19.0	0.472	5.0	105.50	49.798
27.5	0.000	0.5	2373.84	0.000
27.5	0.153	5.0	229.61	35.131
40.0	0.092	5.0	494.55	45.499
58.0	0.051	5.0	1048.45	53.680
83.0	0.034	5.0	2155.30	72.202
120.0	0.023	5.0	4513.75	102.011
250.0		5.0	19617.15	
360.0		5.0	40686.55	

Figure 23: Example of a generated field resistivity curve for Lwala Village, in Kitgum District.

Quantitative data collected was analysed using SPSS and Minitab 17 statistical software's. The data was categorized according to the research objectives and emerging variables from the checklist. The categories were coded to enable classification of answers into meaningful categories so as to bring out their essential pattern and emerging themes. Descriptive statistics and inferential statistics were used for analysis. The descriptive statistics provided a summary on the trend of responses, while the inferential statistics helped to explain the variable relationships.

Data analysis begun with the summary background of the secondary data of the forty boreholes drilled in Agago (08), Kitgum (28) and Pader (04) districts. This was proceeded with the spatial variation of the parameters for groundwater exploration that included pumping test yields, Water strike depths, total wells depth and Average swing angles. Bivariate data analysis was conducted using SPSS software to determine corelation and finally multivariate analysis was done using Minitab 17 software from which the best fitting model to the data was determined to cater for even categorical variable of lithology. During this analysis, Analysis Of Variance (ANOVA) was done.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents, analyses and interprets results of the study that were obtained using descriptive (analysis of data that helped to describe and summarise the data in meaningful patterns) and inferential statistics (making predictions from observations and analysis from the data), as well as the qualitative results.

In order to provide answers to the research objectives and hypotheses, the secondary data from the study area was recorded and entered using SPSS programmer for detailed analysis. All the quantitative responses are presented in terms of frequencies, percentages and correlation matrices. Qualitative results are presented as paraphrases or direct quotations as deemed fit. Data of forty drilled sites was considered for analysis and three types of analyses were used to draw conclusions as explained below;

4.2 Univariate analysis

Univariate analysis involved examination of the distribution of other factors on only one variable at a time for example; number of drilled wells, yield, lithologies and distribution of wells in the districts.

From the 40 drilled sites majority, 28 (70%) were from Kitgum whereas Agago had 8 (20%) and minority coming Pader where only 4 sites (10%) were drilled. Since the largest part of the supply area under the Orom project was in Kitgum district, it dominates the number of sites analysed in the study as shown in Table 3 below.

Table 3: Showing the number of sites drilled per district

District	Frequency	Percentage (%)
AGAGO	8	20.00
KITGUM	28	70.00
PADER	4	10.00
Total	**40**	**100**

All the forty sites were drilled in eight (08) different lithological formations and using coordinates of the surveyed sites (VESes) and drilling logs, it was possible to map out different lithological formations on the geology map. Migmatic garnetiferous gneiss lithology dominated with 57.5% of the total sites drilled, 12.5% in charnockite, 10% in variable deformed granitoid lithology, 7.5% in Kitgum granite, 5% in Awela granodiorite while 2.5% in Alluvium swamp, mafic granite & intermediate granulite as shown in *Table 4* below.

Table 4: The lithological formations of the drilled sites in the study area

Lithological unit/formation	**Frequency.**	**Percentage (%)**
Alluvium, swamp	1	2.50
Awela granodiorite	2	5.00
Charnockite	5	12.50
Intermediate granulite	1	2.50
Kitgum granite	3	7.50
Mafic granite	1	2.50
Migmatic gneiss	23	57.50
Variable deformed granitoid	4	10.00
Total	**40**	**100**

Table 5: R*esults of statistical analysis in SPSS software*

Variable	Obs	Mean	Std. Dev.	Min	Max
PTYIELDM3HR	40	12.975	11.57027	0	41

As per the ***Table 5*** above the average score or the mean yield was 12.975m^3/hr with the highest site yield being 41.0m^3/hr and zero (0) yield from the nine dry sites. For this study, the yields were categorised into dry (0m^3/hr), low (1-5m^3/hr), moderate (6-15m^3/hr), high (16-25m^3/hr) and Very high (>25m^3/hr). Data dissemination as per the category adopted was to determine yield per district against the total number of sites (wells) drilled and results are described in ***Table 6.***

Table 6: shows yields ranges against the number of wells in each district.

	RECODE of PTYIELDM3HR (PT YIELD (M3/HR))				
DISTRICT	DRY SITE	LOW YIELD	MEDIUM YI	HIGH YIEL	Total
AGAGO	3	2	2	1	8
KITGUM	5	12	6	5	28
PADER	1	0	2	1	4
Total	9	14	10	7	40

The idea was to develop characteristic groundwater yield curves for dry, low, moderate, high and very high yielding wells using the secondary data of the drilled sites that shall be used to guide during ground water investigations by other groundwater specialists during the planning process for ground water- based supply projects in order to reduce the uncertainty of low yielding or dry wells.

4.3 Background summary of data used

The data used in Agago district was from wells in the Sub-counties of Paimol, and Omiya-Pachwa; covering the villages of Lai Central, Opira Central, Pawel, Longor, Kalong TC/Ongom, Lawiye-Odunyo, Lakwa B and Wipolo. On the other hand, the data used in Kitgum district was from wells in the Sub-counties of Orom, Mucwini, Labong-Layamo, Omiya-Anyima, Lagoro, Namokora and Kitgum-Matidi; covering the villages of Lakwere Okaro-Kabete, Dognam, Obyen Central, Locomo Central, Luperu, Lakwanya 1&2, Lubiri/Lokoyo, Laluko, Lakongera 1,2,3&4, Wang-Kenya 1&2, Kako, Gili-Gili, Lapene /Lapeitaka 1&2, Agoromin, Agoromin City, Palamene, Lwala, Atocon, Alel East, Labilo B, Kweyo, Lamugo and Mugila. The only data used Pader district was from wells in the Sub-counties of Latanya and Acholibur; covering the villages of Abaneka, Locken, Lageng and Lugede.

4.3.1 Characterization of Total Depth of well in the study area

The Total Depth of boreholes drilled in the study area was found to have a mean of (130.6±3.0) m in Agago District with a minimum value of 110 m, a median value of 129 m and a maximum value of 151 m (as seen in Table 7). However, boreholes in Kitgum district were found to have shallower Total Depth with a mean of (126.9±1.3) m, a minimum depth of 100 m, a median of 120 m and a maximum of 157 m (as also seen in *Table 7*). Similarly, Pader district had wells with the shallowest Total Depths with a mean of (121.0±0.5) m, a minimum depth of 120 m, a median of 120 m and a maximum of 124 m.

Table 7: Descriptive data Summary for Total Depth (m)

District	Mean	SE_Mean	StDev	CoefVar	Minimum	Q1	Median	Q3	Maximum
Agago	130.62	2.95	15.05	11.52	110	120	129	144.25	151
Kitgum	126.94	1.3	14.47	11.4	100	120	120	135	157
Pader	121	0.522	1.81	1.5	120	120	120	123	124

4.3.2 Characterization of Water Strike depths in the study area

The Water Strike Depths in the study area was found to have a mean of (54.7±7.1) m in Agago District with a median value of 43.5 m below ground level (mbgl) and a maximum of 120 m (as shown in *Table 8*). However, boreholes in Kitgum district were found to have deeper Water Strikes at depths with a mean of (64.6±3.1) mbgl, a median of 59 mbgl and a maximum of 147 mbgl (as also seen in *Table 8*). Pader district had Water Strikes at depths with a mean of (55.9±9.2) mbgl, a median of 59 mbgl and a maximum of 101 mbgl. In all the districts, dry wells were found with no Water Strikes as indicated by a minimum value of zero (0) in *Table 8*.

Table 8: Descriptive data Summary for Water Strikes (mbgl)

District	Mean	SE_Mean	StDev	CoefVar	Minimum	Q1	Median	Q3	Maximum
Agago	54.69	7.1	36.19	66.16	0	30.75	43.5	92.25	120
Kitgum	64.62	3.13	34.66	53.64	0	41	59	87	147
Pader	55.92	9.15	31.71	56.7	0	27.5	59	87.25	101

4.3.3 Characterization of Aquifer Yields in the study area

The Aquifer Yields in the study area was analysed based on the Pump Test Yields of the boreholes to have a mean of (11.9±1.2) m^3/hr in Agago District with a minimum value of 0 m^3/hr, a median value of 13.0 m^3/hr and a maximum value of 22.0 m^3/hr (as seen in *Table 9*). However, boreholes in Kitgum district were found to have higher yields with a mean of (17.8±2.5) m^3/hr, a minimum yield of 0 m^3/hr, a median of 21.0 m^3/hr and a maximum of 41.0 m^3/hr (as also seen in *Table 9*). Even on a better note, Pader district had wells with the best yields with a mean of (19.0±4.1) m^3/hr, a minimum yield of 0 m^3/h, a median of 16.5 m^3/h and a maximum of 40 m^3/h (*Table 9*).

Table 9: Descriptive data Summary for Pump Test Yields (m^3/hr)

District	Mean	SE_Mean	StDev	CoefVar	Minimum	Q1	Median	Q3	Maximum
Agago	11.88	1.16	5.68	47.85	0	7.25	13	13	22
Kitgum	17.75	2.53	26.75	150.66	0	8.5	21	20	41
Pader	19	4.08	14.12	74.33	0	5.25	16.5	40	40

4.3.4 Characterization of Average Swing Angle in the study area

The mean Swing Angle of the resistivity curves in the three districts of Agago, Kitgum and Pader were respectively (4.9°±5.6), (17.8°±2.5), and (19.0°±4.1). The minimum Average Swing Angle (ASA) values were (-58°) in Agago, (-56°) in Kitgum and 0° in Pader while the median swing angle values were18.5° for Agago, 21° for Kitgum and 16.5° for Pader. The maximum ASA values of the resistivity curves in the districts of Agago, Kitgum and Pader were respectively 36°, 82° and 40° as indicated in

Table 10.

Table 10: Descriptive data Summary for Average Swing Angle, ASA (°)

District	Mean	SE_Mean	StDev	CoefVar	Minimum	Q1	Median	Q3	Maximum
Agago	4.92	5.56	28.35	575.84	-58	-7.75	18.5	26.25	36
Kitgum	17.75	2.53	26.75	150.66	-56	8.5	21	35	82
Pader	19	4.08	14.12	74.33	0	5.25	16.5	32	40

4.4 Spatial variation of Pump test yields

The spatial plot of the observed data for wells drilled in the three districts of Agago, Kitgum and Pader indicated that most of the aquifers found in the area (two-thirds of the area) has yields of 2.0 m^3/hr to 18.0 m^3/hr, generally classified as low to high yields. The rest of the wells (in a third of the area) had yields of 18.0 m^3/hr to over 38.0 m^3/hr, classified as high to very high yields (as seen in *Figure 24*). Over all, as the distance within the region increases in the Eastern direction, the yield decreases from as high as over 26.0 m^3/hr to as low as below 2.0 m^3/hr. From a distance of 520000 mE to over 570000 mE, the yield is not spatially affected by shifting in the northern direction, i.e., generally no change in yield from 340000 mN to 390000 mN.

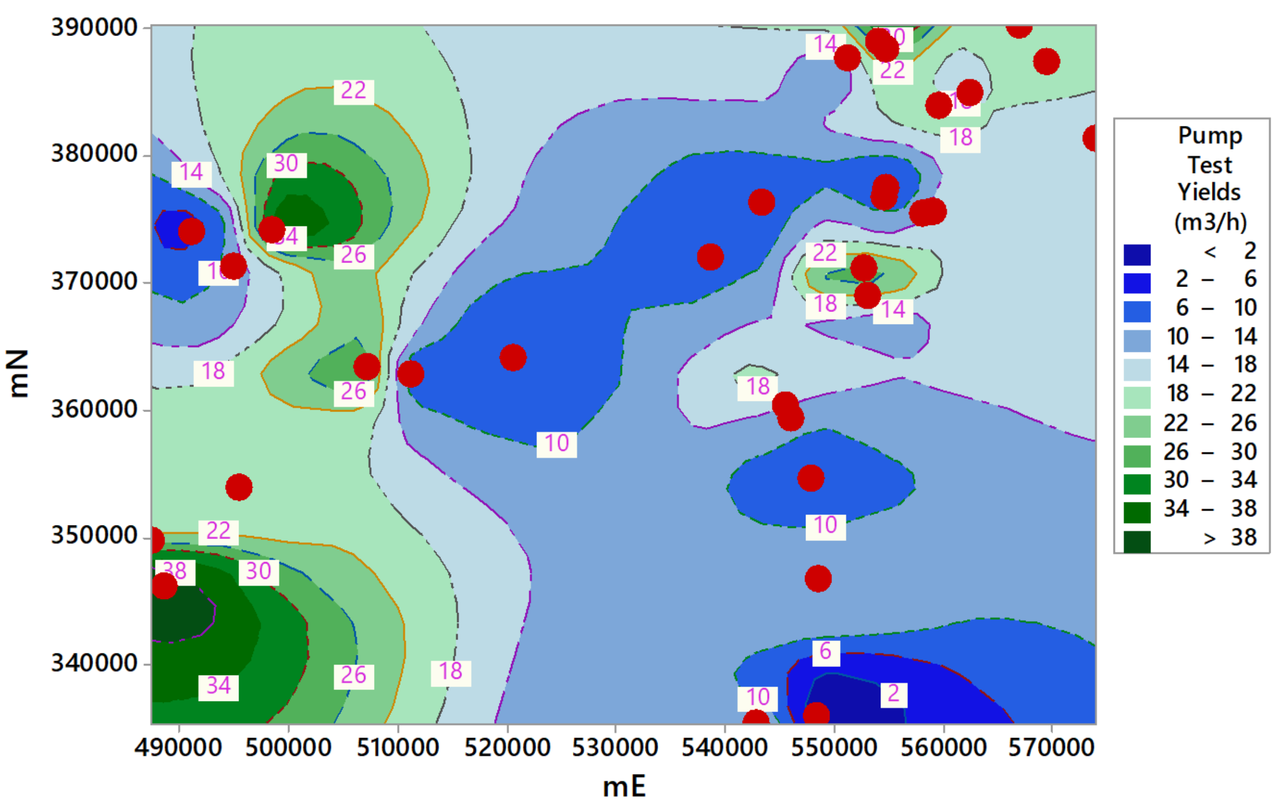


Figure 24: Spatial variation of Pump test yields in the districts of Agago, Kitgum and Pader.

As the distance increases in the eastern direction, the yield decreases from as high as over 26.0 m^3/hr to as low as below 2.0 m^3/hr. Distance in the Northern direction has no significant effect in aquifer yields.

4.5 Spatial variation of Water strikes in metres below ground level (mbgl)

For distances between 335,000 mN to 360,000 mN, the Water Strikes are generally experienced at depths less than 60mbgl, regardless of the eastern distance. This is a similar situation for distances between 490,000 mE to 530,000 mE where Water Strikes are achieved at depths less than 60mbgl, regardless of the distance along the northern. The region where the Water Strikes are attained at depths of less than 60mbgl cover approximately 67% (two -thirds of the area) as seen in Figure 24. However, beyond 360,000 mN and 530,000 mE, the Water Strikes are obtainable at higher depths greater than 60mbgl to as high as 90 to 105mbgl. Areas with Water Strikes less than 15mbgl are located below 370,000 mN and anywhere between 490,000 mE and 550,000 mE.

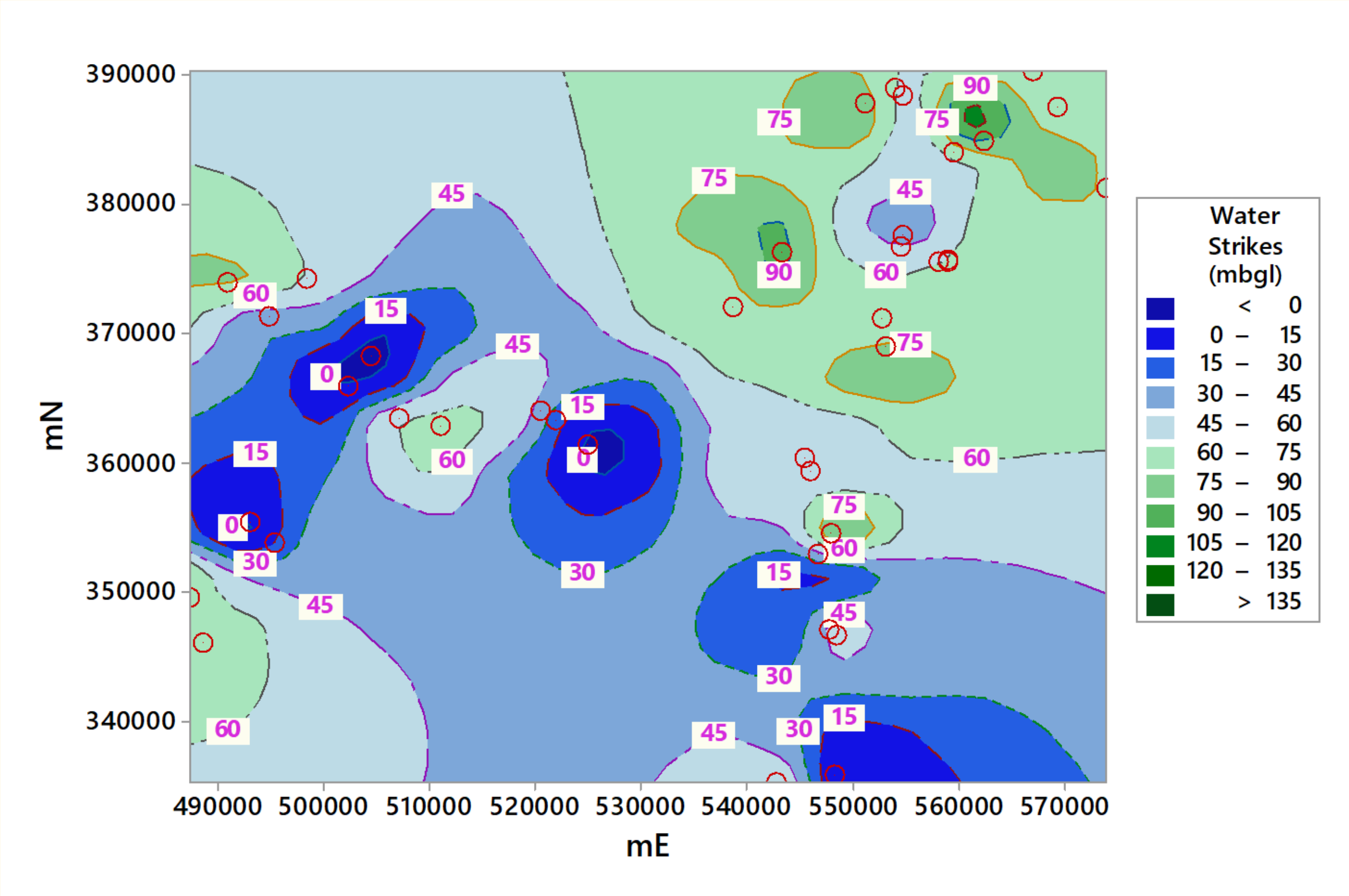


Figure 25: Spatial variation of Water strikes in metres below ground level (mbgl) in the districts of Agago, Kitgum and Pader

4.6 Spatial variation of Total well depth drilled

The Total Depth (TD) of wells vary from 102 m to as high as 156 m, with half of the area having TD of less than 120 m and the other half having depths of 120 to 156 m. Spatially, there is a general similar TD of wells within the region, indicating that there are aquifers within the region are at depths of 102 m to 156 m with an average value of 129 m, as shown in *Figure 26*.

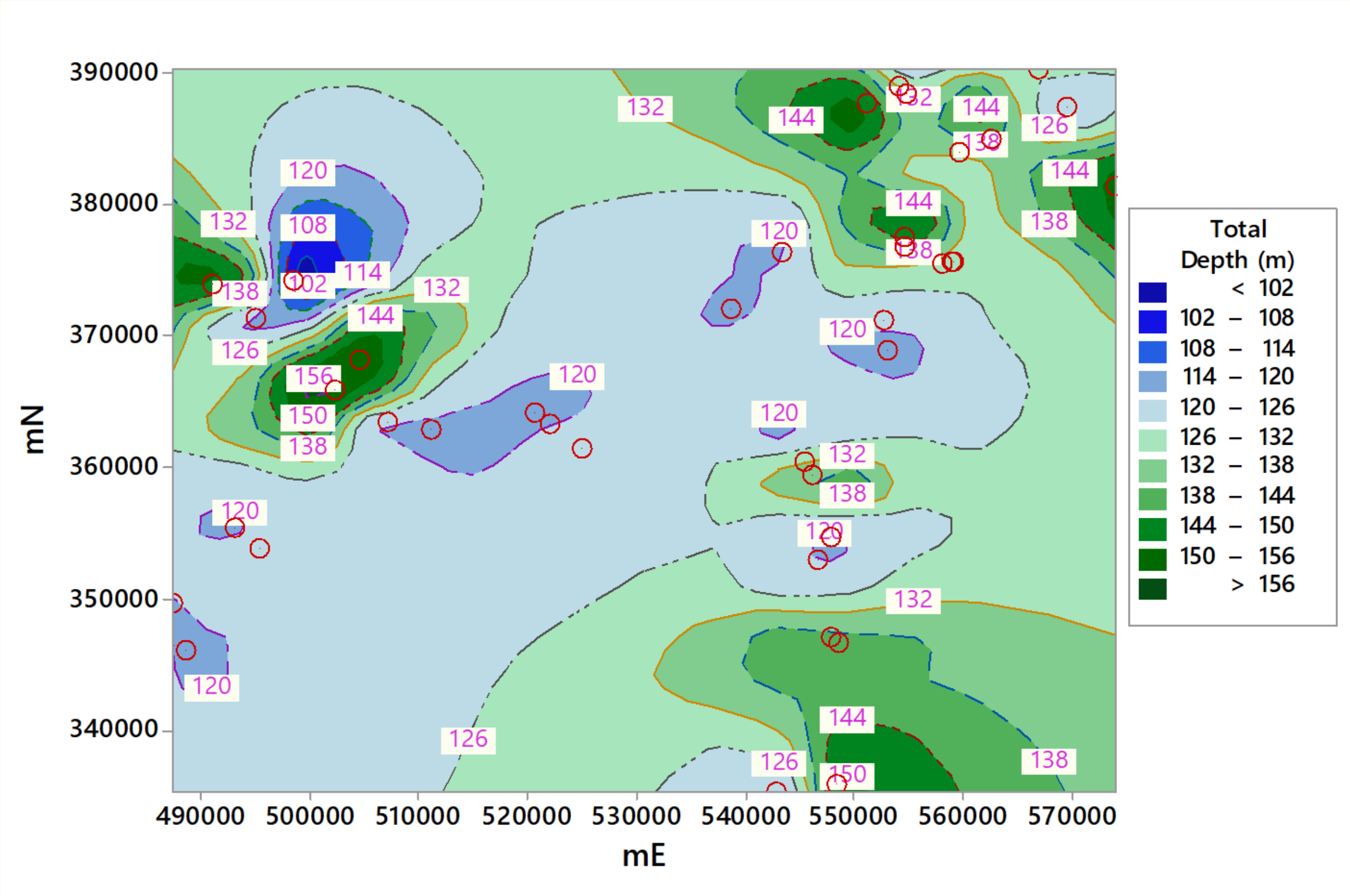


Figure 26: Spatial variation of Total well depth drilled in the districts of Agago, Kitgum and Pader

4.7 Spatial variation of Average swing angle

The Average Swinge Angle (ASA) of the Resistivity Curves typical of the area varies from as low as (-35°) to as high as 40°. Generally, the ASA varies relatively uniform over the area and therefore has no much effect on the groundwater exploration within the area *(Figure 27)*.

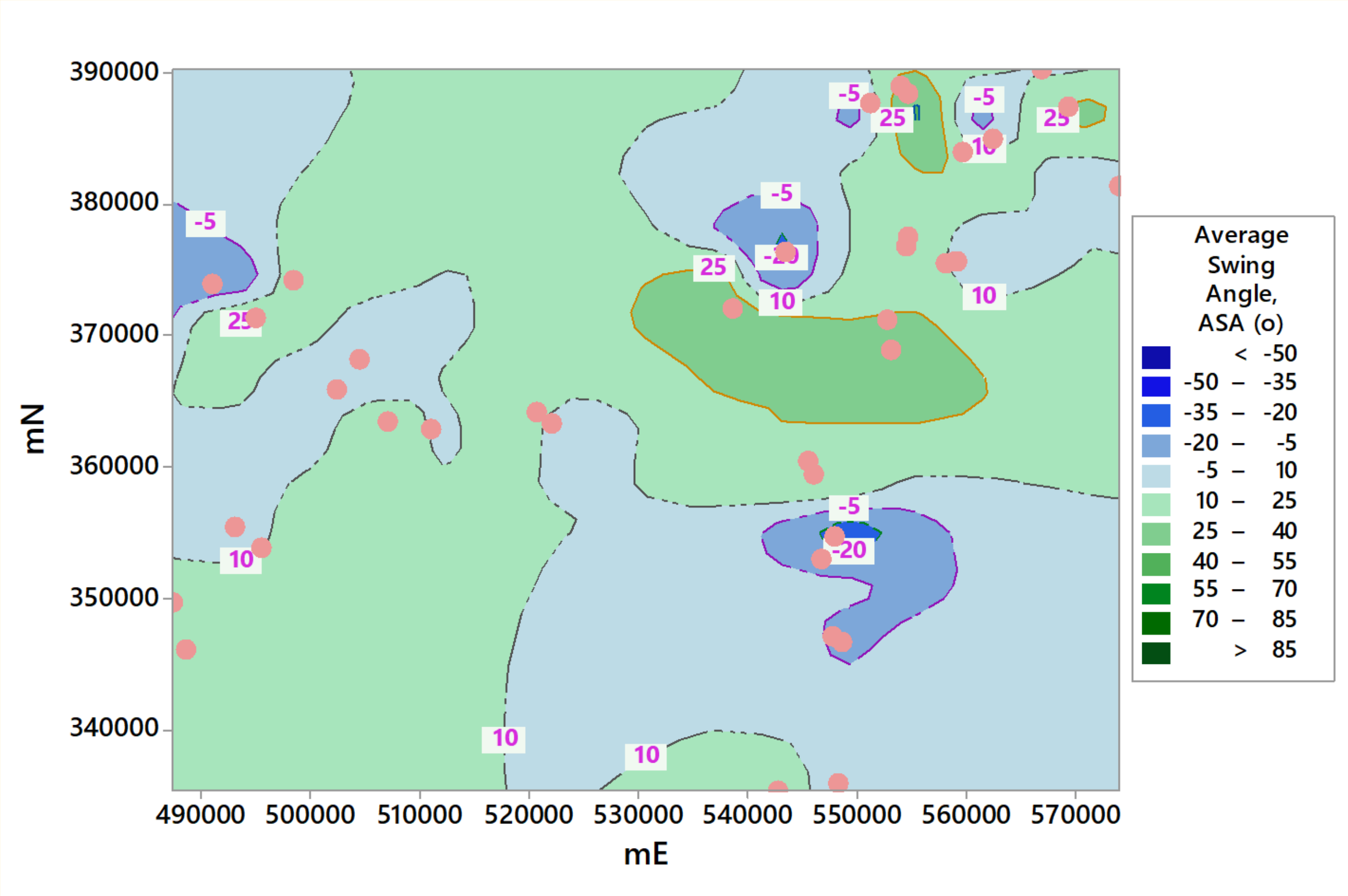


Figure 27: Spatial variation of Average swing angle in the districts of Agago, Kitgum and Pader

4.8 Bivariate analysis

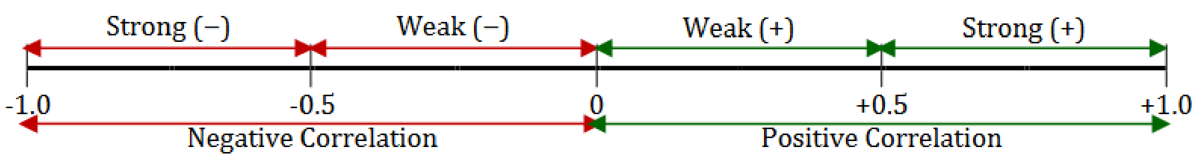
This involved analysis using two variables simultaneously for example well yield and number of water strikes encountered during drilling process, well yield and total depth drilled.

4.8.1 Correlation analysis

Correlation analysis, also known as bivariate analysis for two continuous variables, it's primarily concerned with finding out whether a relationship exists between variables and thereafter determining the magnitude and how strong the relationship is. In this bivariate analysis the researcher was determining an associative relationship between the well yield and the number of water strikes.

In this study, ranking statistical correlation according to Pearson correlation coefficient was adopted since it's a widely used analytical formulae depending on the types of data to be handled. The coefficient operates under the assumption that the data being used is ordinal, which -means that the numbers do not indicate quantity, but rather signify a position of place of the subject's standing and therefore no specific way of interpreting the correlation coefficient.

According to Gogtay and Thatte (2017), by measure, the correlation coefficient can be interpreted based on its value as shown in *Figure 28* below which is the basic spectrum of interpreting correlation coefficient;



(Source: Gogtay and Thatte, 2017, p. 79)

Figure 28: showing the basic spectrum of interpreting correlation coefficient.

With the formula being listed as below, Pearson's mathematical formulation to quantify the degree of relationship (R) between variables, namely, X and Y, can be given as:

$$R = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{n(\sum X^2) - \sum(X^2)}\sqrt{n(\sum Y^2) - \sum(Y^2)}} \quad \text{Equation 2}$$

n= Number of observations

X= Measures of Variable 1

Y= Measures of Variable 2

$\sum XY$= Sum of the product of respective variable measures

$\sum X$= Sum of the measures of Variable 1

$\sum Y$= Sum of the measures of Variable 2

$\sum(X^2)$= Sum of squared values of the measures of Variable 1

$\sum(Y^2)$= Sum of squared values of the measures of Variable 2

The coefficient required a table which displayed the raw data, it's ranks, and the difference between the two ranks. This squared difference between the two ranks clearly indicated whether there was a positive correlation, negative correlation, or no correlation at all between the two variables. The constraint that this coefficient works under is -1 ≤ ***r*** ≤ +1, where a result of 0 would mean that there was no relation between the data whatsoever.

4.8.1.1 Correlation analysis between number of water strikes and yield of a well

Table 11: Showing the correlation analysis between water strikes and yield of a well

		PTYIELD	NUMBE ROF WATER STRIKES
PT YIELD	Pearson Correlation	1	.6160**
	Sig. (2-tailed)		.000
	N	40	40

NUMBER OF WATER STRIKES	Pearson Correlation	.6160**	1
	Sig. (2-tailed)	.000	
	N	40	40

**. Correlation is significant at the 0.01

The correlation analysis for groundwater yield and number of water strikes revealed a high positive correlation, with Pearson correlation of 0.6160**, followed by a P-value of 0.000. This meant that the relationship between the two variables was statistically significant and that number of water strikes was a significant predictor of the water yield. The positive correlation implied that when the number of water strikes increased, there was an increase in the water yield. Therefore, the study hypothesis: 'There is significant relationship between water yield and the number of water strikes.

4.8.1.2 Correlation between well yield against total depth drilled.

Table 12:Showing the correlation between well yield against total depth drilled

		PTYIELD	TOTAL DEPTH
PT YIELD	Pearson Correlation	1	-.4555**
	Sig. (2-tailed)		.000
	N	40	40
TOTAL DEPTH	Pearson Correlation	-.4555**	1

	Sig. (2-tailed)	.000	
	N	40	40

**. Correlation is significant at the 0.00

The correlation analysis for well yield and total depth revealed a negative correlation, with Pearson correlation of -0.4555**, followed by a P-value of 0.000. This meant that the relationship between the two variables was statistically significant and that the Total Depth (TD) of the drilled sites were a significant predictor of the well yield. The negative correlation implied that the deeper the well does not have a significant impact on the water yield.

4.8.2 Pump test yield variation with the Total depths drilled and the Water strikes

Below Total Depth (TD) of 115 m, regardless of the Water Strike depths, the Pump test yield varies from as low as 18.0 m^3/hr to as high as greater than 38.0 m^3/hr. Above Total Depths of greater 140 m, the Pump Test Yield decreases from as high as 22.0 m^3/hr to as low as below 2.0 m^3/hr, regardless of the Water Strike depths.

Between Total Depths of 120 m and 140 m, the Pump Test Yields are relatively higher, ranging from 18.0m^3/hr to as high as 30.0 m^3/hr (*Figure 29*).

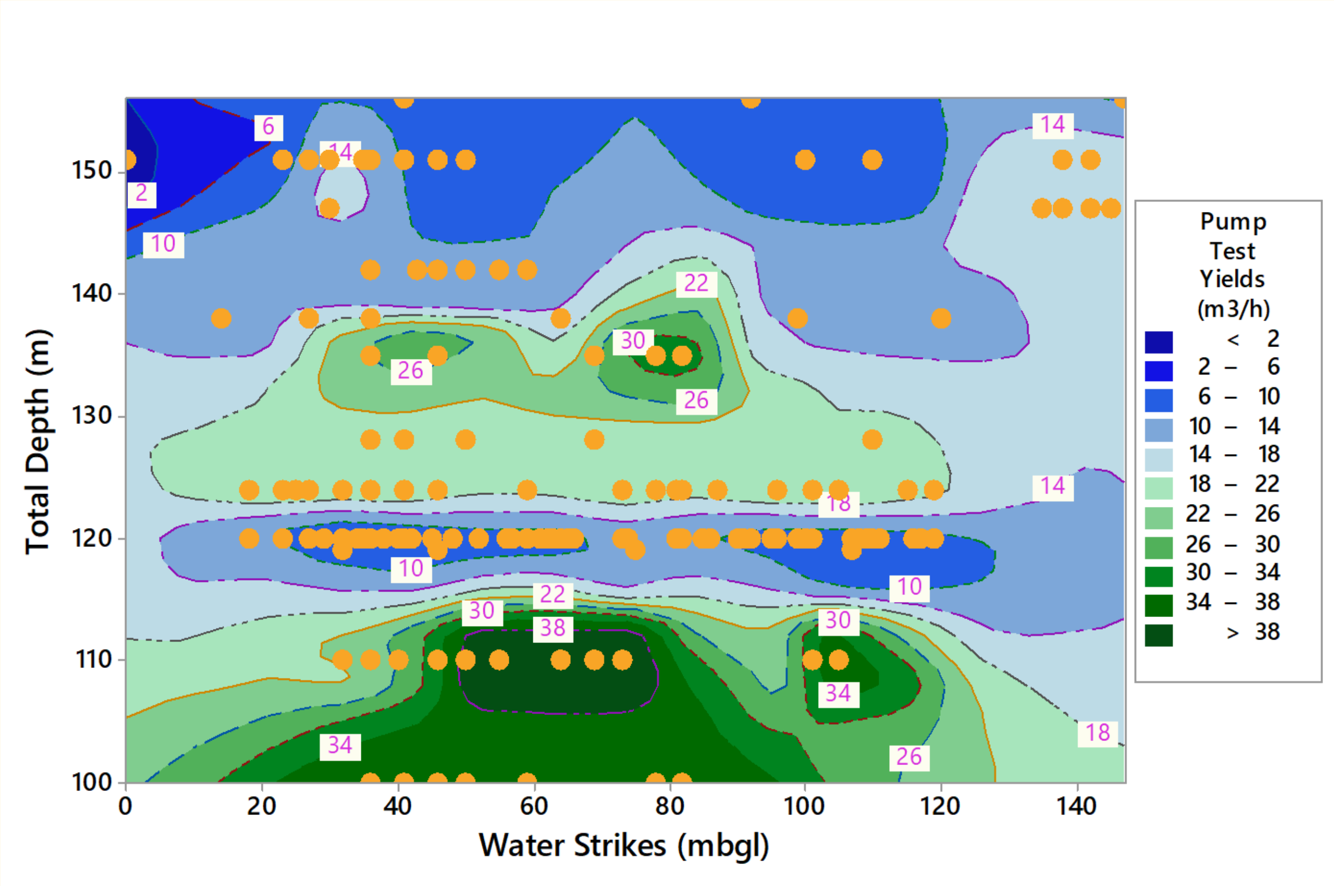


Figure 29: Pump test yield variation with the Total depths drilled and the Water strikes within the districts of Agago, Kitgum and Pader. Above the Total Depth of 136m, the yields are realatively low (2 – 14 m^3/hr) while between 100 and 115 m Total Depth, the yields are high (18 – 38 m^3/hr).

4.8.3 Water Strike Depth variation with the Total depths drilled and the Average swing angle.

In the region, for boreholes of Total Depths of less than 135 m and with resistivity curves having Average Swing Angles (ASAs) of (-55°) to 20°, the water strike depths vary from 53 mbgl to just over 113 mbgl. Similarly, for boreholes of less than 135 m and with resistivity curves having ASAs of 40° to just over 75°, the water strike depths also vary from 53 mbgl to just over 113 mbgl. However, for boreholes of same Total

Depths of less than 135 m and with resistivity curves having ASAs of 20° to 40°, the water strikes occur at shallower depths less than 53 mbgl. For Boreholes with Total Depths of greater than 135 m, the ASAs do not significantly influence the Water Strike Depths, as Water Strikes are most of time (over 95% of cases) attained at depths of less than 65 mbgl, as seen in *Figure 30*.

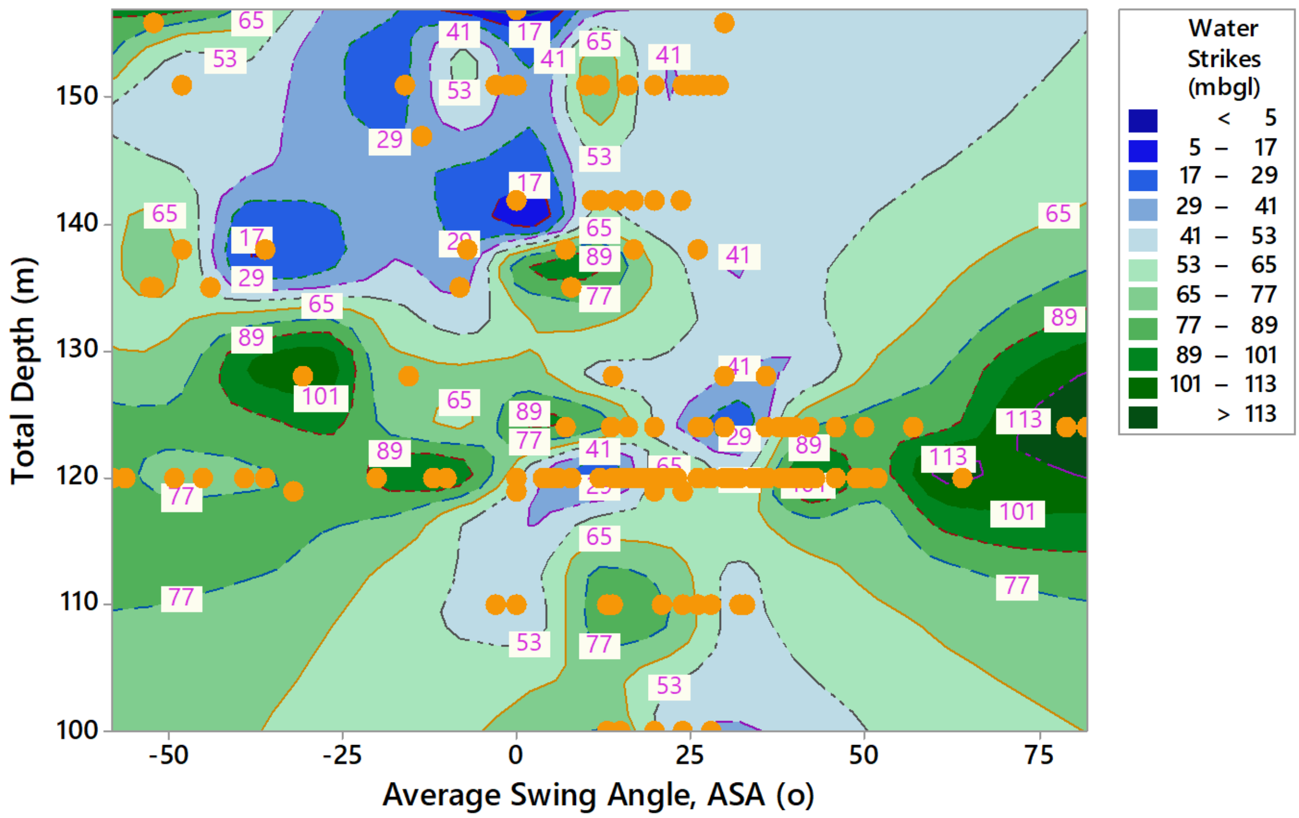


Figure 30: Water Strike variation with the Total depths drilled and the Average swing angle within the districts of Agago, Kitgum and Pader. Below 135m Total Depth and between Swing Angles -55^{0} to -5 and 30 to 80, the WSDs are relatively deeper i.e., 53m to 101m and 53m to 113m respectively

4.8.4 Pump test yield variation with the Total depths drilled and the Average swing angle

For boreholes of Total Depths (TDs) less than 120 m and with resistivity curves having ASAs of (-35°) to 50°, the Pump Test Yields (PTYs) vary from as low as 18.0m^3/hr to as high as over 38.0 m^3/hr. For the boreholes with TDs of 110 m to 120 m and resistivity curves having ASAs of less than (-25°) or between 50° and 75°, the PTYs vary from 6.0 m^3/hr to as high as 18.0 m^3/hr. The boreholes of TDs of 125 m to 140 m, the PTYs are less influenced by the ASAs of the resistivity curves and vary from 18.0 m^3/hr to as high as 30.0 m^3/hr. In a similar way, boreholes with TDs of above 140 m, the PTYs are also less influenced by the ASAs resistivity curves, though vary from as low as 2.0 m^3/hr to as high as 14.0 m^3/hr, as seen in *Figure 31*.

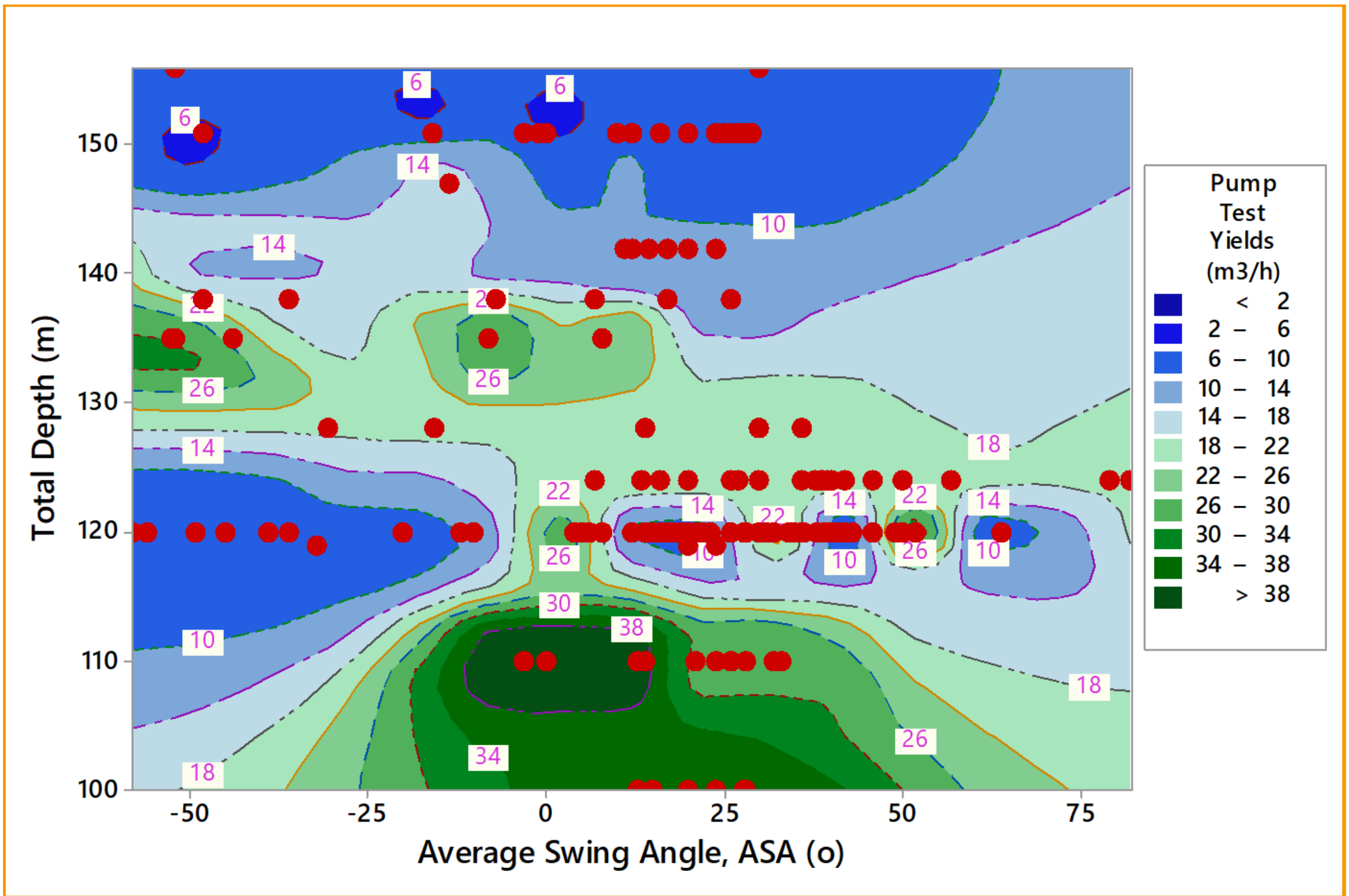


Figure 31: Pump test yield variation with the Total depths drilled and the Average swing angle within the districts of Agago, Kitgum and Pader. Abouve 140m TD, the yields are relatively low (<14m3/hr), regardless of the Swing Angles.

4.9 Multivariate Statistical Data Analysis

Regression analysis is one of the most sought out methods used in data analysis. It follows a supervised machine-learning algorithm hence allowing us to examine the relationship between two or more variables in the dataset. Regression analysis is a way of mathematically differentiating variables that have an impact. It answers the questions: the important variables? Which can be ignored? How do they interact with each other? And most important is how certain we are about these variables.

Multiple linear regression was adopted in this study as it estimates the relationship between two or more independent variables and one dependent variable. Groundwater well yield was the dependent variable being the main factor the research tried to understand or predict and the main independent variables included lithology, water strikes and total well depth, these factors were used because from the bivariate analysis they showed an impact on the dependent variable.

The earlier analysis had already categorized the yield into Dry, Low, Moderate, High and Very High as shown in Table 13. *Based on this aquifer yield clustering, some of the data far above the values indicated in the* Table 13 *were adjusted to be within the range as indicated in*

Table *14*, to avoid them being Outliers in the analysis. They could not be eliminated as outliers, since they were for the few Boreholes in Pader district and part of the very high yields in Kitgum district. Therefore, data modification for these few very highly yielding Boreholes of 30.0 m^3/hr to 40.0 m^3/hr.

Table 13: Clustering of Pump Test Yields of boreholes in Agago, Kitgum and Pader Districts

Pump Test Yield (m^3/hr)	**Description (Yield classification)**
0	Dry
1 - 5	Low
6 - 15	Moderate
16 -25	High
>25	Very High

Table 14: Modification of PTYs of boreholes in the region based on clustering in *Table 13* with the highest observed yield of 40 m^3/hr fixed at 25m^3/hr.

Observed Yield (m^3/h)	**Modified Yield (m^3/hr)**
41	25
40	24.4
37	22.6

32	19.5
30	18.3

A multivariate regression model was sought that adequately fitted the data. Linear regression models did not fit the data as Coefficient of Determination (R^2) of less than 40% was obtained. Therefore, a non-linear model was sought that could be linearized and its Coefficients determined by linear regression. The best predictive model for Aquifer Yield (*Y*) as the Dependent Variable (Response) within the study area based on Total Depth (*TD*) and Water Strike Depths (*WSD*) as the Independent Predictor variables for each Lithological Feature as the Categorical variables coded with indicator variables as (1, 0); can be expressed as Equation 1 with a satisfactory Coefficient of Determination (R^2) of 66.78%, and Adjusted R^2 of 64.8%. Therefore, the model developed which best fits the groundwater data of the existing boreholes, account for two-thirds (66.7%) of the available data and can be considered as adequate to guide in ground water exploration within the region

$$Y_i = \beta_0 + \beta_1 \ln(TD) + \beta_2 \ln(WSD) \dots\dots\dots\dots\dots (1)$$

Where Y_i= The Pump Test Yield for a borehole of Lithology 'i' in m^3/hr; TD =Total Depth of the borehole in m; WSD= Water Strike Depth in m; β_0, β_1 and β_2 are the Regression Coefficients determinable by Multiple Linear Regression method.

This Equation can mathematically be re-written as in Equation 2.

$$e^{(Y_i - \beta_0)} = (TD)^{\beta_1}(WSD)^{\beta_2} \dots\dots\dots\dots\dots\dots. (2)$$

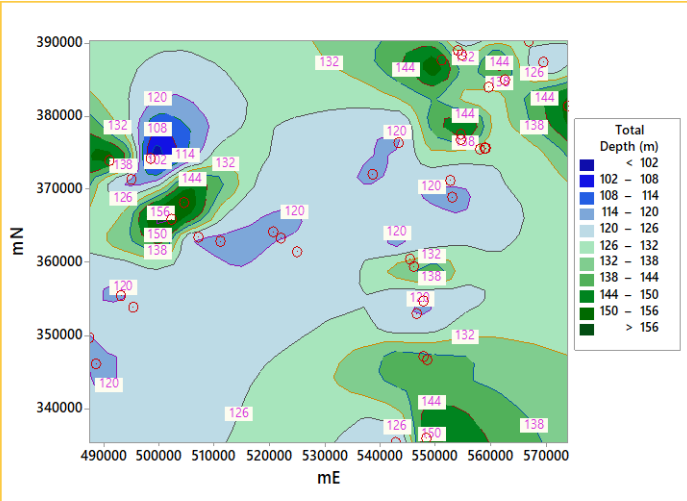
Through Multiple Linear Regression using Minitab 17 Statistical Software, a series of linear equations as in Equation 1 were obtained for each of the eight (8) Lithologies in the region and summarized using matrix notation in Equation 3.

$$\begin{pmatrix} Y_{AGG} \\ Y_{ASLD} \\ Y_{BGC} \\ Y_{IGSVDP} \\ Y_{KG} \\ Y_{MG} \\ Y_{MGG} \\ Y_{VDG} \end{pmatrix} = \begin{pmatrix} 175.7 & -32.67 & 0.712 \\ 174.7 & -32.67 & 0.712 \\ 176.2 & -32.67 & 0.712 \\ 160.5 & -32.67 & 0.712 \\ 169.0 & -32.67 & 0.712 \\ 176.0 & -32.67 & 0.712 \\ 167.5 & -32.67 & 0.712 \\ 165.8 & -32.67 & 0.712 \end{pmatrix} \begin{pmatrix} 1 \\ ln(TD) \\ ln\,(WSD) \end{pmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

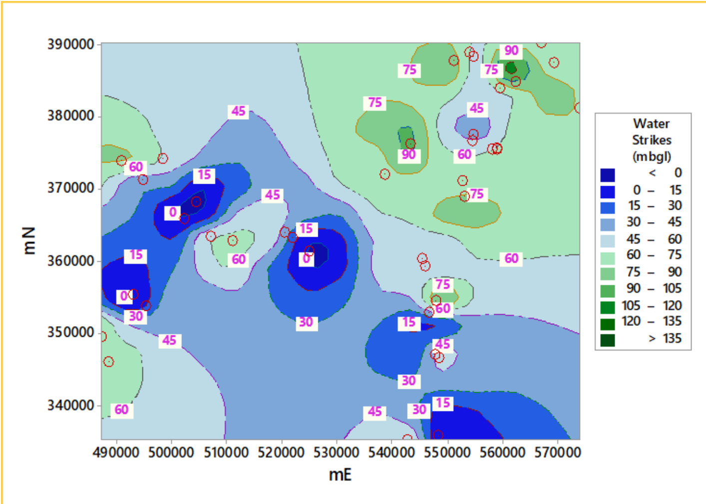
4.10 Application guide to regional groundwater exploration

The procedure begins with the determination of the location UTM coordinates (mN and mE) of the site. These coordinates will help to identify the Lithology of the site by using the Iso-lithology map of the study area. This will then guide to identify the Pumping Test Yield equation (curve) to be used in groundwater exploration. With the location coordinates used on the Iso-water strike depth graph and the Iso-total depth graph, the values of Water Strike Depths (WSD) and the Total Depth (TD) to be drilled for the potential borehole will be determined.

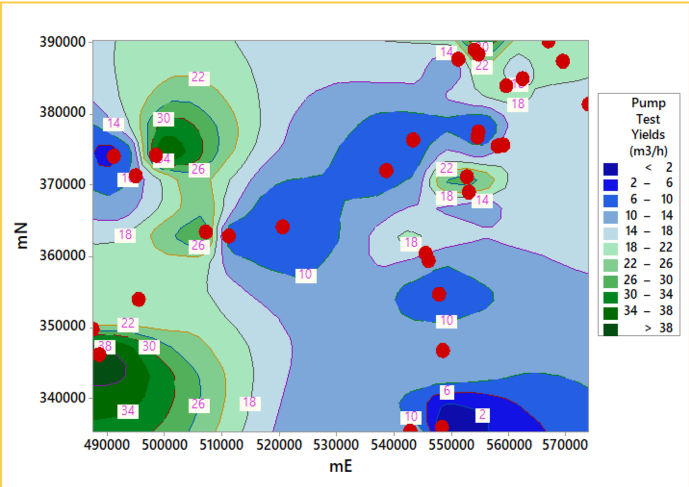
Using these values in the Pumping Test Yield Equation and the site lithology, the expected yield for the site is determined. The resulting predicted yield will then be used as a guide to groundwater exploration within the region. Potential sites for groundwater production wells could easily be determined and drilling easily done without possibility of striking dry wells. In other words, areas of good water strike depths and moderate total drill depth can be determined for potential production wells in suitable lithology to make mini-water supply scheme to mitigate against over-drilling of aquifers that results in downward depression of the phreatic surface, an occurrence that could potentially decrease yield. The Iso-water strike depth, the Iso-total depth, the Iso-lithology graph and the Iso-pump test yield graphs are shown in Figure 32 as a guide to regional groundwater exploration.



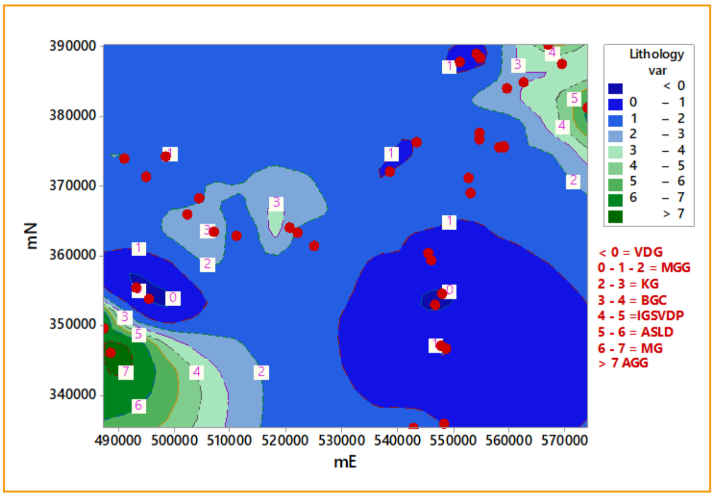
Regional Iso-total depth graph



Regional Iso-water strike graph



Regional Iso-Pump Test Yield graph



Regional Iso-lithology graph

Figure 32: The Iso-water strike depth, the Iso-total depth, the Iso-lithology graph and the Iso-pump test yield graphs developed in Agago, Kitgum and Pader Districts.

The summarized discussion of results showed that careful characterisation and spatial analysis of more data sets in the study area is important for prediction of GW potential. In other words, areas of good water strike depths and moderate total drill depth can be determined for potential production wells in suitable lithology to mitigate against over-drilling of aquifers that results in downward depression of the phreatic surface, an occurrence that could potentially decrease yield.

GW well yield and number of water strikes revealed a high/strong positive correlation, implying that accurate records of water strike depths will improve validity of developed yield curves.

Generally, the ASA varies relatively uniform over the area and therefore has no much effect on the groundwater exploration within the area.

The resulting predicted yield curve will then be used as a guide to groundwater exploration within the region. Potential sites for groundwater production wells could easily be determined and drilling easily done without possibility of striking dry wells.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study yielded the following key findings and conclusions;

The Total Depth of boreholes drilled in the study area was found to be highest with a mean of (130.6±3.0) m in Agago District, followed by (126.9±1.3) m in Kitgum district and lowest in Pader District with (121.0±0.5) m. On the other hand, mean water strike depth were found to be deepest in Kitgum (64.6±3.1) mbgl, followed by Pader (55.9±9.2) mbgl and shallowest in Agago District with (54.7±7.1) mbgl.

However, the mean aquifer yield was highest in Pader district (19.0±4.1) m^3/hr, (17.8±2.5) m^3/hr in Kitgum district and (11.9±1.2) m^3/hr in Agago District. The mean Swing Angle of the resistivity curves in the three districts of Agago, Kitgum and Pader were respectively $(4.9±5.6)^o$, $(17.8±2.5)^o$, and $(19.0±4.1)^o$

Over all, as the distance within the region increases in the Eastern direction, the yield decreases from as high as over 26.0 m^3/hr to as low as below 2.0 m^3/hr. From a distance of 520000 mE to over 570000 mE, the yield is not spatially affected by shifting in the northern direction, i.e. generally no change in yield from 340000 mN to 390000 mN. For distances between 335,000 mN to 360,000 mN, the Water Strikes are generally experienced at depths less than 60 mbgl, regardless of the eastern distance. This is a similar situation for distances between 490,000 mE to 530,000 mE where Water Strikes are achieved at depths less than 60mbgl, regardless of the distance along the northern direction.

The Total Depth (TD) of wells vary from 102 m to as high as 156 m, with half of the area having TD of less than 120 m and the other half having depths of 120 to 156 m.

Spatially, there is a general similar TD of wells within the region, indicating that there are aquifers within the region at depths of 102 m to 156 m with an average value of 129 m.

The Average Swing Angle (ASA) of the Resistivity Curves typical of the area varies from as low as $(-35)^{o}$ to as high as 40^{o}. Generally, the ASA varies relatively uniform over the area and therefore has no much effect on the groundwater exploration within the area.

Below Total Depth (TD) of 115 m, regardless of the Water Strike depths, the Pump Test yield varies from as low as 18.0 m^3/hr to as high as greater than 38.0 m^3/hr. Above Total Depths of greater 140 m, the Pump Test Yield decreases from as high as 22.0 m^3/hr to as low as below 2.0 m^3/hr, regardless of the Water Strike depths. Between Total Depths of 120 m and 140 m, the Pump Test Yields are relatively higher, ranging from 18.0m^3/hr to as high as 30.0 m^3/hr.

The best predictive model for Aquifer Yield (*Y*) within the study area based on Total Depth (*TD*) and Water Strike Depths (*WSD*) for each Lithological Feature was found to have satisfactory Coefficient of Determination (R^2) of 66.8% and is of the form,

$$Y_i = \beta_0 + \beta_1 \ln(TD) + \beta_2 \ln(WSD)$$

Where Y_i= The Pump Test Yield for a borehole of Lithology 'i' in m^3/h; TD =Total Depth of the borehole in m; WSD= Water Strike Depth in m; β_0, β_1 and β_2 are the Regression Coefficients determinable by Multiple Linear Regression method. These coefficients were determined for each of the eight (8) Lithologies in the region and summarized using matrix notation as:

$$\begin{pmatrix} Y_{AGG} \\ Y_{ASLD} \\ Y_{BGC} \\ Y_{IGSVDP} \\ Y_{KG} \\ Y_{MG} \\ Y_{MGG} \\ Y_{VDG} \end{pmatrix} = \begin{pmatrix} 175.7 & -32.67 & 0.712 \\ 174.7 & -32.67 & 0.712 \\ 176.2 & -32.67 & 0.712 \\ 160.5 & -32.67 & 0.712 \\ 169.0 & -32.67 & 0.712 \\ 176.0 & -32.67 & 0.712 \\ 167.5 & -32.67 & 0.712 \\ 165.8 & -32.67 & 0.712 \end{pmatrix} \begin{pmatrix} 1 \\ ln(TD) \\ ln\,(WSD) \end{pmatrix}$$

To determine the yield, multiply row by column in Matrix Form for example:

Y_{AGG} = 175.7*(1) - 32.67*(ln TD) + 0.712*(ln WSD), It's a notation for all equations for each geological feature and predicted GW yield curves included in Appendix 4. Therefore, this study major finding will guide groundwater exploration within the region by identifying and determining the yield based on lithology.

This study has further revealed that the occurrence and movement of groundwater within the study area is controlled mainly by the geology/lithology and geological structures of the area. Areas of highest groundwater potential are found in unconsolidated alluvial sediments which occurs mainly within the rivers' valleys. However, these unconsolidated alluvial sediments have variable yield, mainly depending on lithology. Where the alluvium is dominated by coarse grained deposits such as gravel and coarse sand, storage capacity and transmissivity are high, this resulted in high yields.

The North Western (extended network of geological structures of fractures and faults) and North Eastern regions (with direct connectivity with the main aquifer/alluvial sediments) of the project area specifically in Kitgum District constitute good groundwater potential for prospecting, while based on the data density, the Northern part of Pader and Agago constitute good potential areas for groundwater prospecting as shown in appendix 3.

In conclusion, the research on developing characteristic regional groundwater yield curves in different geological settings is crucial for sustainable groundwater resource management. It will provide valuable information for decision-makers, stakeholders, and practitioners to make informed choices regarding groundwater development, land-use planning, and environmental protection. Therefore, continued research and collaboration among scientists, hydrologists, geologists and policymakers are essential to advance our understanding of groundwater systems and ensure the responsible and sustainable use of this vital resource.

5.2 Recommendations and Limitations of the study

It is essential to establish standardized methodologies for developing characteristic regional groundwater yield curves. Consistency in data collection, analysis, and modelling techniques will facilitate comparability and enable more accurate assessments across different geological settings. The approach used in the study can be applied during groundwater investigations to identify potential drilling points for groundwater supplies while minimizing cases of dry or low yielding wells.

More comprehensive and reliable data on geological, hydrological, and environmental parameters are required to enhance the accuracy of groundwater yield curves developed for the study area. Investments in data collection networks for example regular update of the National Groundwater Database, monitoring programs, and technology advancements can provide valuable information for research purposes.

Foster collaboration and knowledge sharing among researchers, practitioners and all stakeholders involved in groundwater development projects. Establishing platforms for sharing experiences, methodologies, and findings to advance the understanding and development of characteristic regional groundwater yield curves can help leverage expertise, resources, and data from multiple sources, leading to more robust and comprehensive research outcomes.

Implementing these recommendations will contribute to the advancement of research on developing characteristic regional groundwater yield curves for different geological or lithological settings across the country. It will enhance the understanding of groundwater resources, support sustainable water management practices and aid decision-makers in making informed choices regarding groundwater allocation and protection projects.

Limited datasets especially for Pader and Agago districts could contrain the accuracy and robustness of the yield curves. Since the study focused on a specific period of time for data analysis hence potentially missing long-term trends or variations in GW yield. Also, model assumptions about aquifer properties may not hold true in all geological settings for example hydraulic conductivity. Lastly, the changes in climate patterns such as precipitation and temperature can influence groundwater recharge rates and availability, this study may not fully account for the impact of climate variability.

Researchers should acknowledge the limitations explicitly and therefore conduct robust data validation, quality control and consider uncertainties in the results to ensure reliability and validity of the yield curves developed for further studies.

5.2.1 Recommendation for further studies.

Further analysis or study is recommended with more existing borehole data sets within the study area especially Pader and Agago districts and use them to further test the validity of the generated regression model (R^2-value from 66% to about 85%) as well as carrying out sensitivity analysis hence increasing the prediction of the aquifer yield.

Validation of the developed groundwater yield curves through field measurements and monitoring is also recommended for further study by comparing the predicted groundwater yields from the curves developed with actual observed values. This validation process will help assess the accuracy and reliability of the generated yield curves and identify any necessary adjustments or refinements.

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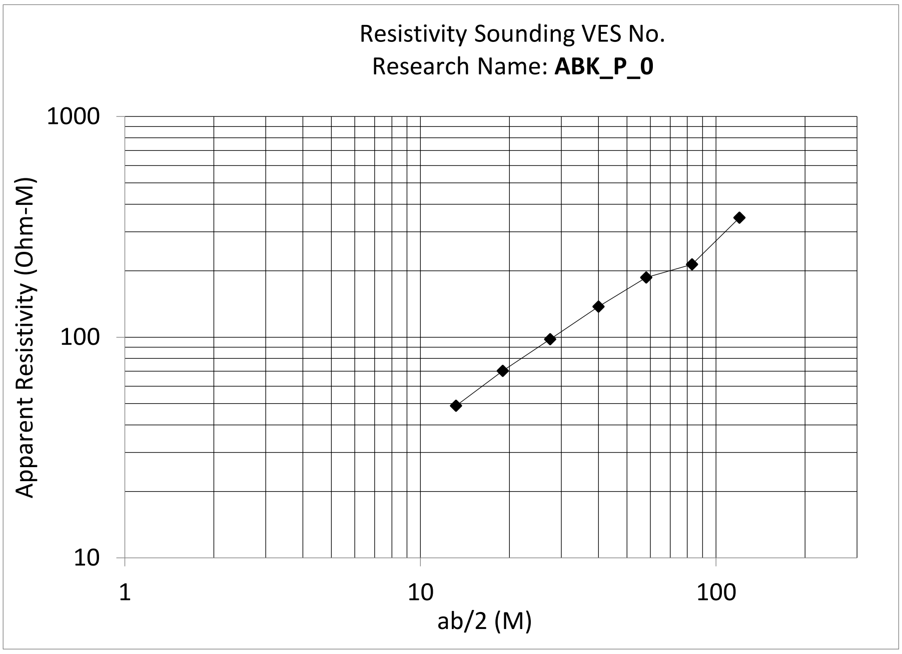
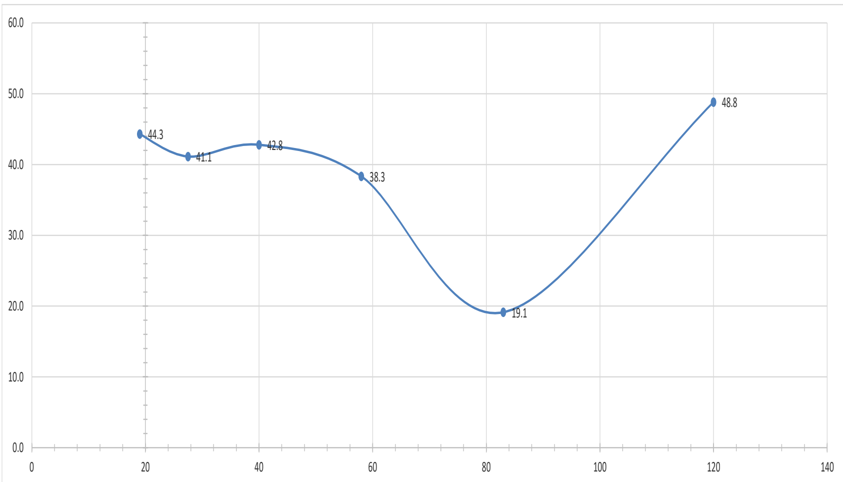
APPENDICES

APPENDIX 1(VES ARRAY DATA)



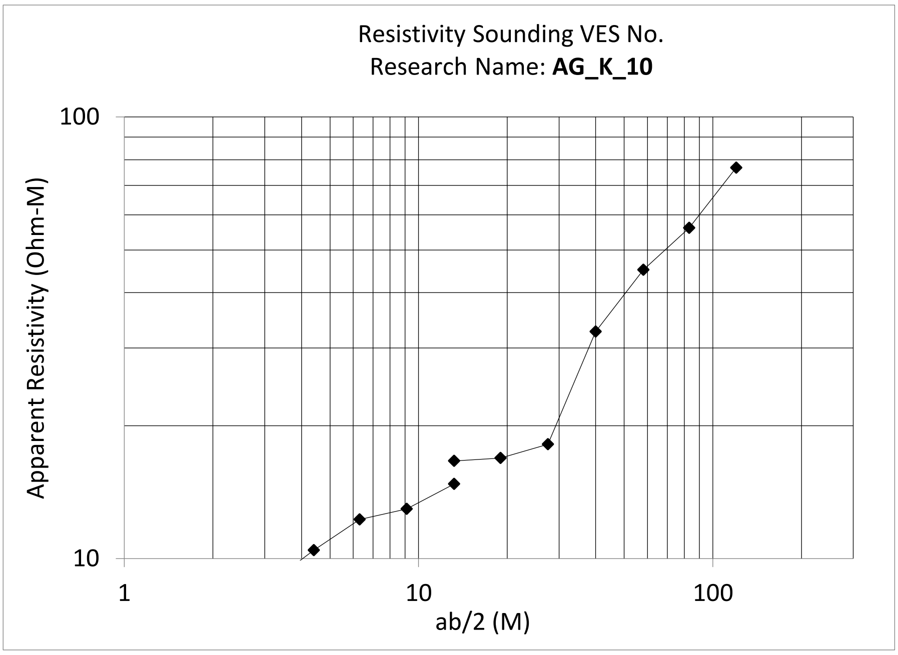


ab/2(m)	resistivity (ohm-m)
1.5	
2.1	
3.0	
4.4	
6.3	
9.1	
13.2	
13.2	1.043
19.0	
19.0	0.667
27.5	
27.5	0.426
40.0	0.278
58.0	0.178
83.0	0.099
120.0	0.077

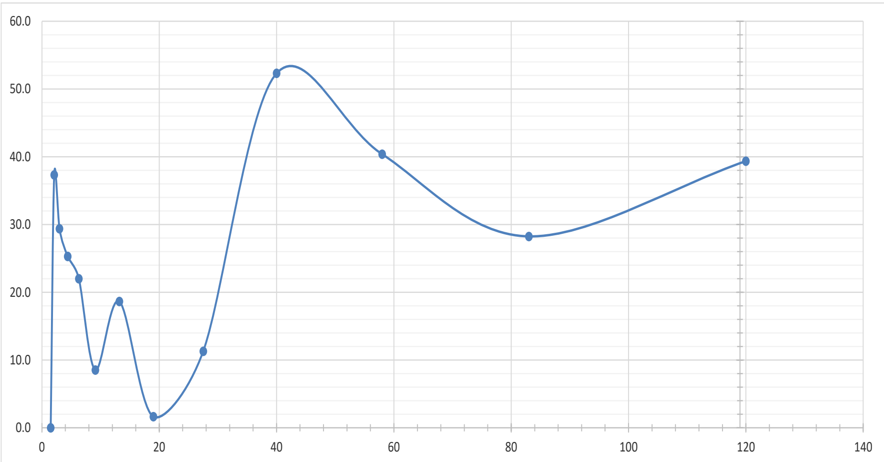
ab/2 (m)	Abenaka
1.5	
2.1	
3	
4.4	
6.3	
9.1	
13.2	
19	44.3
27.5	41.1
40	42.8
58	38.3
83	19.1
120	48.8

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
493122	355432	60623	Abaneka	ABK_P_0	Latanya	Pader	Variable deformed granitoid

	Water stirke zones
	Average angles



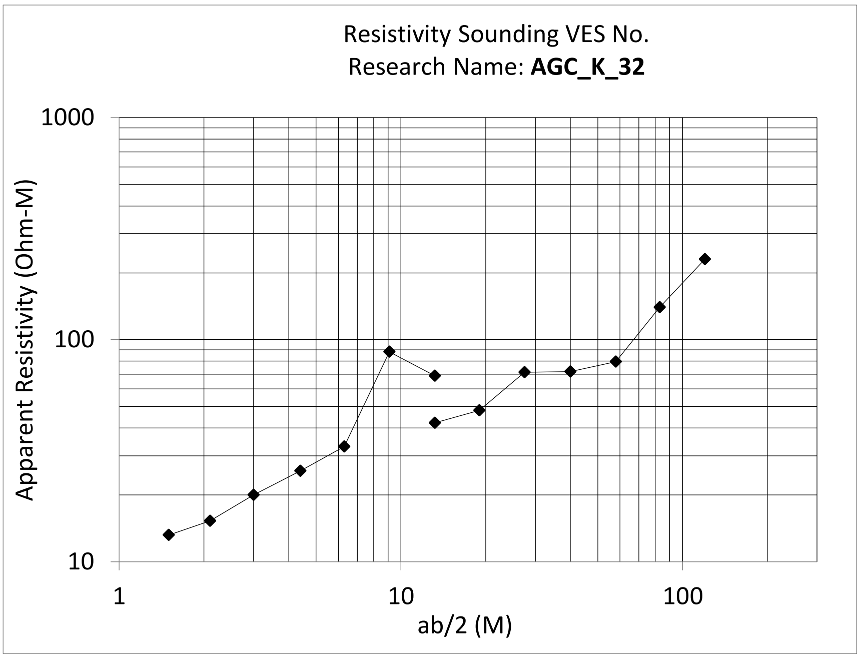
ab/2(m)	resistivity (ohm-m)
1.5	0.813
2.1	0.526
3.0	0.314
4.4	0.174
6.3	0.099
9.1	0.050
13.2	0.027
13.2	0.355
19.0	0.000
19.0	0.160
27.5	0.000
27.5	0.079
40.0	0.066
58.0	0.043
83.0	0.026
120.0	0.017



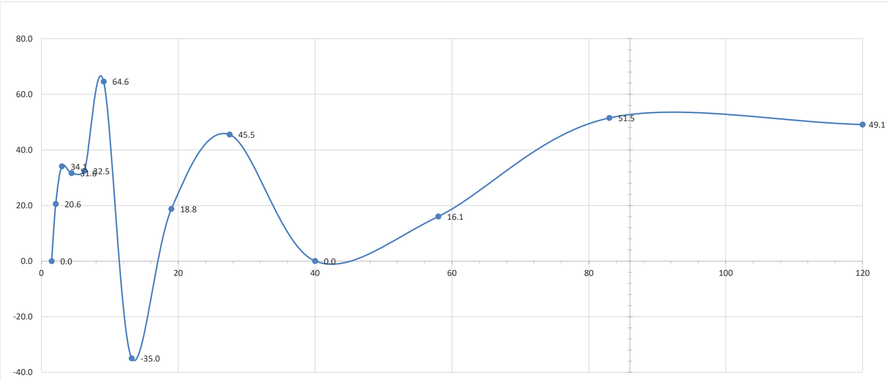
ab/2 (m)	Agoromin
1.5	0.0
2.1	37.3
3	29.4
4.4	25.3
6.3	22.0
9.1	8.5
13.2	18.6
19	1.6
27.5	11.3
40	52.3
58	40.4
83	28.2
120	39.4

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
553099	368952	61459	Agoromin	AG_K_10	Orom	Kitgum	Migmatitic garnetiferous gneiss

48	64	92	108	119	**Water stirke zones**
50	36.2	29.9	35	39	**Average angles**



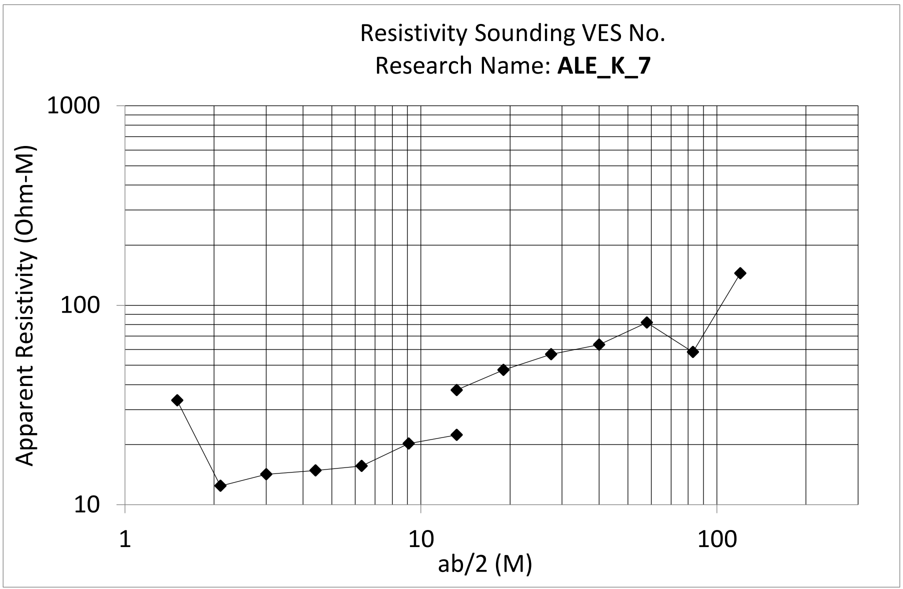
ab/2(m)	resistivity (ohm-m)
1.5	2.100
2.1	1.170
3.0	0.728
4.4	0.427
6.3	0.267
9.1	0.340
13.2	0.126
13.2	0.901
19.0	0.000
19.0	0.456
27.5	0.000
27.5	0.311
40.0	0.145
58.0	0.076
83.0	0.065
120.0	0.051



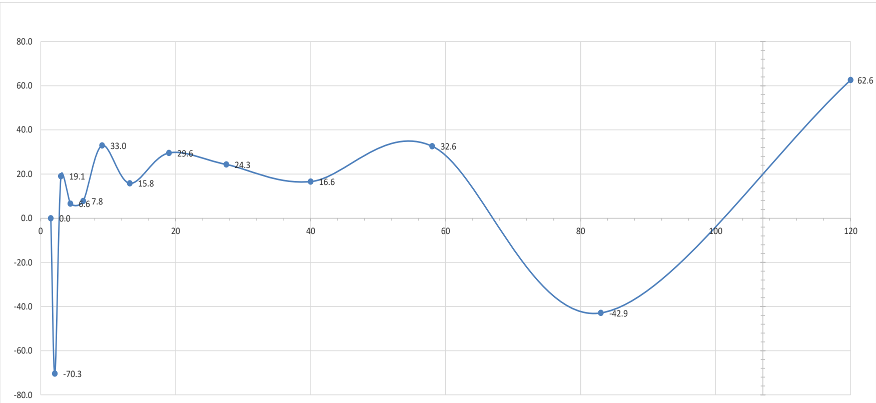
ab/2 (m)	Agoromin City
1.5	0.0
2.1	20.6
3	34.1
4.4	31.6
6.3	32.5
9.1	64.6
13.2	-35.0
19	18.8
27.5	45.5
40	0.0
58	16.1
83	51.5
120	49.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
552691	371163	61458	Agoromin City	AGC_K_32	Orom	Kitgum	Migmatitic garnetiferous gneiss

48	57	65	86	**Water stirke zones**
3.9	15	27.8	52	**Average angles**



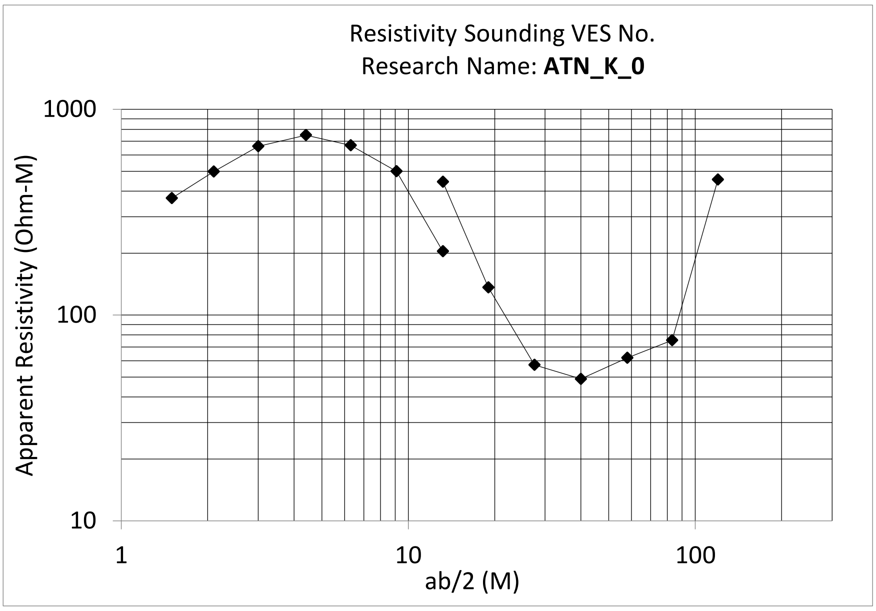
ab/2(m)	resistivity (ohm-m)
1.5	5.300
2.1	0.950
3.0	0.516
4.4	0.247
6.3	0.126
9.1	0.078
13.2	0.041
13.2	0.802
19.0	0.000
19.0	0.448
27.5	0.000
27.5	0.247
40.0	0.128
58.0	0.078
83.0	0.027
120.0	0.032

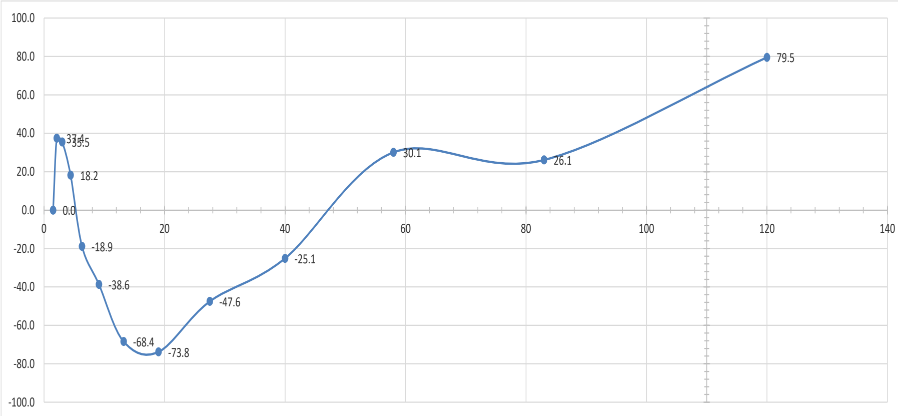


ab/2 (m)	**Alel East**
1.5	0.0
2.1	-70.3
3	19.1
4.4	6.6
6.3	7.8
9.1	33.0
13.2	15.8
19	29.6
27.5	24.3
40	16.6
58	32.6
83	-42.9
120	62.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
511092	362875	61455	Alel East	ALE_K_7	Lagoro	Kitgum	Migmatitic garnetiferous gneiss

32	46	75	107	**Water stirke zones**
20	24	-32	20	**Average angles**



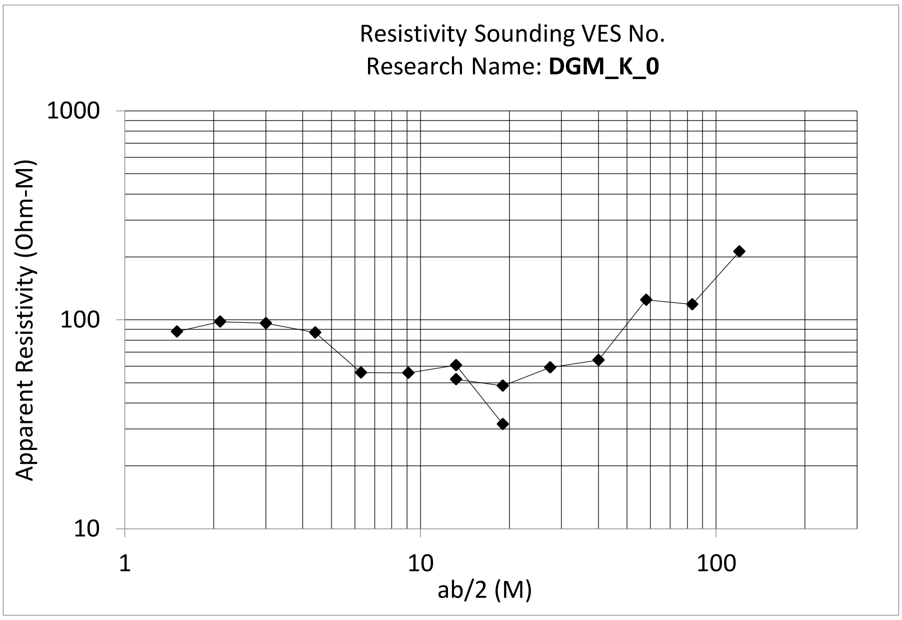


ab/2(m)	resistivity (ohm-m)
1.5	58.930
2.1	38.150
3.0	24.030
4.4	12.470
6.3	5.390
9.1	1.930
13.2	0.373
13.2	9.470
19.0	0.000
19.0	1.290
27.5	0.000
27.5	0.249
40.0	0.099
58.0	0.059
83.0	0.035
120.0	0.101

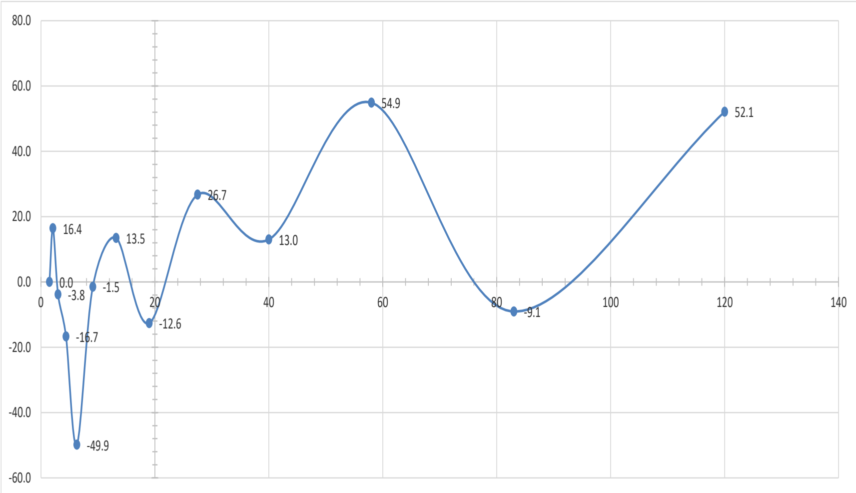
ab/2 (m)	Atocon(Dry)
1.5	0.0
2.1	37.4
3	35.5
4.4	18.2
6.3	-18.9
9.1	-38.6
13.2	-68.4
19	-73.8
27.5	-47.6
40	-25.1
58	30.1
83	26.1
120	79.5

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
522005	363369	61456	Atocon	ATN_K_0	Omiya Anyima	Kitgum	Migmatitic garnetiferous gneiss

	Water stirke zones
	Average angles



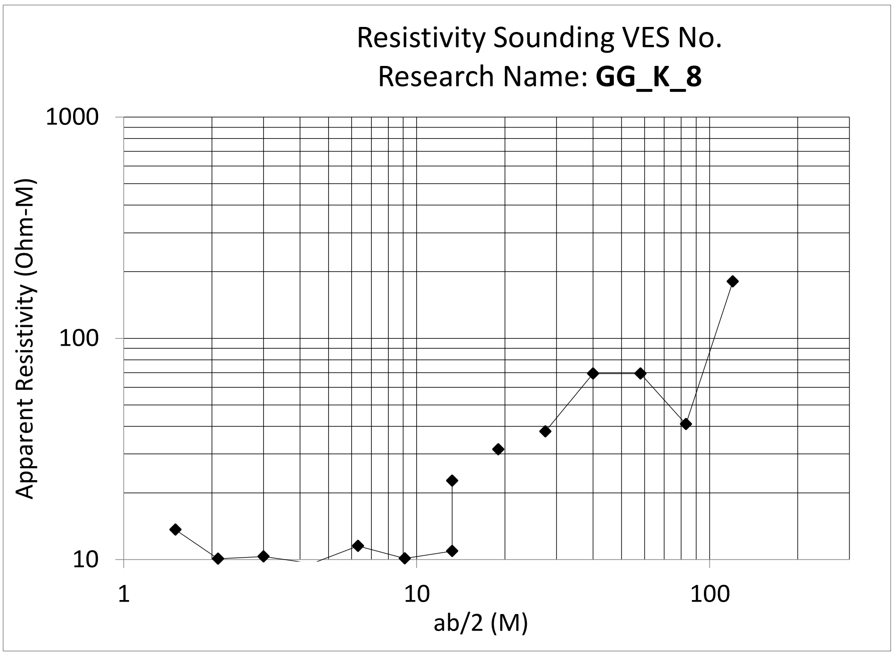
ab/2(m)	resistivity (ohm-m)
1.5	14.000
2.1	7.500
3.0	3.500
4.4	1.450
6.3	0.452
9.1	0.215
13.2	0.111
13.2	1.110
19.0	0.028
19.0	0.458
27.5	
27.5	0.258
40.0	0.130
58.0	0.119
83.0	0.055
120.0	0.047

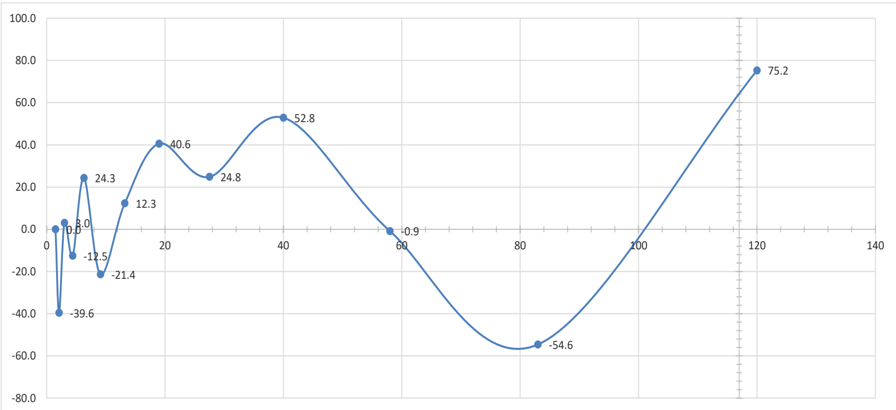


ab/2 (m)	Dognam
1.5	0.0
2.1	16.4
3	-3.8
4.4	-16.7
6.3	-49.9
9.1	-1.5
13.2	13.5
19	-12.6
27.5	26.7
40	13.0
58	54.9
83	-9.1
120	52.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
502312	365953	60768	Dognam	DGM_K_0	Kitgum Matidi	Kitgum	Kitgum granite

	Water strike zones
	Average angles



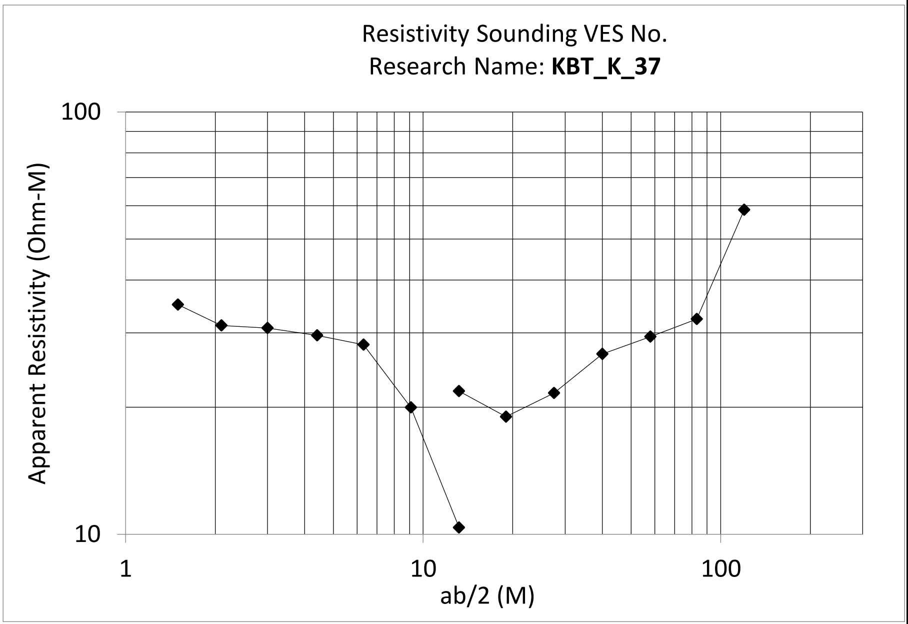


ab/2(m)	resistivity (ohm-m)
1.5	2.170
2.1	0.773
3.0	0.376
4.4	0.160
6.3	0.093
9.1	0.039
13.2	0.020
13.2	0.485
19.0	0.000
19.0	0.298
27.5	0.000
27.5	0.165
40.0	0.140
58.0	0.066
83.0	0.019
120.0	0.040

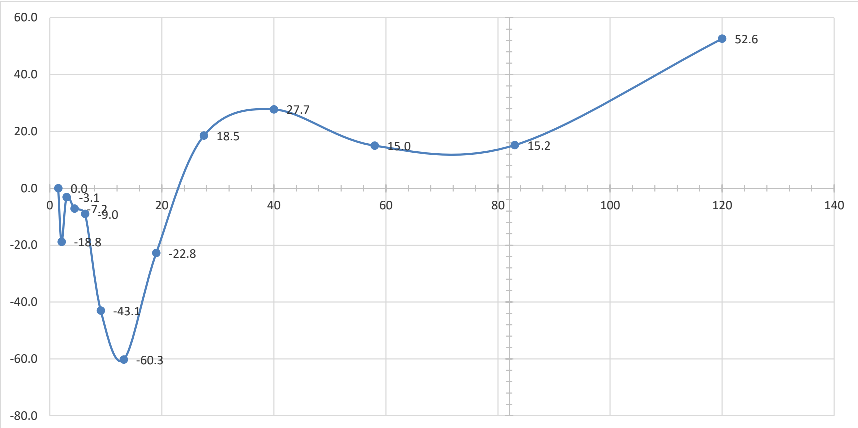
ab/2 (m)	Gili Gili
1.5	0.0
2.1	-39.6
3	3.0
4.4	-12.5
6.3	24.3
9.1	-21.4
13.2	12.3
19	40.6
27.5	24.8
40	52.8
58	-0.9
83	-54.6
120	75.2

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
543369	376375	61462	Gili-Gili	GG_K_8	Namokora	Kitgum	Migmatitic garnetiferous gneiss

73	82	91	96	117	**Water strike zones**
-49	-56	-36	-20	64	**Average angles**



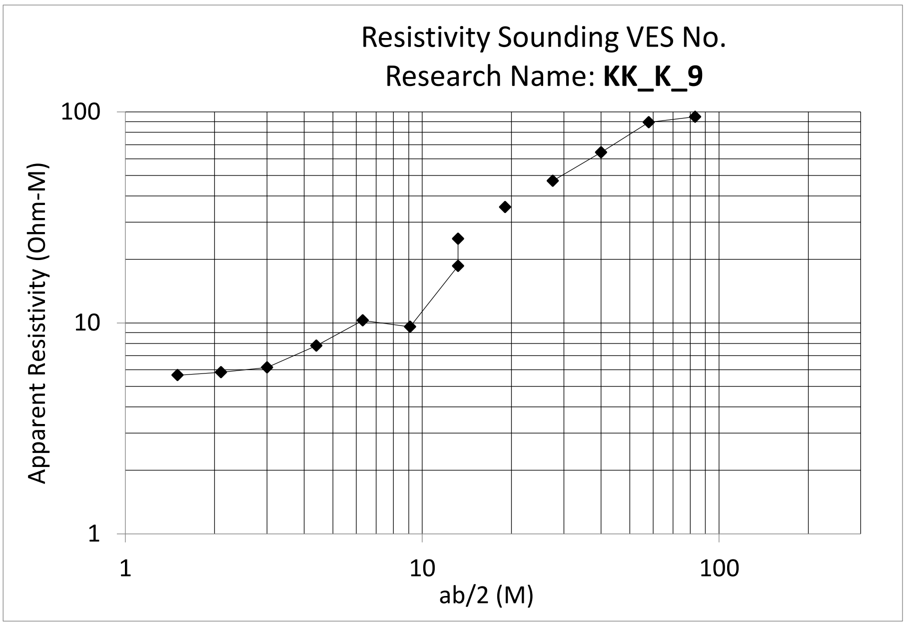
ab/2(m)	resistivity (ohm-m)
1.5	5.570
2.1	2.390
3.0	1.120
4.4	0.493
6.3	0.227
9.1	0.077
13.2	0.019
13.2	0.466
19.0	0.000
19.0	0.180
27.5	0.000
27.5	0.094
40.0	0.054
58.0	0.028
83.0	0.015
120.0	0.013



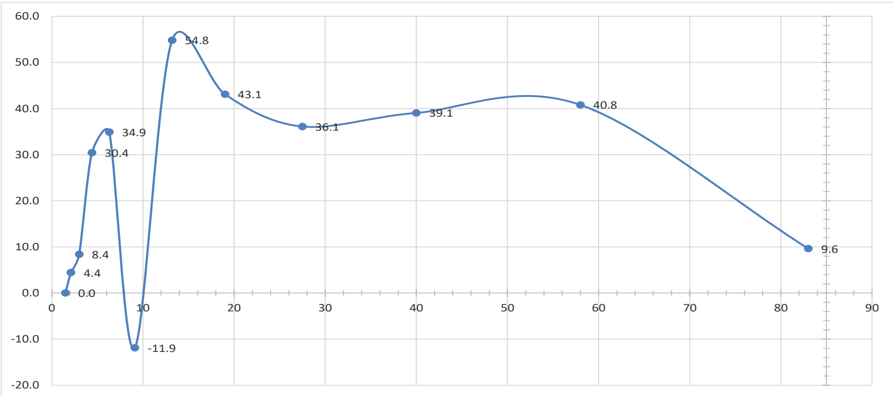
ab/2 (m)	Lakwere Okaro(Kabete)
1.5	0.0
2.1	-18.8
3	-3.1
4.4	-7.2
6.3	-9.0
9.1	-43.1
13.2	-60.3
19	-22.8
27.5	18.5
40	27.7
58	15.0
83	15.2
120	52.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
498443	374255	60772	Lakwere Okaro-Kabete	KBT_K_37	Mucwini	Kitgum	Migmatitic garnetiferous gneiss

36	41	46	50	59	78	82	**Water strike zones**
28	27.9	24	20	15	13	15.0	**Average angles**



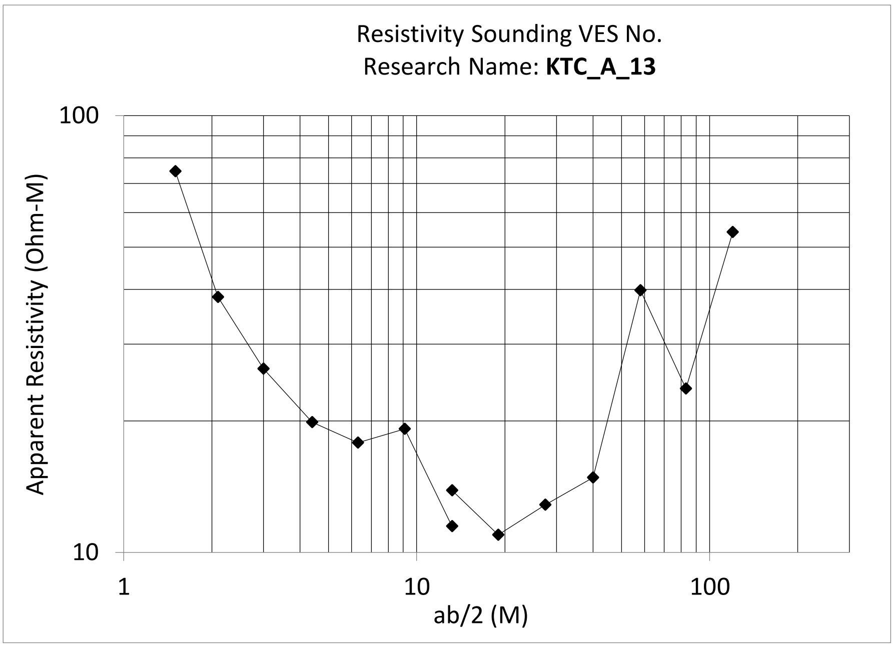
ab/2(m)	resistivity (ohm-m)
1.5	0.899
2.1	0.446
3.0	0.224
4.4	0.130
6.3	0.083
9.1	0.037
13.2	0.034
13.2	0.534
19.0	0.000
19.0	0.335
27.5	0.000
27.5	0.205
40.0	0.130
58.0	0.085
83.0	0.044
120.0	0.000



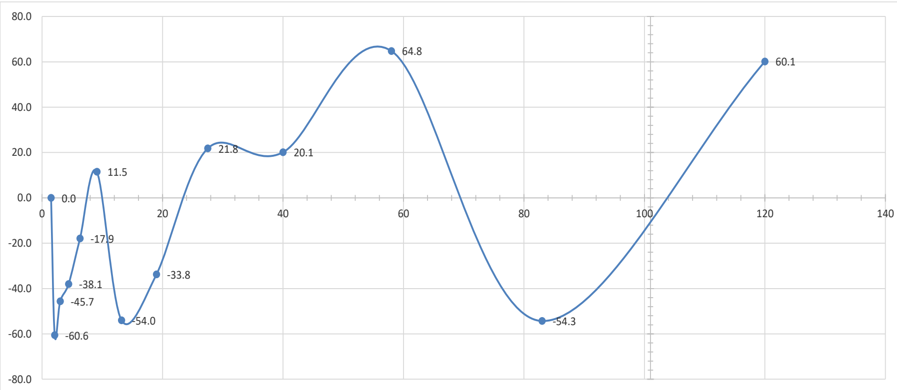
ab/2 (m)	Kako
1.5	0.0
2.1	4.4
3	8.4
4.4	30.4
6.3	34.9
9.1	-11.9
13.2	54.8
19	43.1
27.5	36.1
40	39.1
58	40.8
83	9.6
120	

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
538635	372027	61463	Kako	KK_K_9	Namokora	Kitgum	Migmatitic garnetiferous gneiss

36	40	52	74	85	116	**Water strike zones**
38	39.5	43	22	N/A	N/A	**Average angles**



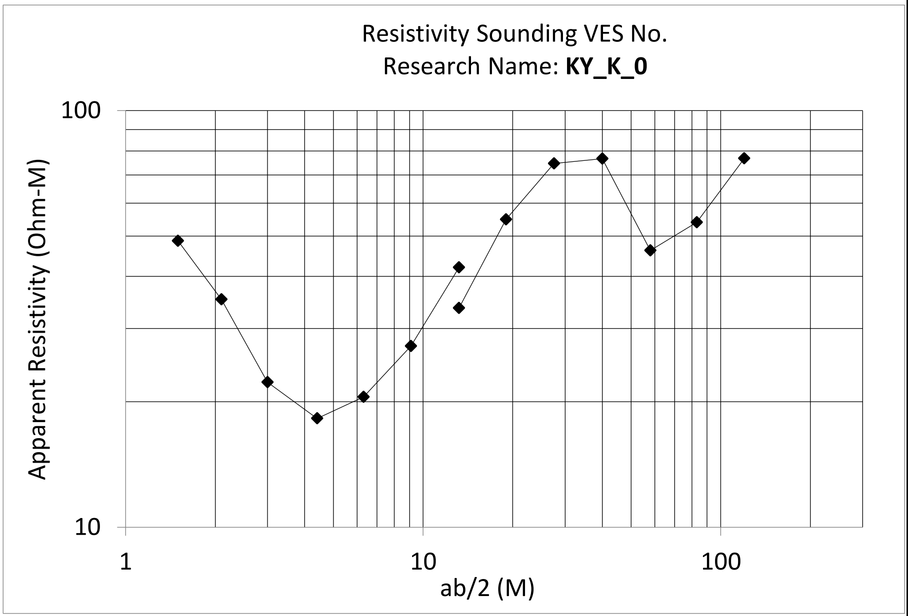
ab/2(m)	resistivity (ohm-m)
1.5	11.870
2.1	2.940
3.0	0.958
4.4	0.331
6.3	0.144
9.1	0.074
13.2	0.021
13.2	0.296
19.0	0.000
19.0	0.104
27.5	0.000
27.5	0.056
40.0	0.030
58.0	0.038
83.0	0.011
120.0	0.012



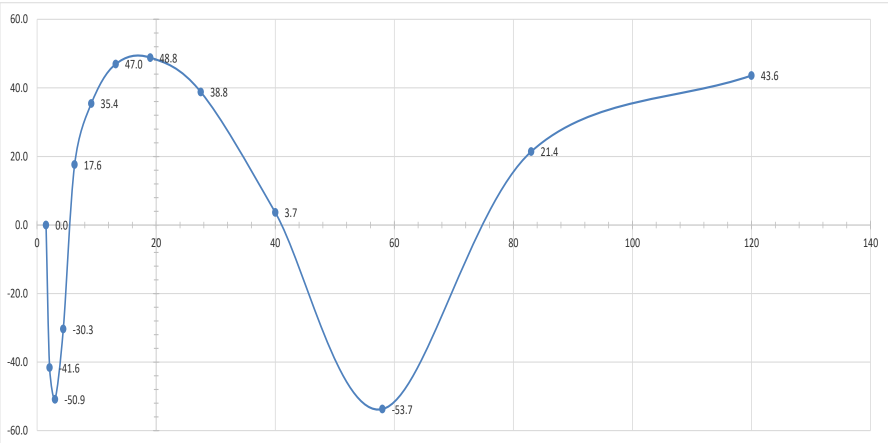
ab/2 (m)	Ongam(Kalongo TC)
1.5	0.0
2.1	-60.6
3	-45.7
4.4	-38.1
6.3	-17.9
9.1	11.5
13.2	-54.0
19	-33.8
27.5	21.8
40	20.1
58	64.8
83	-54.3
120	60.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
542782	335363	61453	Kalongo TC/Ongam	KTC_A_13	Paimol	Agago	Migmatitic garnetiferous gneiss

27	35	61	101	**Water strike zones**
21	20	34	-10	**Average angles**



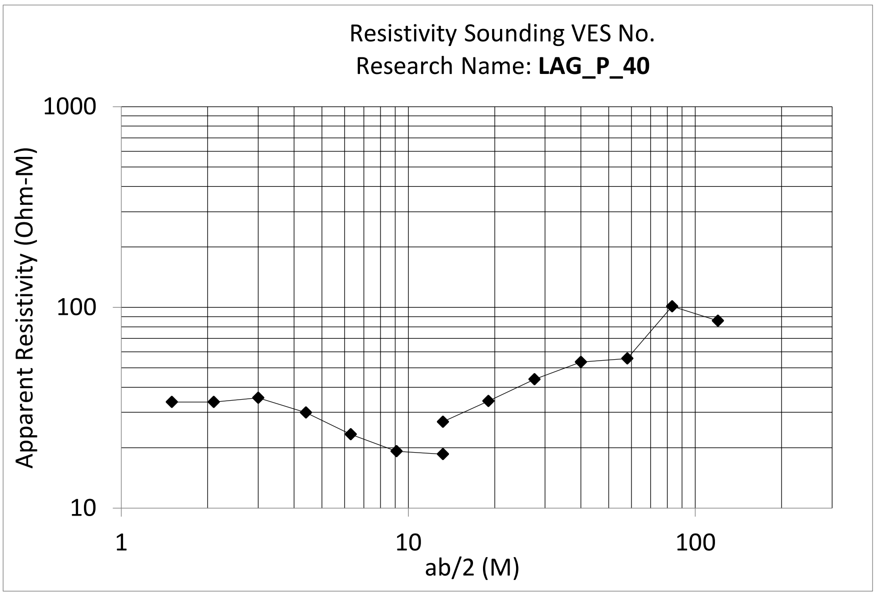
ab/2(m)	resistivity (ohm-m)
1.5	7.751
2.1	2.695
3.0	0.811
4.4	0.304
6.3	0.166
9.1	0.105
13.2	0.077
13.2	0.717
19.0	0.000
19.0	0.519
27.5	0.000
27.5	0.325
40.0	0.155
58.0	0.044
83.0	0.025
120.0	0.017

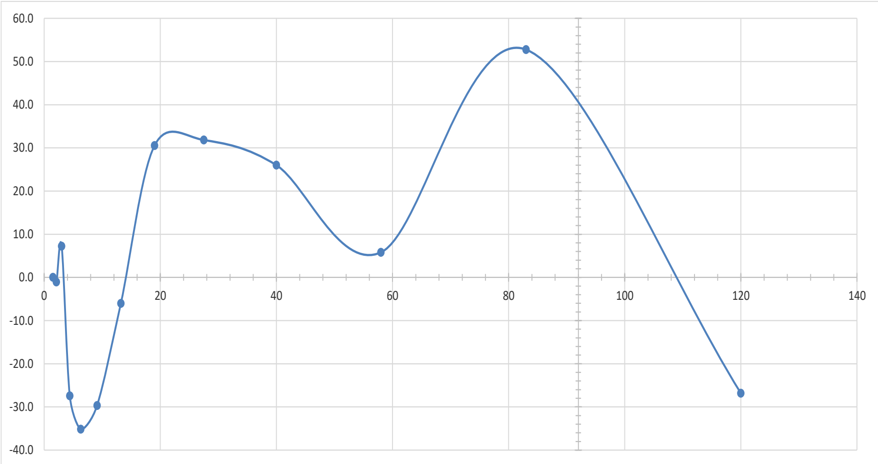


ab/2 (m)	Kweyo dry
1.5	0.0
2.1	-41.6
3	-50.9
4.4	-30.3
6.3	17.6
9.1	35.4
13.2	47.0
19	48.8
27.5	38.8
40	3.7
58	-53.7
83	21.4
120	43.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
524981	361406	60590	Kweyo	KY_K_0	Omiya Anyima	Kitgum	Migmatitic garnetiferous gneiss

	Water strike zones
	Average angles



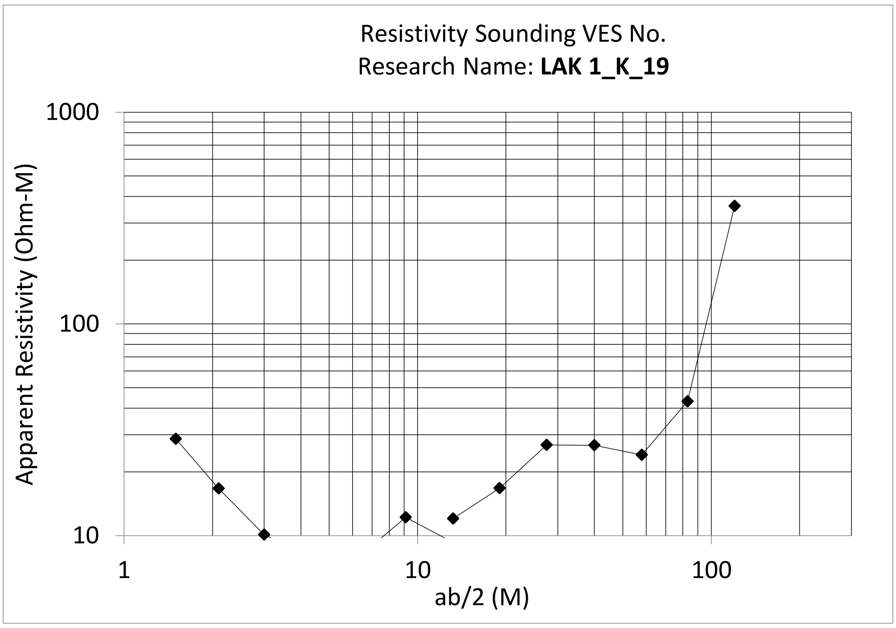


ab/2(m)	resistivity (ohm-m)
1.5	5.389
2.1	2.586
3.0	1.290
4.4	0.498
6.3	0.188
9.1	0.074
13.2	0.034
13.2	0.575
19.0	0.000
19.0	0.324
27.5	0.000
27.5	0.191
40.0	0.108
58.0	0.053
83.0	0.047
120.0	0.019

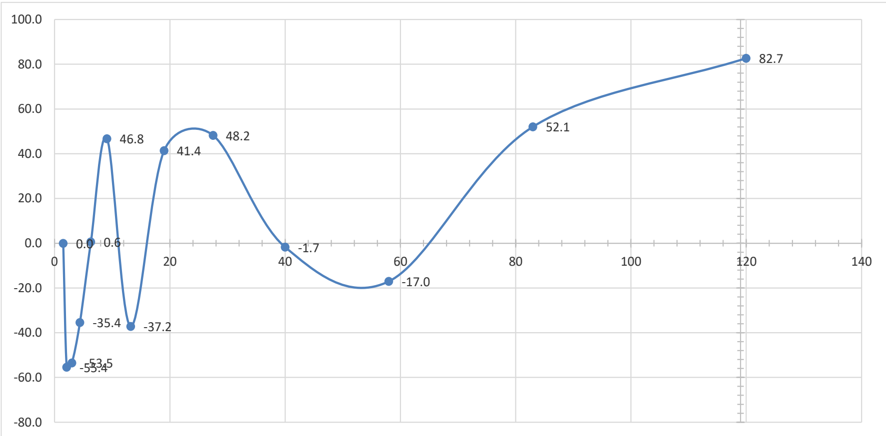
ab/2 (m)	Lageng
1.5	0.0
2.1	-1.1
3	7.2
4.4	-27.4
6.3	-35.2
9.1	-29.7
13.2	-6.0
19	30.5
27.5	31.8
40	26.0
58	5.8
83	52.8
120	-26.8

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
488595	346081	60600	Lageng	LAG_P_40	Acholibur	Pader	Awela granodiorite gneiss

29	59	64	92	**Water strike zones**
32	6	17	40	**Average angles**



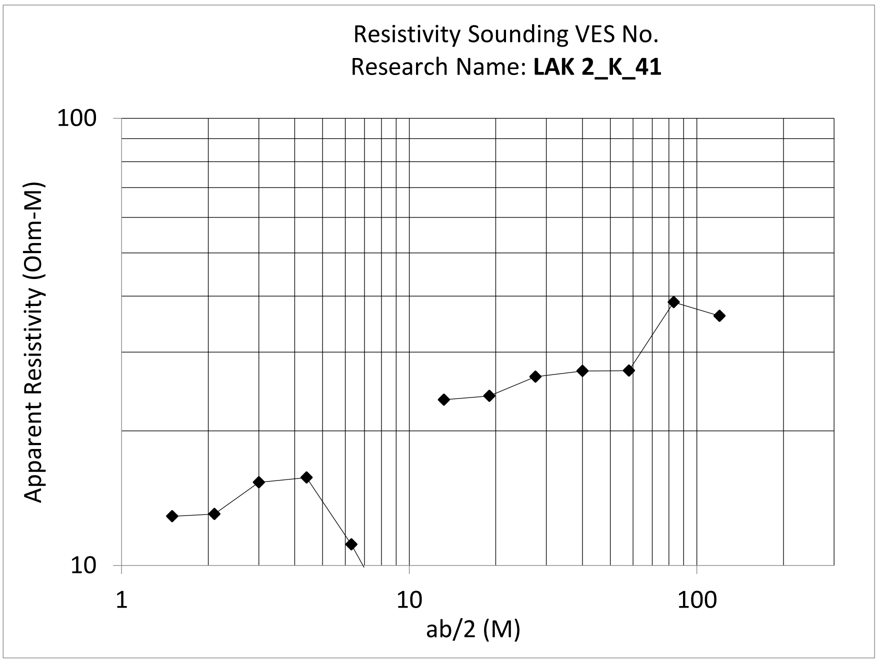
ab/2(m)	resistivity (ohm-m)
1.5	4.570
2.1	1.280
3.0	0.368
4.4	0.131
6.3	0.064
9.1	0.047
13.2	0.017
13.2	0.257
19.0	0.000
19.0	0.159
27.5	0.000
27.5	0.117
40.0	0.054
58.0	0.023
83.0	0.020
120.0	0.080



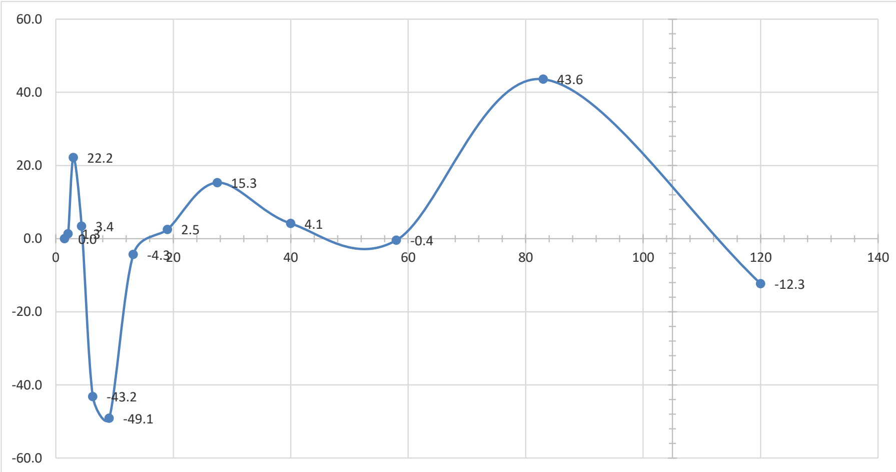
ab/2 (m)	Lakongera 1_Akilok 1
1.5	0.0
2.1	-55.4
3	-53.5
4.4	-35.4
6.3	0.6
9.1	46.8
13.2	-37.2
19	41.4
27.5	48.2
40	-1.7
58	-17.0
83	52.1
120	82.7

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
554687	388374	60635	Lakongera 1	LAK 1_K_19	Orom	Kitgum	Migmatitic garnetiferous gneiss

78	82	87	115	119	**Water strike zones**
42.0	50.0	57.0	79.0	82.0	**Average angles**



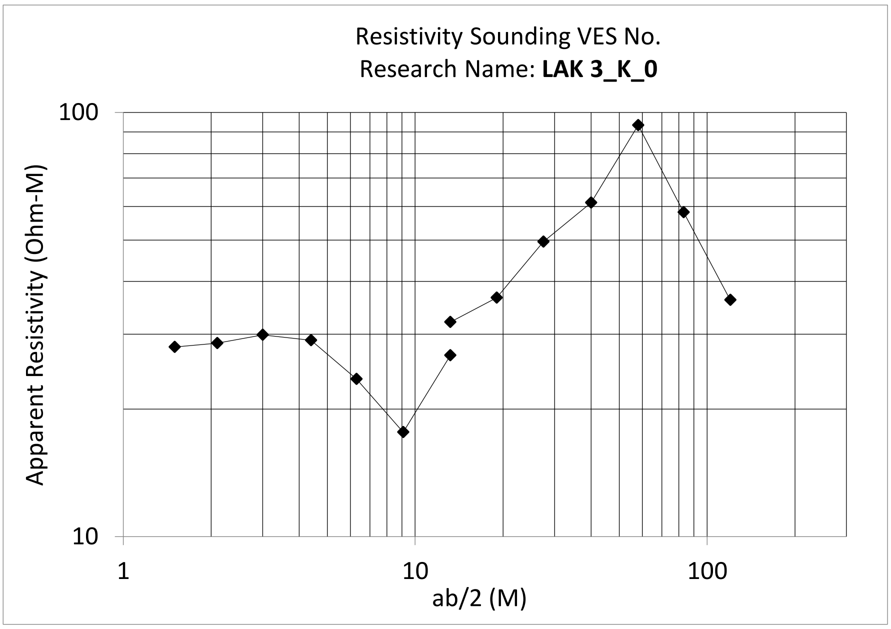
ab/2(m)	resistivity (ohm-m)
1.5	2.050
2.1	0.998
3.0	0.558
4.4	0.262
6.3	0.090
9.1	0.028
13.2	0.013
13.2	0.501
19.0	0.000
19.0	0.227
27.5	0.000
27.5	0.115
40.0	0.055
58.0	0.026
83.0	0.018
120.0	0.008



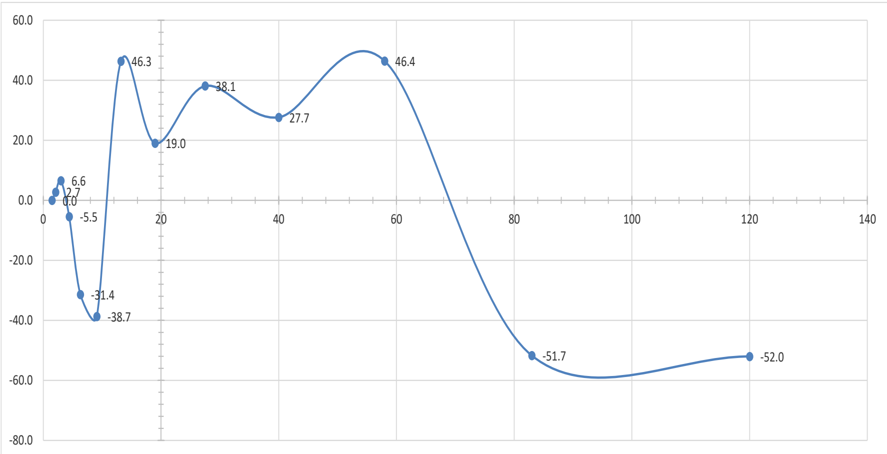
ab/2 (m)	Lakongera 2_Akilok 2
1.5	0.0
2.1	1.3
3	22.2
4.4	3.4
6.3	-43.2
9.1	-49.1
13.2	-4.3
19	2.5
27.5	15.3
40	4.1
58	-0.4
83	43.6
120	-12.3

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
554052	389034	60637	Lakongera 2	LAK 2_K_41	Orom	Kitgum	Migmatitic garnetiferous gneiss

46	50	55	64	69	73	105	**Water strike zones**
0	-3	-3	13.0	24.0	33.0	14.0	**Average angles**



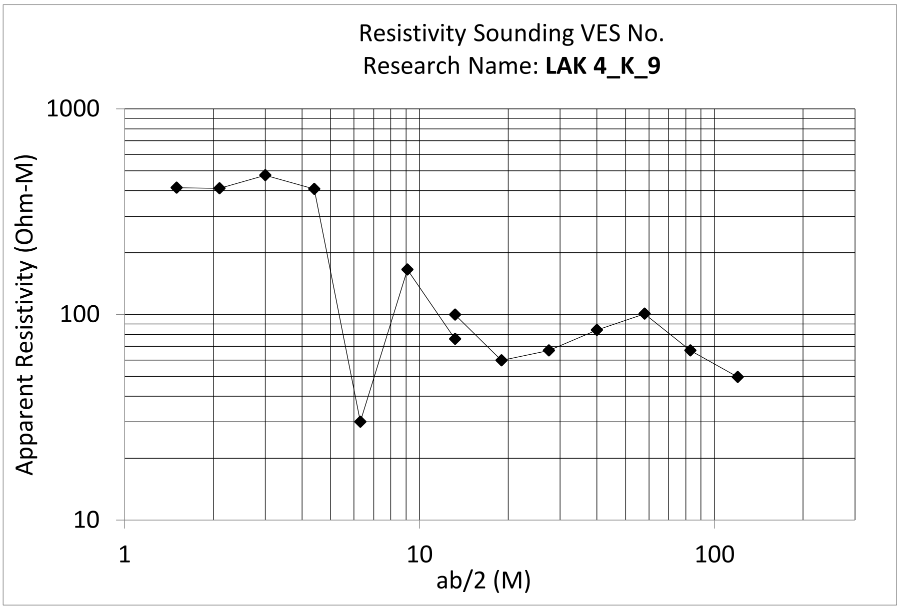
ab/2(m)	Resistivity (ohm-m)
1.5	4.460
2.1	2.190
3.0	1.088
4.4	0.484
6.3	0.190
9.1	0.068
13.2	0.049
13.2	0.684
19.0	0.000
19.0	0.347
27.5	0.000
27.5	0.216
40.0	0.124
58.0	0.089
83.0	0.027
120.0	0.008



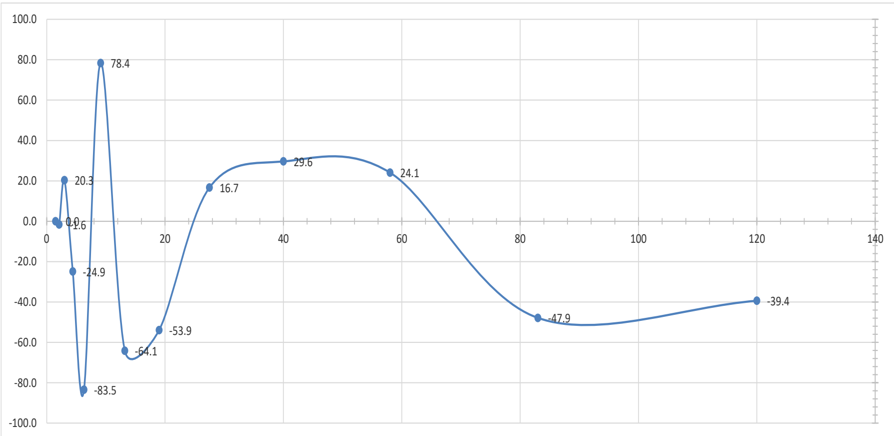
ab/2 (m)	Lakongera 3_Akilok 3
1.5	0.0
2.1	2.7
3	6.6
4.4	-5.5
6.3	-31.4
9.1	-38.7
13.2	46.3
19	19.0
27.5	38.1
40	27.7
58	46.4
83	-51.7
120	-52.0

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
554763	388389	60647	Lakongera 3	LAK 3_K_0	Orom	Kitgum	Migmatitic garnetiferous gneiss

	Water strike zones
	Average angles



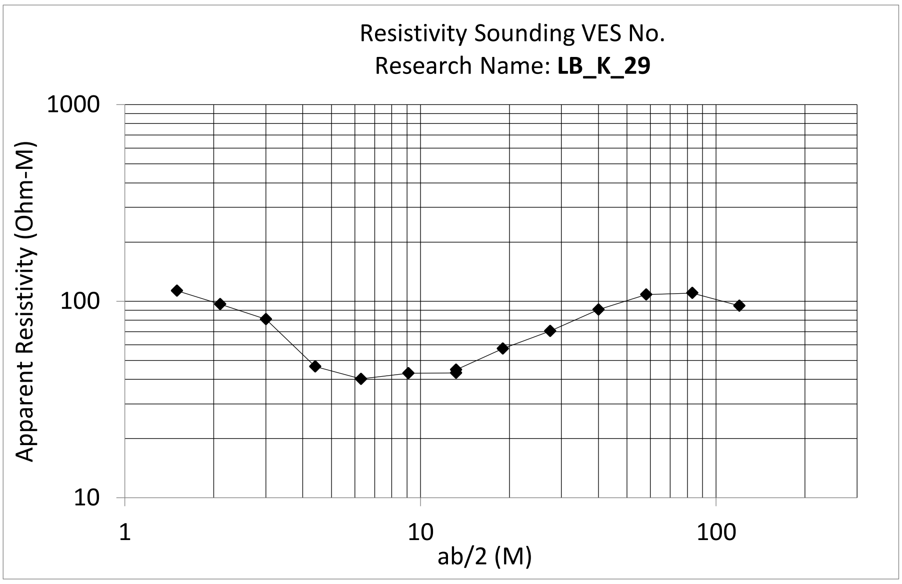
ab/2(m)	resistivity (ohm-m)
1.5	65.760
2.1	31.450
3.0	17.290
4.4	6.790
6.3	0.243
9.1	0.637
13.2	0.139
13.2	2.130
19.0	
19.0	0.567
27.5	
27.5	0.291
40.0	0.170
58.0	0.096
83.0	0.031
120.0	0.011



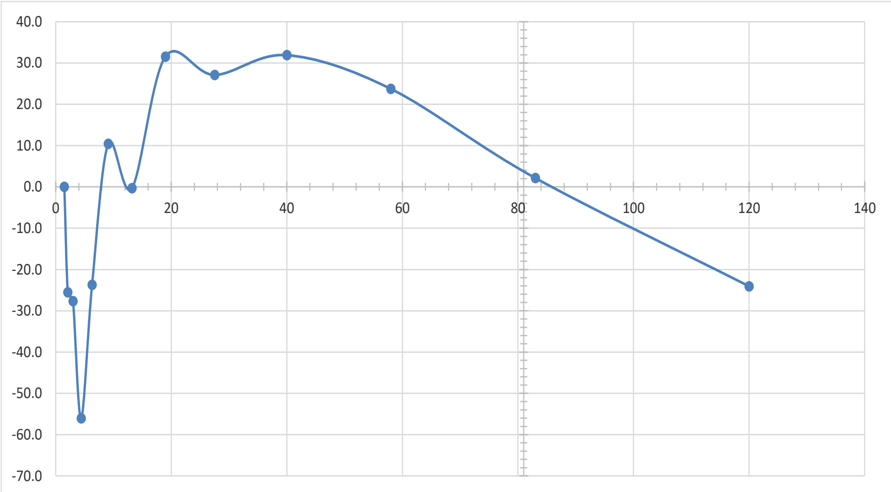
ab/2 (m)	Lakongera 4 - Lalekan
1.5	0.0
2.1	-1.6
3	20.3
4.4	-24.9
6.3	-83.5
9.1	78.4
13.2	-64.1
19	-53.9
27.5	16.7
40	29.6
58	24.1
83	-47.9
120	-39.4

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
551163	387772	60758	Lakongera 4	LAK 4_K_9	Orom	Kitgum	Migmatitic garnetiferous gneiss

41	92	147	Water strike zones
30	-52		Average angles



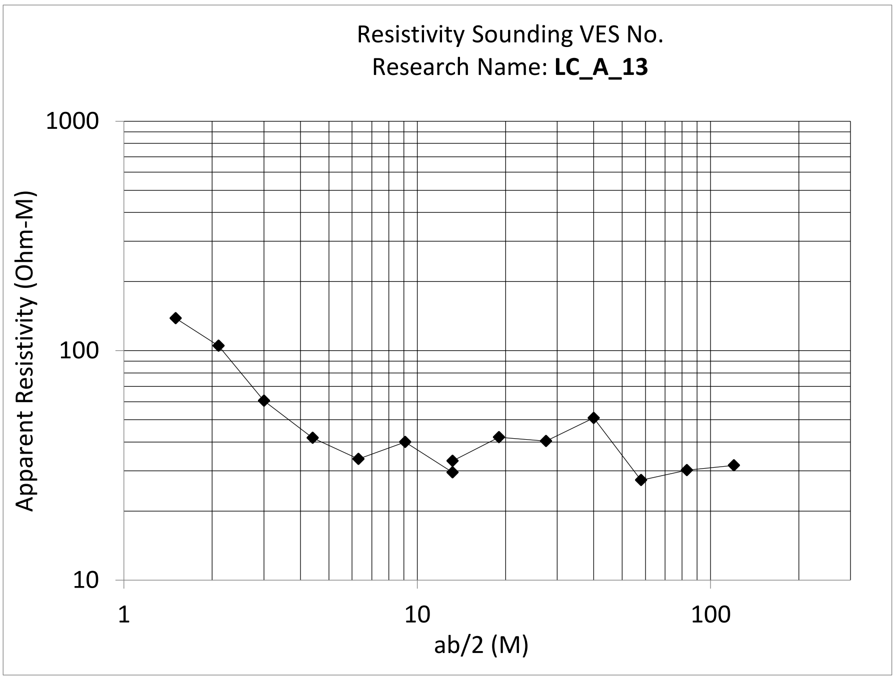
ab/2(m)	resistivity (ohm-m)
1.5	18.000
2.1	7.390
3.0	2.950
4.4	0.776
6.3	0.325
9.1	0.166
13.2	0.079
13.2	0.955
19.0	0.000
19.0	0.543
27.5	0.000
27.5	0.307
40.0	0.183
58.0	0.103
83.0	0.051
120.0	0.021



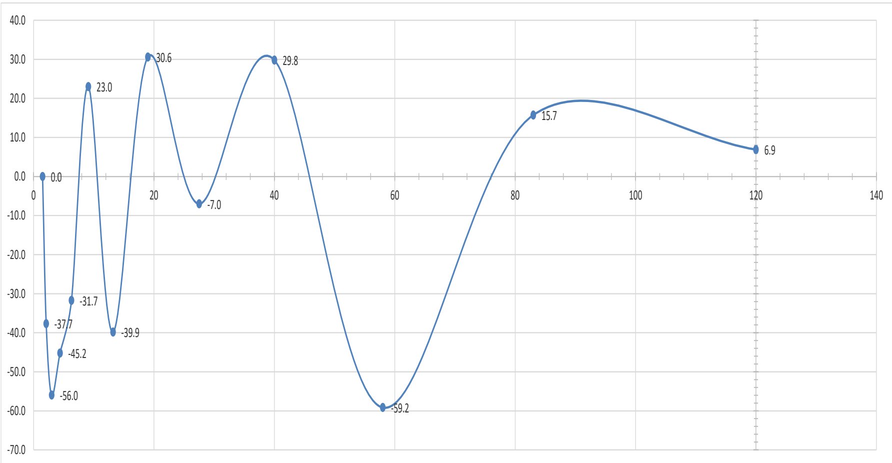
ab/2 (m)	Labilo B
1.5	0.0
2.1	-25.5
3	-27.7
4.4	-56.1
6.3	-23.7
9.1	10.4
13.2	-0.3
19	31.6
27.5	27.1
40	31.9
58	23.7
83	2.2
120	-24.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
507107	363450	61454	Labilo B	LB_K_29	Lagoro	Kitgum	Charnockite

36	45	65	81	**Water strike zones**
31	31	18	4	**Average angles**



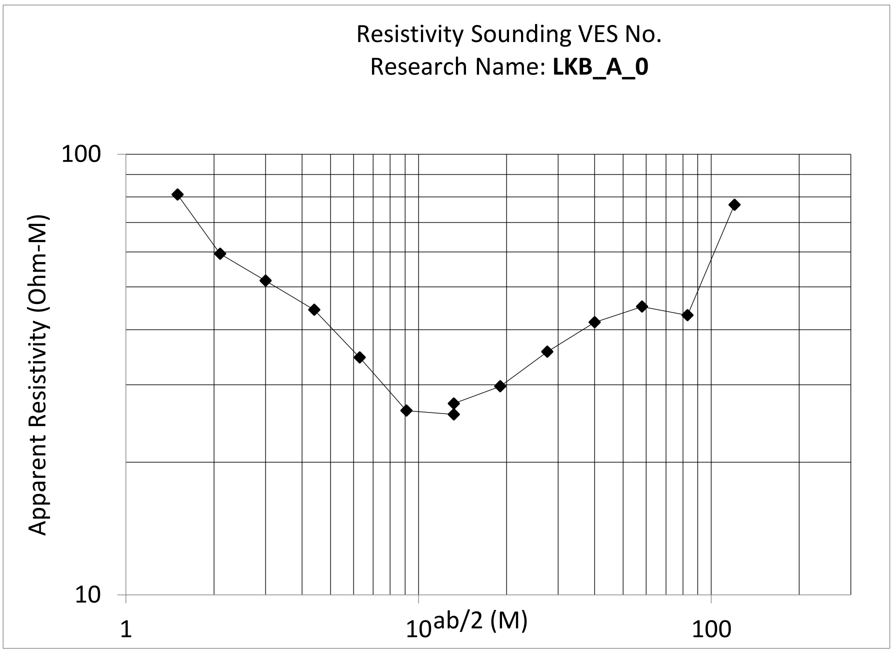
ab/2(m)	resistivity (ohm-m)
1.5	22.070
2.1	8.040
3.0	2.200
4.4	0.695
6.3	0.272
9.1	0.154
13.2	0.054
13.2	0.706
19.0	0.000
19.0	0.398
27.5	0.000
27.5	0.176
40.0	0.103
58.0	0.026
83.0	0.014
120.0	0.007

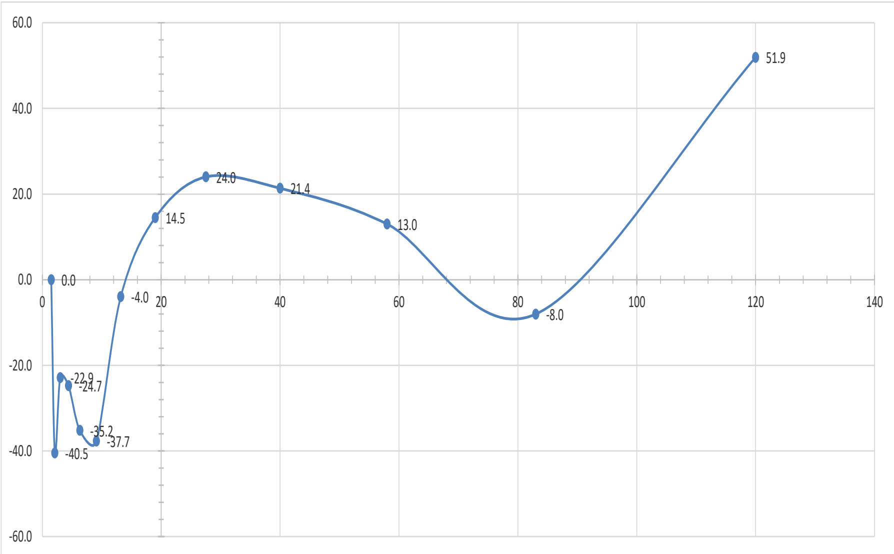


ab/2 (m)	Lai Central
1.5	0.0
2.1	-37.7
3	-56.0
4.4	-45.2
6.3	-31.7
9.1	23.0
13.2	-39.9
19	30.6
27.5	-7.0
40	29.8
58	-59.2
83	15.7
120	6.9

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
548557	346716	60627	Lai Central	LC_A_13	Paimol	Agago	Migmatitic garnetiferous gneiss

14	27	36	64	99	120	Water strike zones
-36	-7	26	-48	17	7.0	Average angles



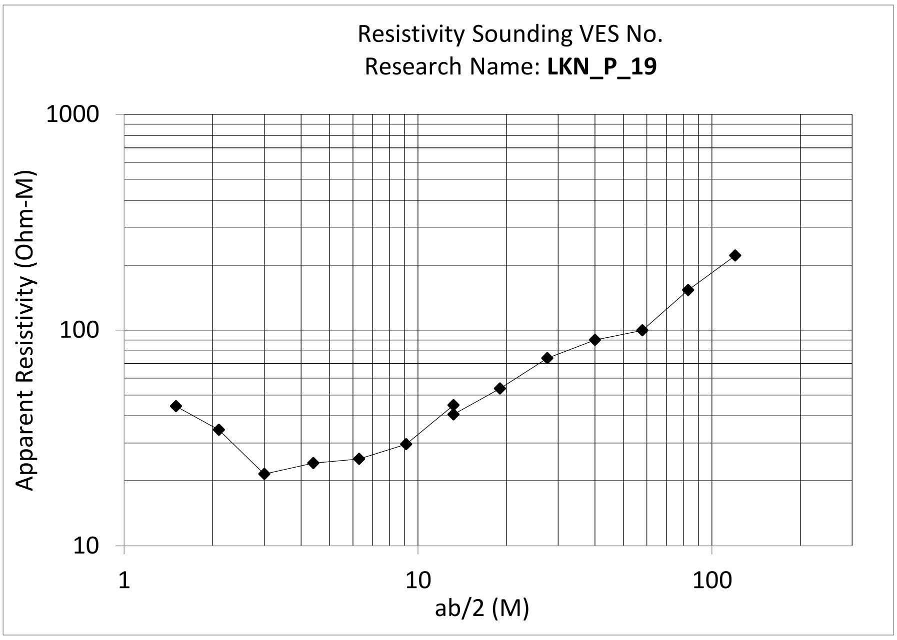


ab/2(m)	resistivity (ohm-m)
1.5	12.900
2.1	4.550
3.0	1.880
4.4	0.739
6.3	0.279
9.1	0.101
13.2	0.047
13.2	0.580
19.0	0.000
19.0	0.282
27.5	0.000
27.5	0.155
40.0	0.084
58.0	0.043
83.0	0.020
120.0	0.017

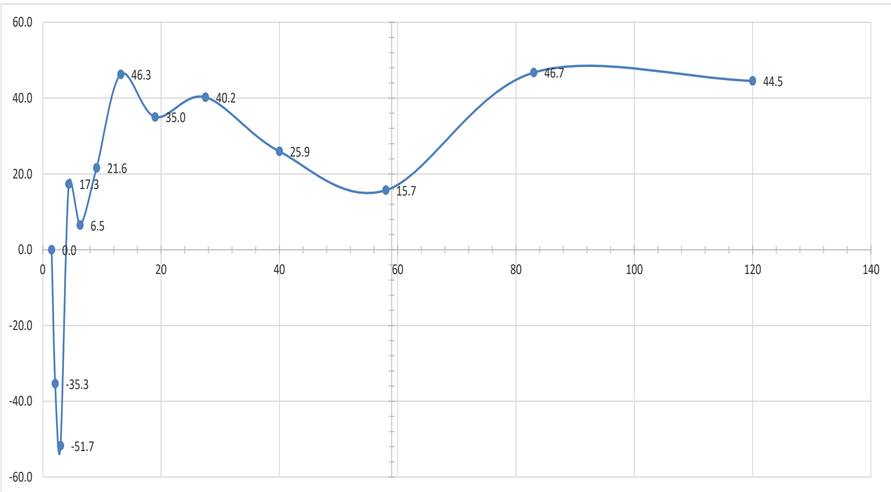
ab/2 (m)	Lakwabi
1.5	0.0
2.1	-40.5
3	-22.9
4.4	-24.7
6.3	-35.2
9.1	-37.7
13.2	-4.0
19	14.5
27.5	24.0
40	21.4
58	13.0
83	-8.0
120	51.9

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
546661	352960	61465	Lakwa B	LKB_A_0	Omiya Pachwa	Agago	Variable deformed granitoid

	Water strike zones
	Average angles



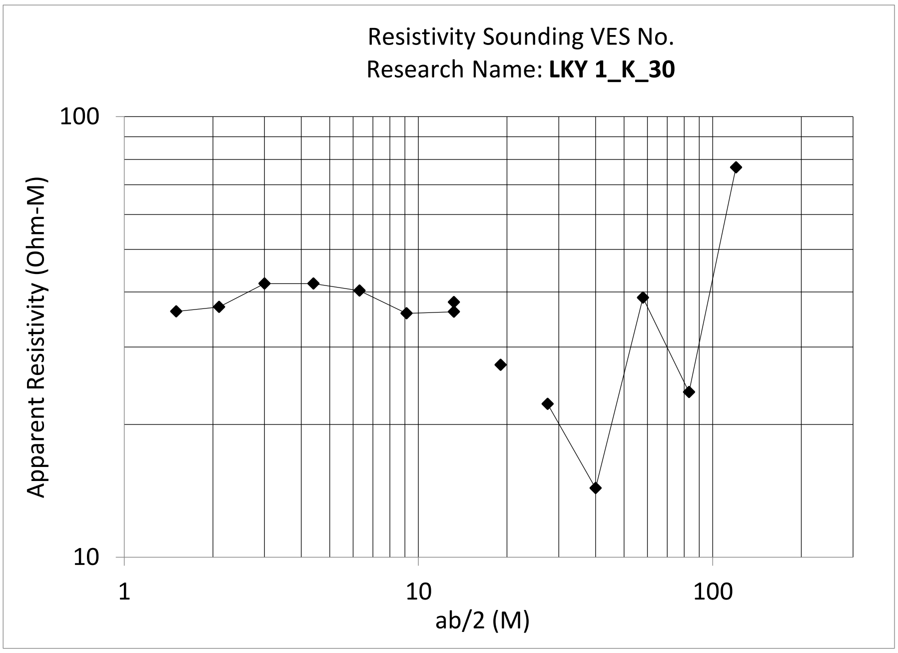
ab/2(m)	resistivity (ohm-m)
1.5	7.060
2.1	2.640
3.0	0.783
4.4	0.403
6.3	0.204
9.1	0.114
13.2	0.082
13.2	0.867
19.0	0.000
19.0	0.508
27.5	0.000
27.5	0.322
40.0	0.182
58.0	0.095
83.0	0.071
120.0	0.049



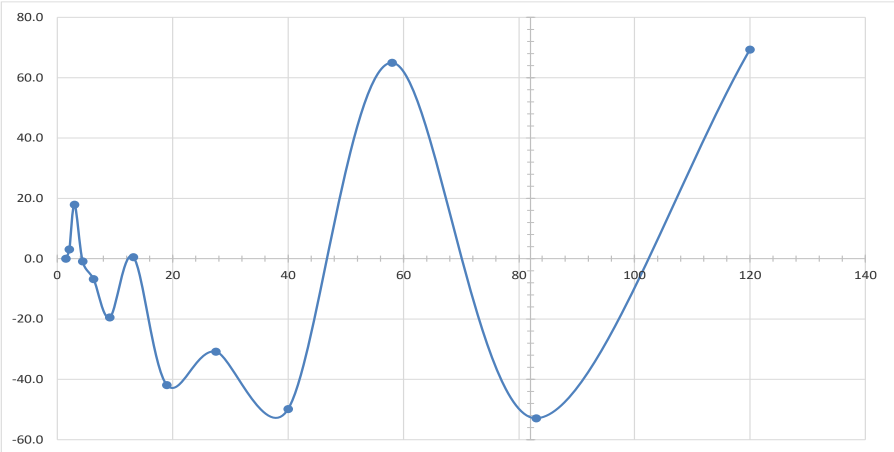
ab/2 (m)	Locken
1.5	0.0
2.1	-35.3
3	-51.7
4.4	17.3
6.3	6.5
9.1	21.6
13.2	46.3
19	35.0
27.5	40.2
40	25.9
58	15.7
83	46.7
120	44.5

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOL
495438	353855	60622	Locken	LKN_P_19	Latanya	Pader	Variabl granito

25	46	59	**Water strike zones**
40	20	16	**Average angles**



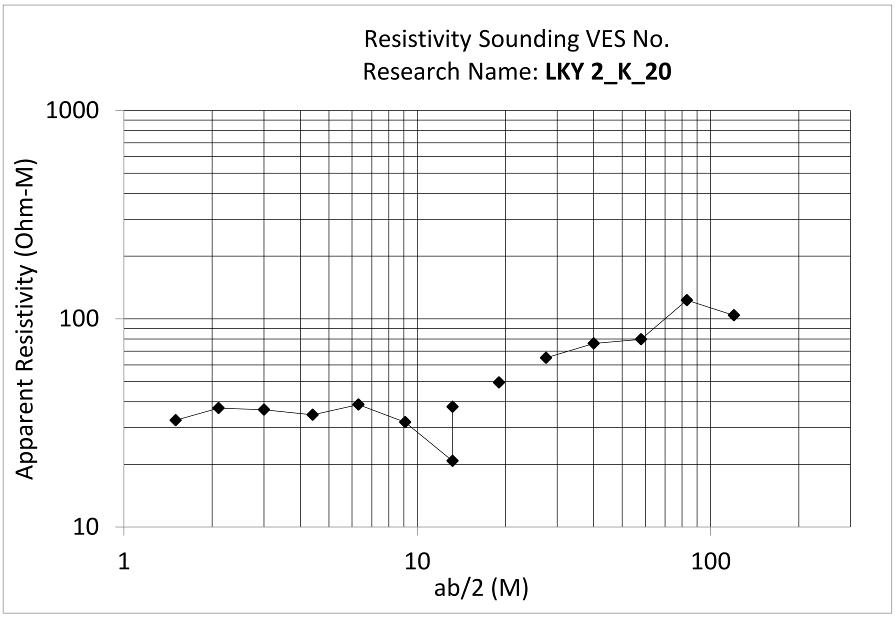
ab/2(m)	resistivity (ohm-m)
1.5	5.750
2.1	2.830
3.0	1.521
4.4	0.696
6.3	0.325
9.1	0.138
13.2	0.066
13.2	0.809
19.0	0.000
19.0	0.259
27.5	0.000
27.5	0.097
40.0	0.029
58.0	0.037
83.0	0.011
120.0	0.017



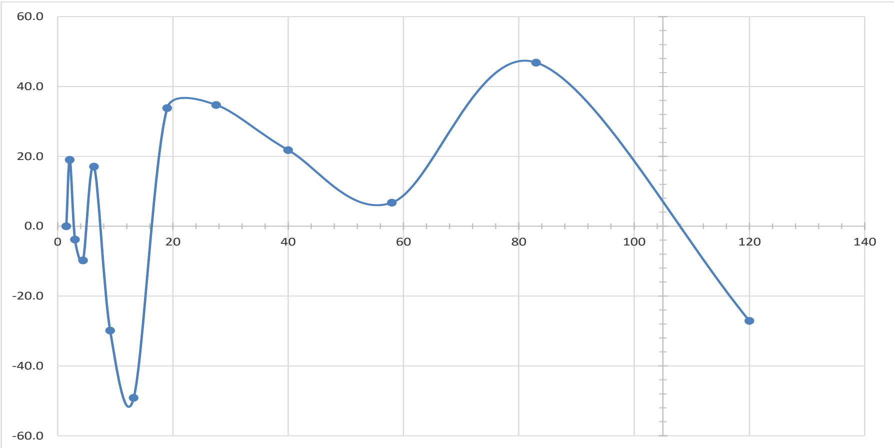
ab/2 (m)	Lapeitai(Lakwanya 1)
1.5	0.0
2.1	3.1
3	17.9
4.4	-0.9
6.3	-6.8
9.1	-19.5
13.2	0.5
19	-41.9
27.5	-30.8
40	-49.8
58	65.0
83	-52.9
120	69.3

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
559095	375677	60648	Lakwanya 1(Lapeitai)	LKY 1_K_30	Orom	Kitgum	Banded granulite and charnockite

36	46	69	78	82	**Water strike zones**
-52	-8	8	-44	-52.5	**Average angles**



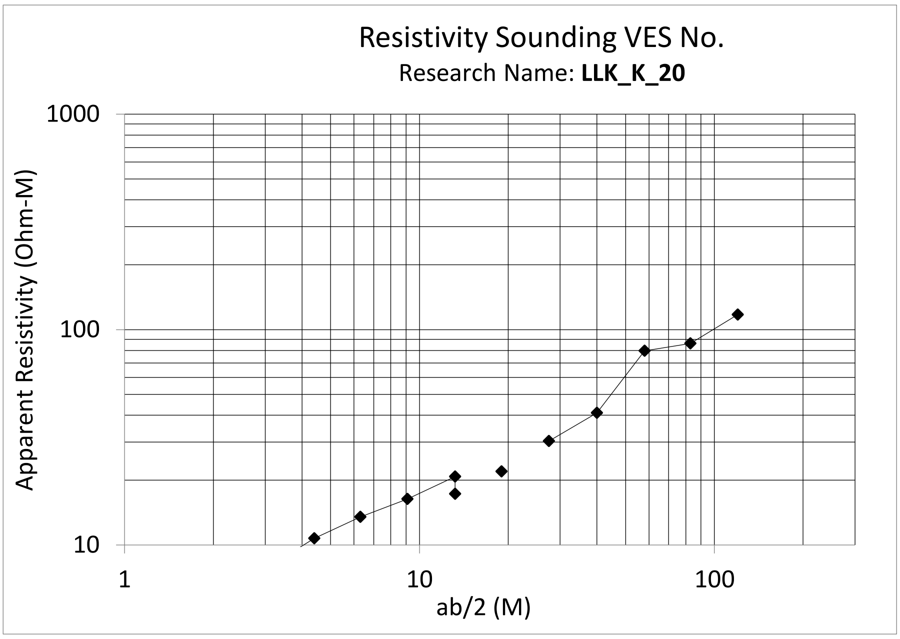
ab/2(m)	resistivity (ohm-m)
1.5	5.190
2.1	2.850
3.0	1.330
4.4	0.576
6.3	0.313
9.1	0.123
13.2	0.038
13.2	0.807
19.0	0.000
19.0	0.468
27.5	0.000
27.5	0.283
40.0	0.154
58.0	0.076
83.0	0.057
120.0	0.023

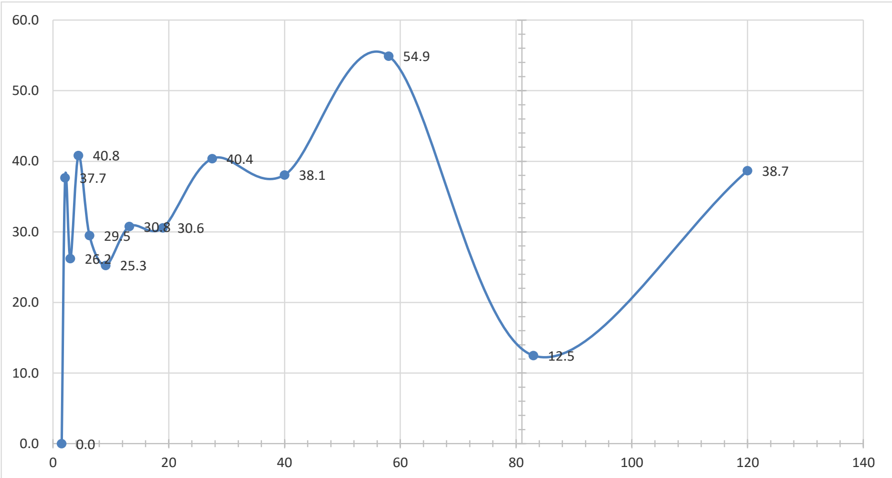


ab/2 (m)	Lakwanya 2
1.5	0.0
2.1	19.0
3	-3.8
4.4	-9.8
6.3	17.1
9.1	-29.9
13.2	-49.1
19	33.8
27.5	34.7
40	21.8
58	6.8
83	46.9
120	-27.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
569400	387477	60777	Lakwanya 2	LKY 2_K_20	Orom	Kitgum	Banded granulite and charnockite

18	41	73	78	96	101	105	**Water strike zones**
26	20	38.5	46	27	16	7.0	**Average angles**



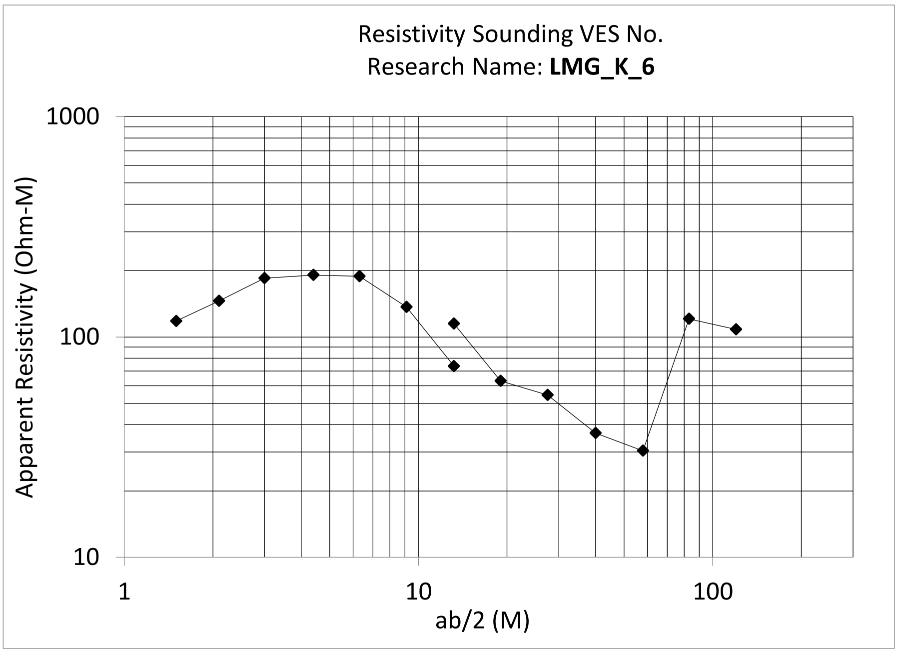


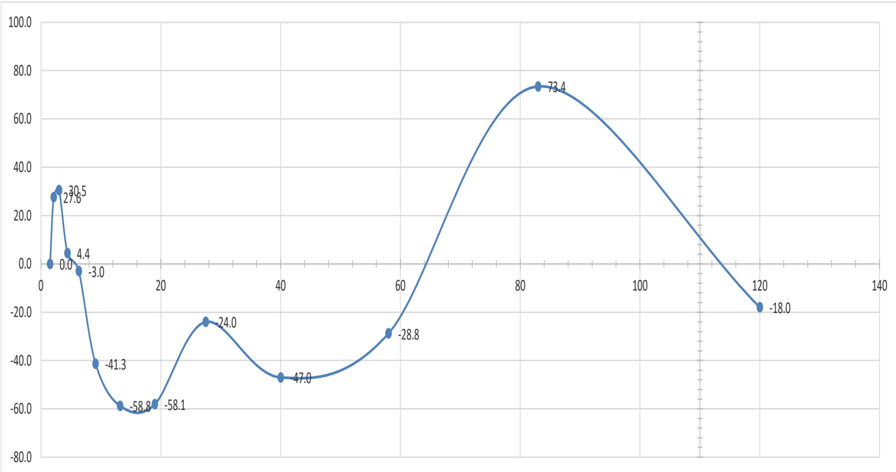
ab/2(m)	resistivity (ohm-m)
1.5	0.749
2.1	0.486
3.0	0.282
4.4	0.179
6.3	0.109
9.1	0.063
13.2	0.038
13.2	0.369
19.0	0.000
19.0	0.208
27.5	0.000
27.5	0.132
40.0	0.083
58.0	0.076
83.0	0.040
120.0	0.026

ab/2 (m)	Loluko
1.5	0.0
2.1	37.7
3	26.2
4.4	40.8
6.3	29.5
9.1	25.3
13.2	30.8
19	30.6
27.5	40.4
40	38.1
58	54.9
83	12.5
120	38.7

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
559599	383992	60639	Laluko	LLK_K_20	Orom	Kitgum	Banded granulite and charnockite

18	23	27	32	36	41	81	**Water strike zones**
30	36	40	39.5	37.9	38.9	13.5	**Average angles**



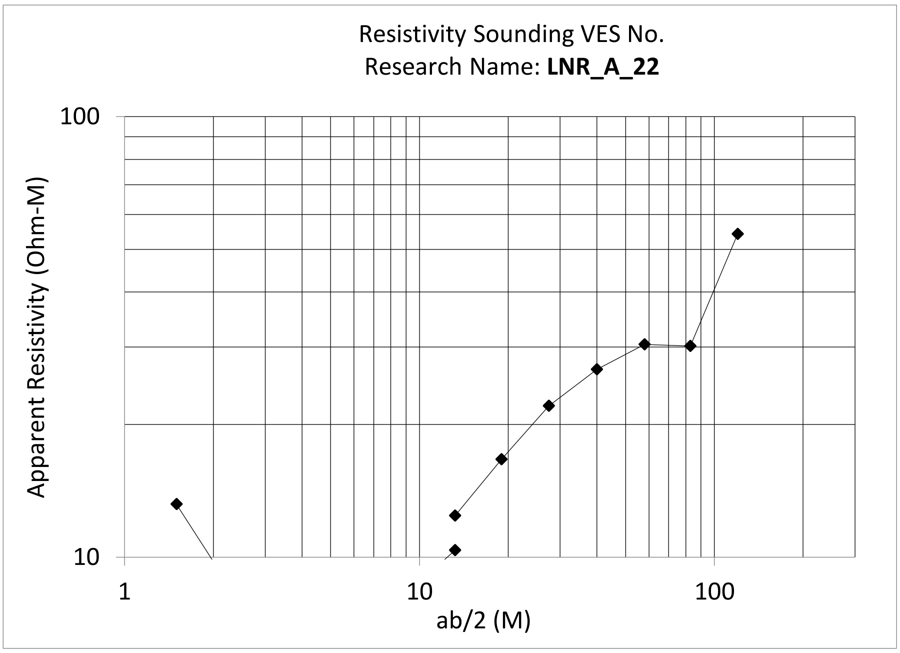


ab/2(m)	resistivity (ohm-m)
1.5	18.790
2.1	11.160
3.0	6.730
4.4	3.180
6.3	1.520
9.1	0.527
13.2	0.135
13.2	2.450
19.0	0.000
19.0	0.598
27.5	0.000
27.5	0.237
40.0	0.074
58.0	0.029
83.0	0.056
120.0	0.024

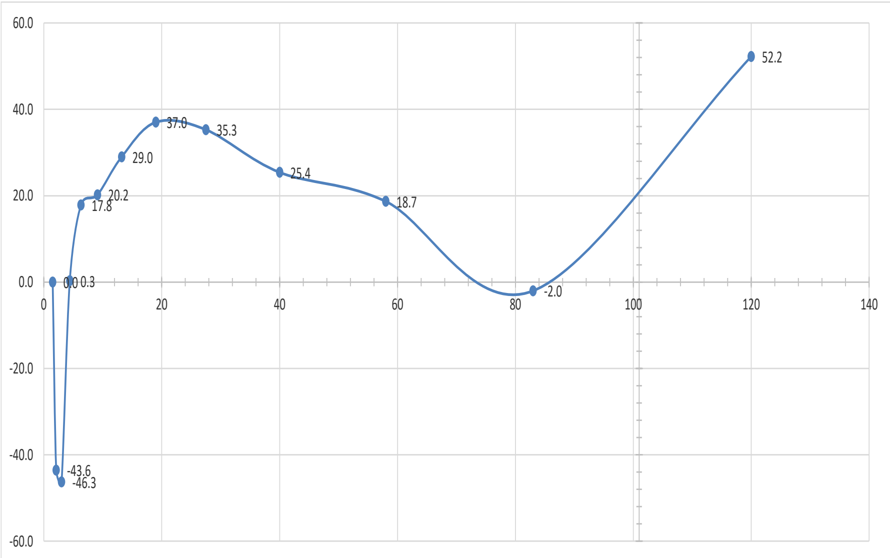
ab/2 (m)	Lamugo
1.5	0.0
2.1	27.6
3	30.5
4.4	4.4
6.3	-3.0
9.1	-41.3
13.2	-58.8
19	-58.1
27.5	-24.0
40	-47.0
58	-28.8
83	73.4
120	-18.0

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
491033	374016	60588	Lamugo	LMG_K_6	Labong Layamo	Kitgum	Kitgum Granite

46	110	**Water strike zones**
-48.0	12.0	**Average angles**



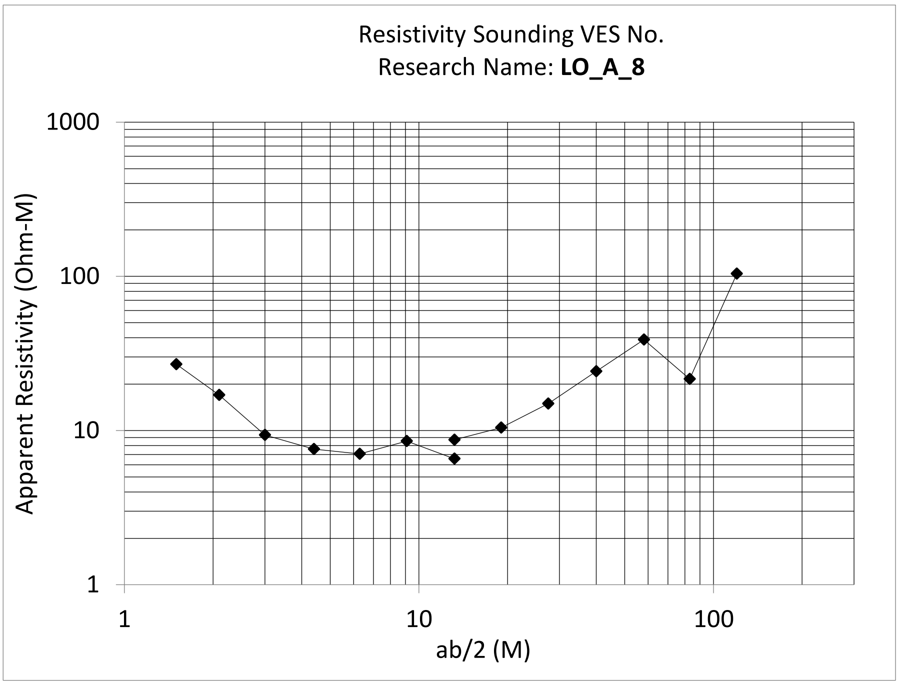
ab/2(m)	resistivity (ohm-m)
1.5	2.100
2.1	0.712
3.0	0.230
4.4	0.106
6.3	0.058
9.1	0.032
13.2	0.019
13.2	0.265
19.0	0.000
19.0	0.158
27.5	0.000
27.5	0.096
40.0	0.054
58.0	0.029
83.0	0.014
120.0	0.012



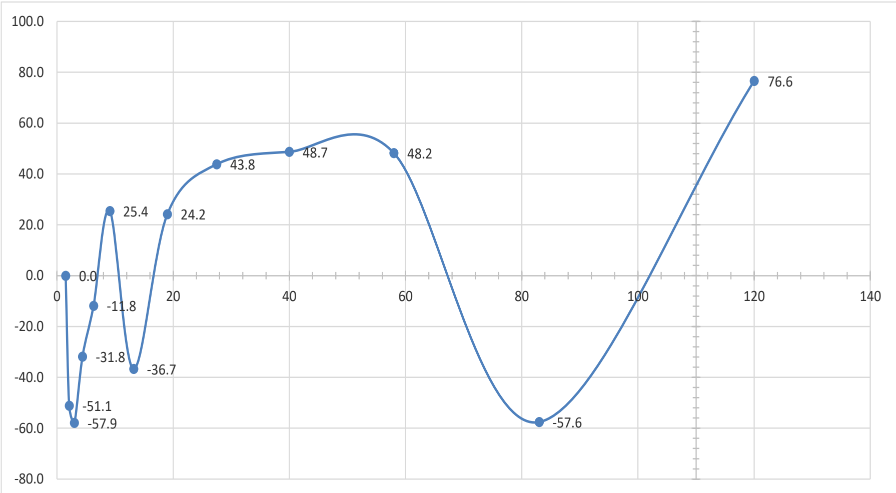
ab/2 (m)	Longor
1.5	0.0
2.1	-43.6
3	-46.3
4.4	0.3
6.3	17.8
9.1	20.2
13.2	29.0
19	37.0
27.5	35.3
40	25.4
58	18.7
83	-2.0
120	52.2

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
545445	360439	60605	Longor	LNR_A_22	Omiya Pachwa	Agago	Migmatitic garnetiferous gneiss

32	36	40	101	**Water strike zones**
32	28	26	21	**Average angles**



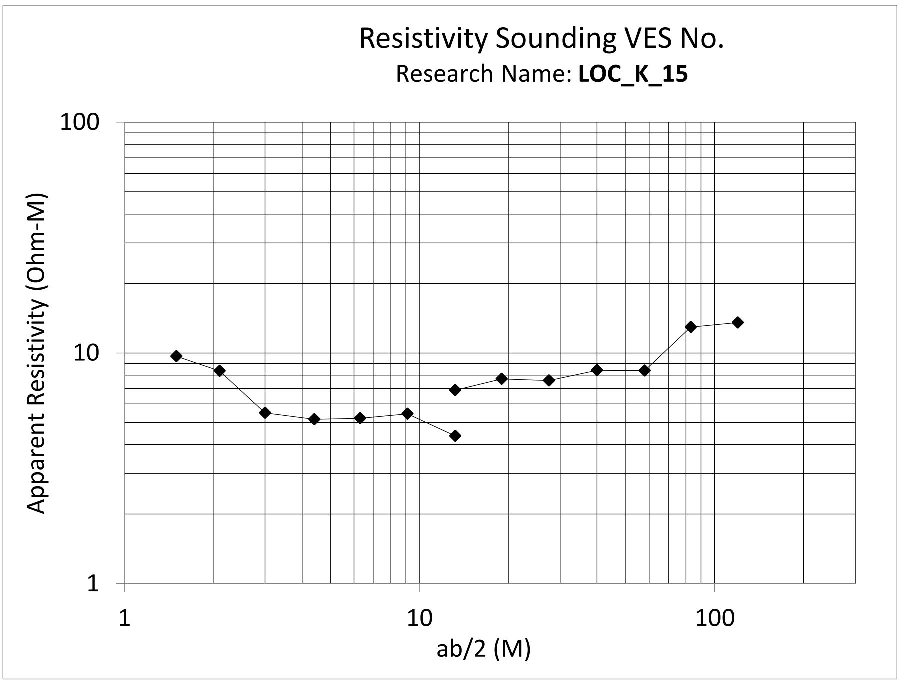
ab/2(m)	resistivity (ohm-m)
1.5	4.290
2.1	1.300
3.0	0.341
4.4	0.126
6.3	0.057
9.1	0.033
13.2	0.012
13.2	0.186
19.0	
19.0	0.099
27.5	0.000
27.5	0.065
40.0	0.049
58.0	0.037
83.0	0.010
120.0	0.023



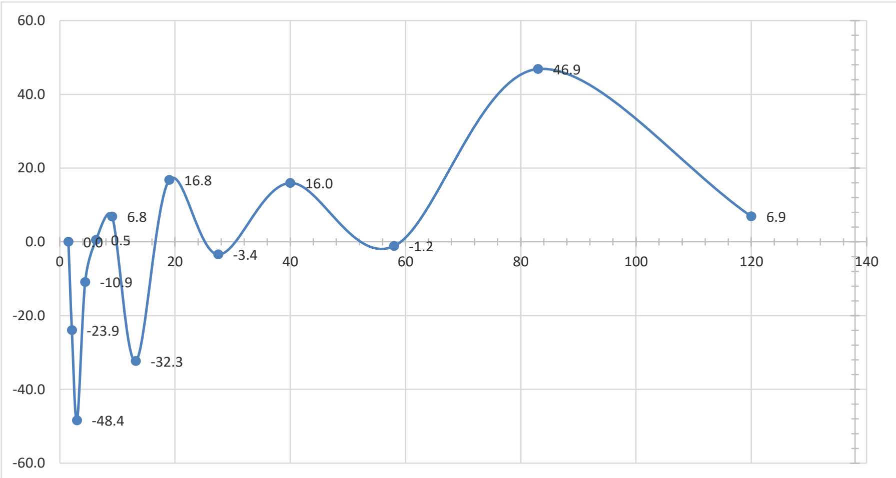
ab/2 (m)	Lawiyo Oduny
1.5	0.0
2.1	-51.1
3	-57.9
4.4	-31.8
6.3	-11.8
9.1	25.4
13.2	-36.7
19	24.2
27.5	43.8
40	48.7
58	48.2
83	-57.6
120	76.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
547900	354662	61464	Lawiye - Odunyo	LO_A_8	Omiya Pachwa	Agago	Variable deformed granitoid

74	82	90	110	Water strike zones
-39	-58	-45	36	Average angles



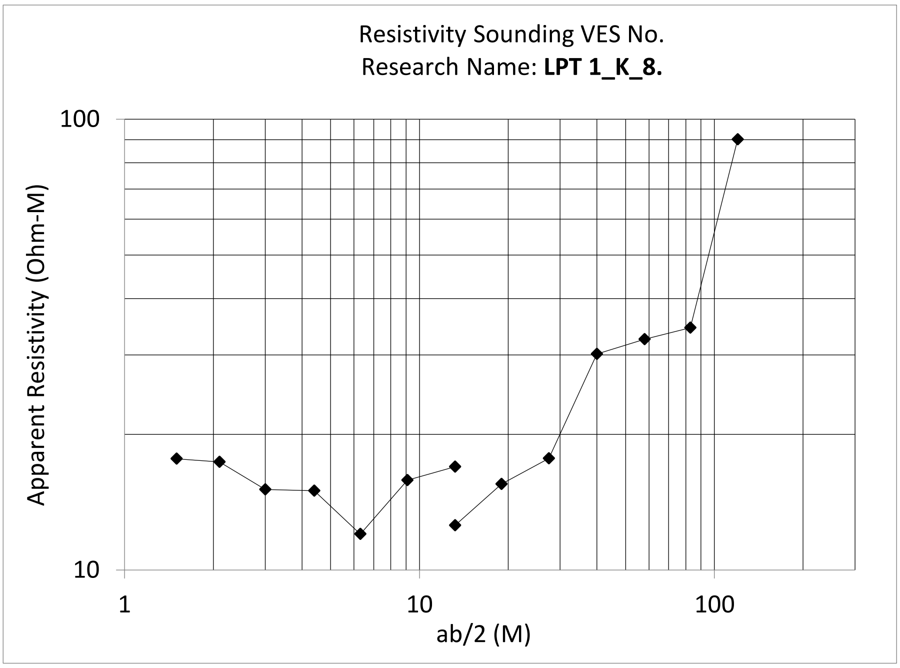
ab/2(m)	resistivity (ohm-m)
1.5	1.540
2.1	0.639
3.0	0.200
4.4	0.086
6.3	0.042
9.1	0.021
13.2	0.008
13.2	0.147
19.0	0.000
19.0	0.073
27.5	0.000
27.5	0.033
40.0	0.017
58.0	0.008
83.0	0.006
120.0	0.003



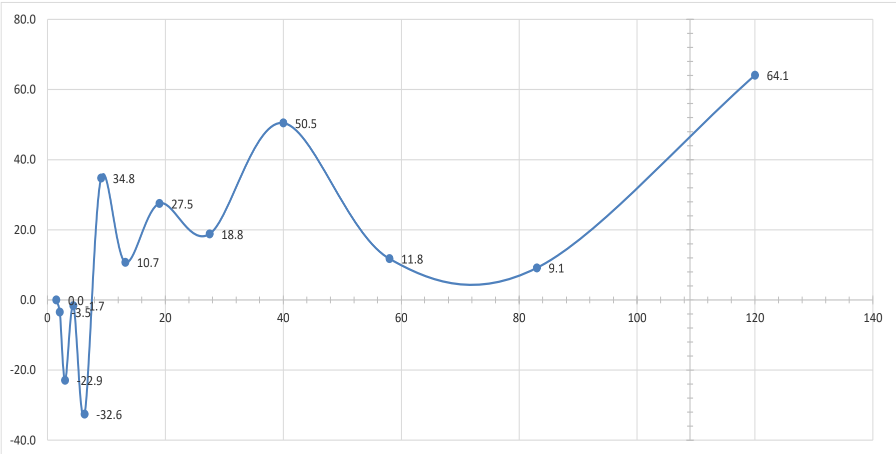
ab/2 (m)	Locomo Central
1.5	0.0
2.1	-23.9
3	-48.4
4.4	-10.9
6.3	0.5
9.1	6.8
13.2	-32.3
19	16.8
27.5	-3.4
40	16.0
58	-1.2
83	46.9
120	6.9

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
573979	381334	60757	Locomo Central	LOC_K_15	Orom	Kitgum	Mafic granulite

30	35	41	46	138	142	**Water strike zones**
-1	10	16	10			**Average angles**



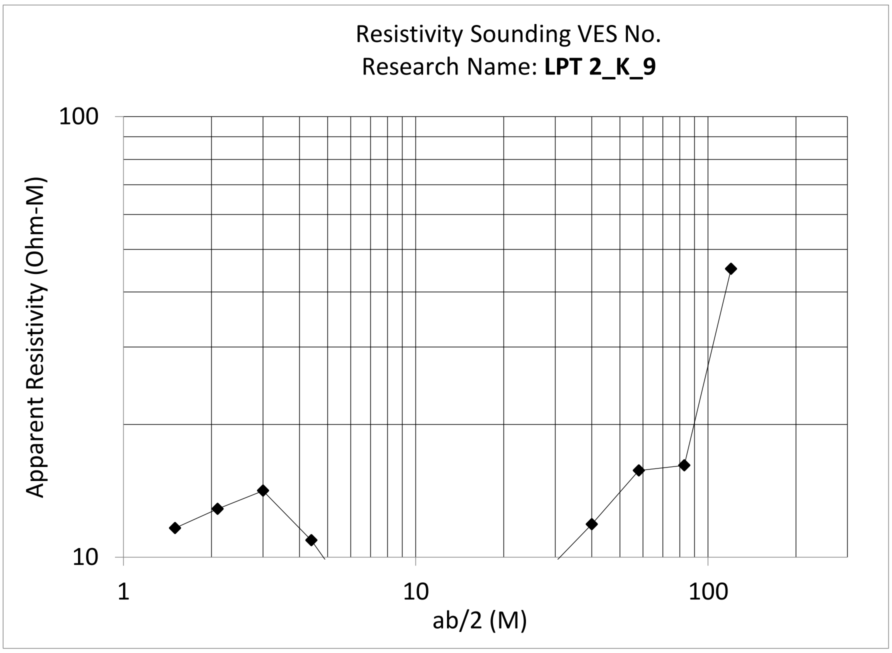
ab/2(m)	resistivity (ohm-m)
1.5	2.810
2.1	1.329
3.0	0.549
4.4	0.250
6.3	0.097
9.1	0.061
13.2	0.031
13.2	0.268
19.0	0.000
19.0	0.147
27.5	0.000
27.5	0.077
40.0	0.061
58.0	0.031
83.0	0.016
120.0	0.020



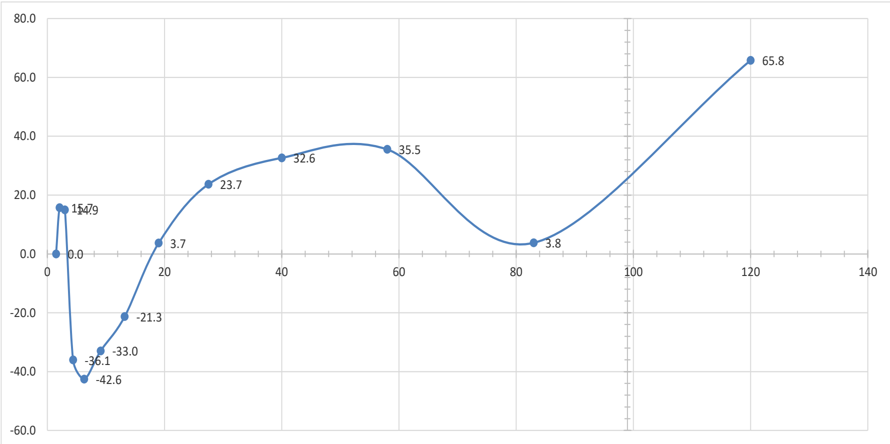
ab/2 (m)	Lapene(Lapeitac 1)
1.5	0.0
2.1	-3.5
3	-22.9
4.4	-1.7
6.3	-32.6
9.1	34.8
13.2	10.7
19	27.5
27.5	18.8
40	50.5
58	11.8
83	9.1
120	64.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
558972	375602	61460	Lapene 1/Lapeitaka 1	LPT 1_K_8	Orom	Kitgum	Migmatitic garnetiferous gneiss

38	42	56	62	100	109	**Water strike zones**
49.0	49.0	14.0	8.0	32.0	46.0	**Average angles**



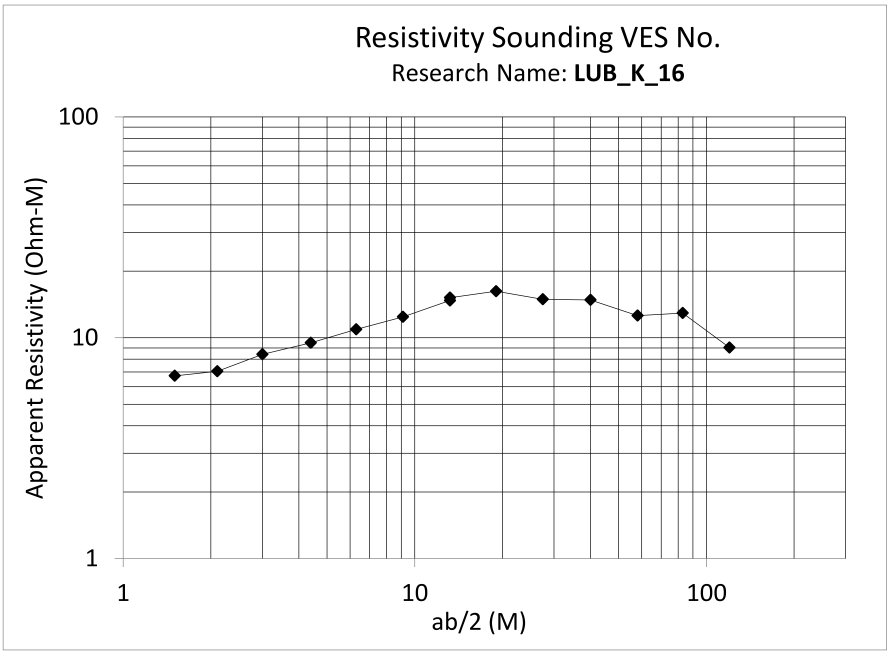
ab/2(m)	resistivity (ohm-m)
1.5	1.853
2.1	0.986
3.0	0.515
4.4	0.182
6.3	0.063
9.1	0.024
13.2	0.010
13.2	0.160
19.0	0.000
19.0	0.073
27.5	0.000
27.5	0.040
40.0	0.024
58.0	0.015
83.0	0.008
120.0	0.010



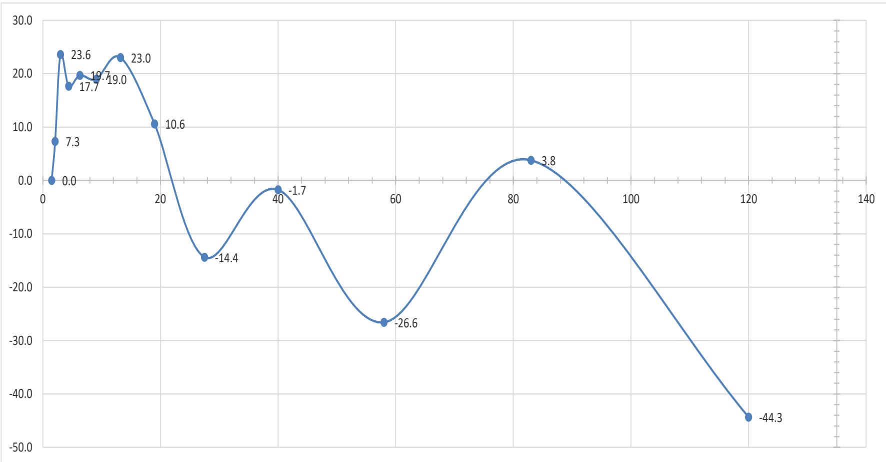
ab/2 (m)	Lapene(Lapeitac 2)
1.5	0.0
2.1	15.7
3	14.9
4.4	-36.1
6.3	-42.6
9.1	-33.0
13.2	-21.3
19	3.7
27.5	23.7
40	32.6
58	35.5
83	3.8
120	65.8

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
558121	375549	61461	Lapene 2/Lapeitaka 2	LPT 2_K_9	Orom	Kitgum	Migmatitic garnetiferous gneiss

34	45	63	66	95	99	**Water strike zones**
30.0	34.5	28.1	23.0	19.0	26.0	**Average angles**



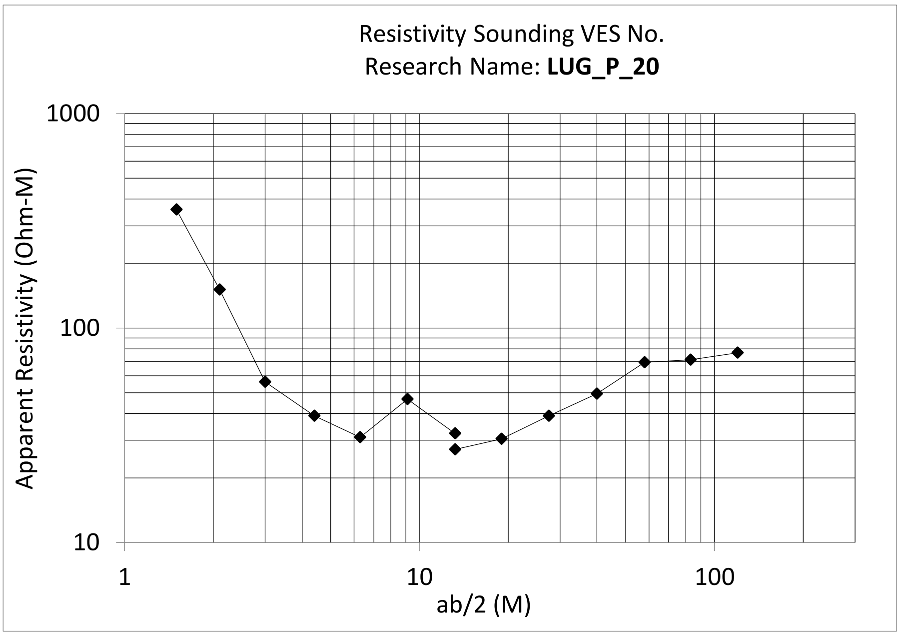
ab/2(m)	resistivity (ohm-m)
1.5	1.070
2.1	0.540
3.0	0.306
4.4	0.158
6.3	0.088
9.1	0.048
13.2	0.027
13.2	0.324
19.0	0.000
19.0	0.154
27.5	0.000
27.5	0.065
40.0	0.030
58.0	0.012
83.0	0.006
120.0	0.002

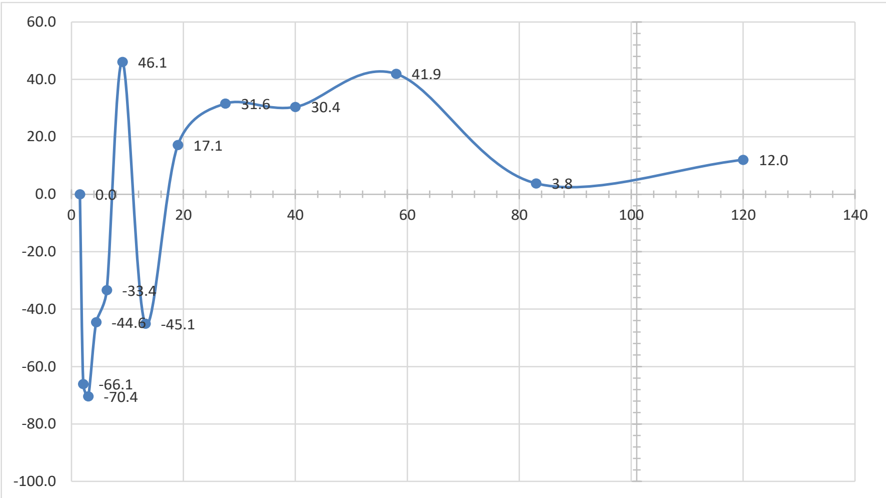


ab/2 (m)	Lubiri
1.5	0.0
2.1	7.3
3	23.6
4.4	17.7
6.3	19.7
9.1	19.0
13.2	23.0
19	10.6
27.5	-14.4
40	-1.7
58	-26.6
83	3.8
120	-44.3

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
562485	384926	60642	Lubiri/Lokongo	LUB_K_16	Orom	Kitgum	Banded granulite and charnockite

30	135	138	142	145	Water strike zones
-13.5					Average angles



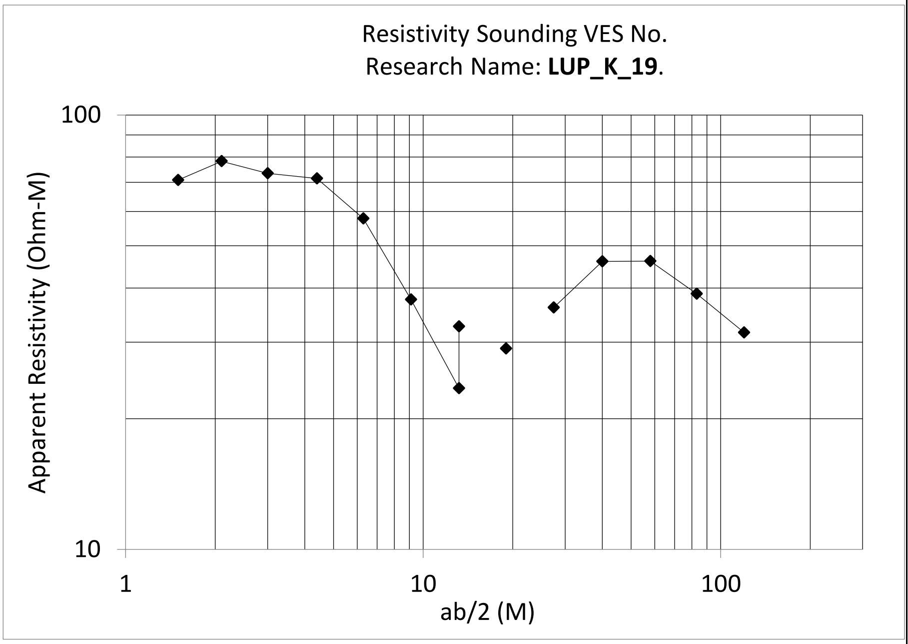


ab/2(m)	resistivity (ohm-m)
1.5	56.810
2.1	11.560
3.0	2.040
4.4	0.650
6.3	0.250
9.1	0.180
13.2	0.059
13.2	0.580
19.0	0.000
19.0	0.289
27.5	0.000
27.5	0.170
40.0	0.100
58.0	0.066
83.0	0.033
120.0	0.017

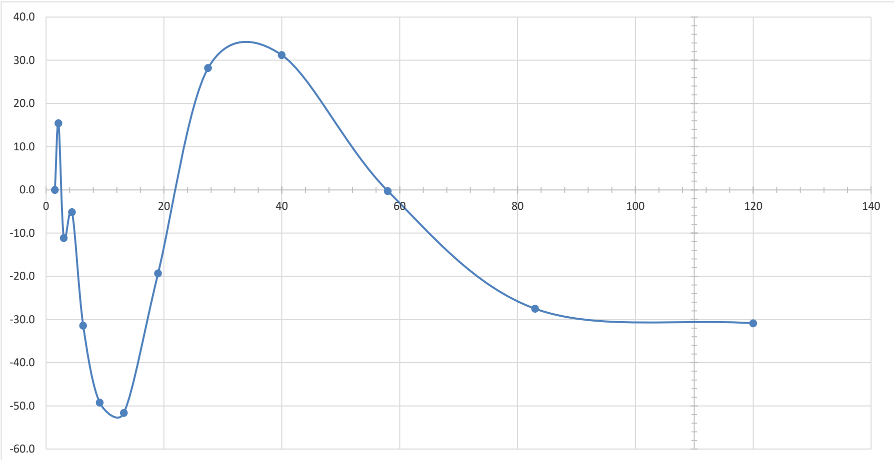
ab/2 (m)	Lugedde 2
1.5	0.0
2.1	-66.1
3	-70.4
4.4	-44.6
6.3	-33.4
9.1	46.1
13.2	-45.1
19	17.1
27.5	31.6
40	30.4
58	41.9
83	3.8
120	12.0

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
487386	349702	60596	Lugede	LUG_P_20	Acholibur	Pader	Awela granodiorite gneiss

27	73	96	101	**Water strike zones**
32	16	4	5	**Average angles**



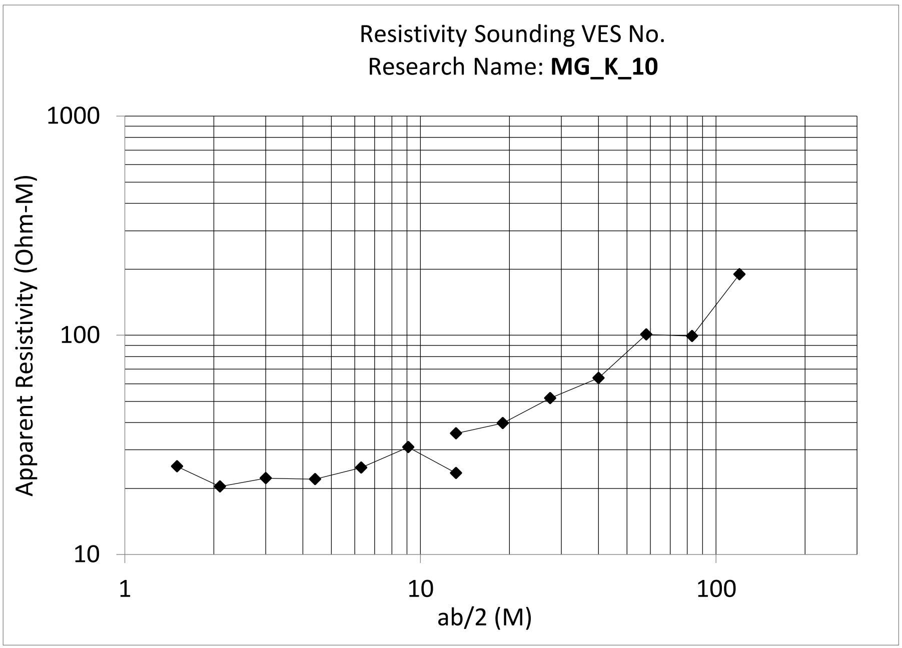
ab/2(m)	resistivity (ohm-m)
1.5	11.290
2.1	5.990
3.0	2.670
4.4	1.190
6.3	0.467
9.1	0.145
13.2	0.043
13.2	0.696
19.0	0.000
19.0	0.275
27.5	0.000
27.5	0.157
40.0	0.093
58.0	0.044
83.0	0.018
120.0	0.007



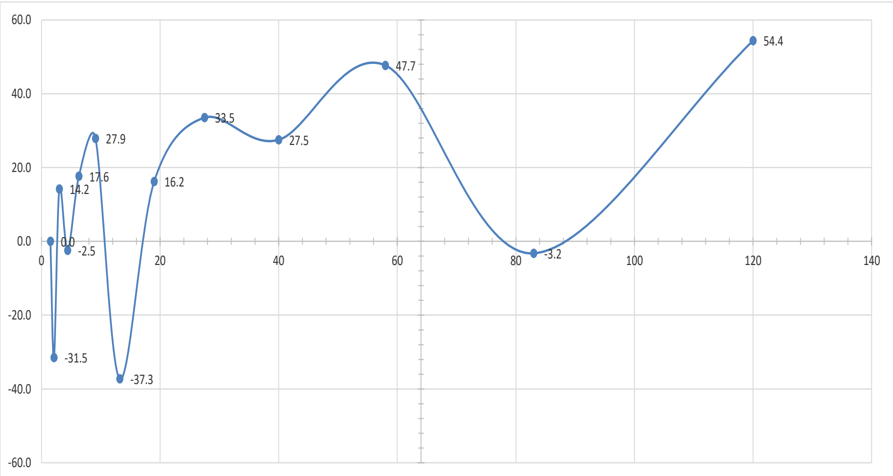
ab/2 (m)	Aturum(Luperu)
1.5	0.0
2.1	15.4
3	-11.2
4.4	-5.2
6.3	-31.4
9.1	-49.2
13.2	-51.6
19	-19.3
27.5	28.2
40	31.2
58	-0.3
83	-27.5
120	-30.9

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
566953	390297	60649	Luperu	LUP_K_19	Orom	Kitgum	Alluvium, swamp, lacustrine deposits

36	41	50	69	110	**Water strike zones**
36	30	14	-15.5	-30.5	**Average angles**



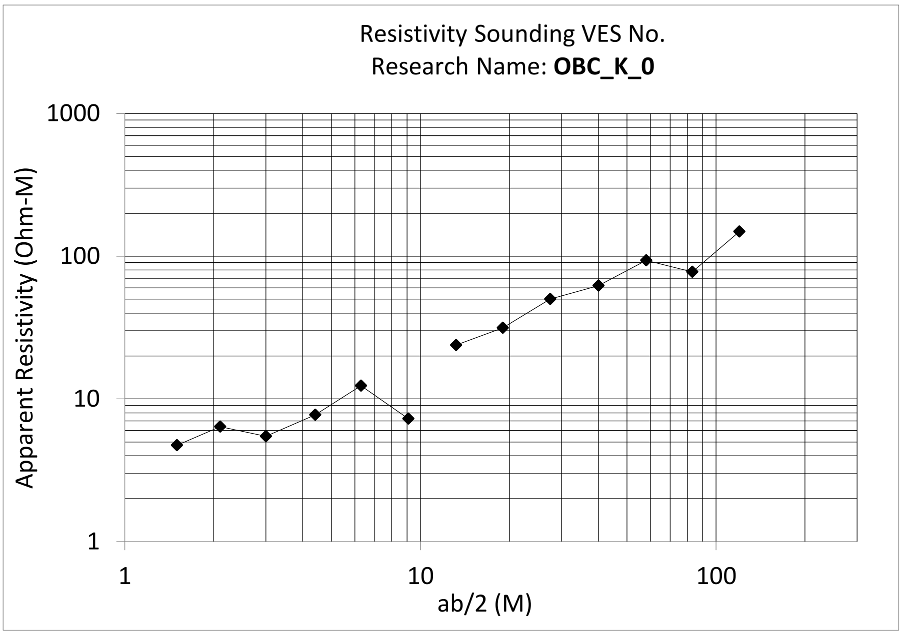
ab/2(m)	resistivity (ohm-m)
1.5	4.017
2.1	1.563
3.0	0.812
4.4	0.368
6.3	0.201
9.1	0.119
13.2	0.043
13.2	0.761
19.0	0.000
19.0	0.376
27.5	0.000
27.5	0.225
40.0	0.129
58.0	0.096
83.0	0.046
120.0	0.042



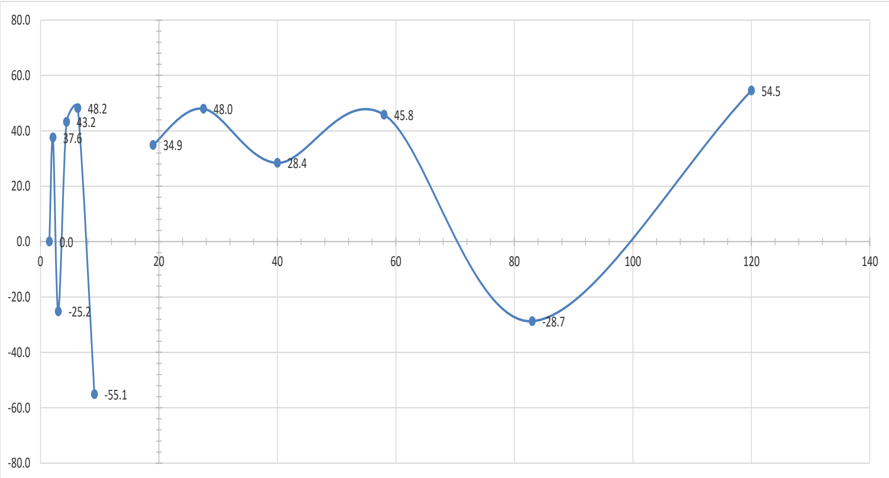
ab/2 (m)	Mugila
1.5	0.0
2.1	-31.5
3	14.2
4.4	-2.5
6.3	17.6
9.1	27.9
13.2	-37.3
19	16.2
27.5	33.5
40	27.5
58	47.7
83	-3.2
120	54.4

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
494929	371302	60593	Mugila	MG_K_10	Mucwini	Kitgum	Migmatitic garnetiferous gneiss

18	23	64	**Water strike zones**
12.0	28.0	36.0	**Average anles**



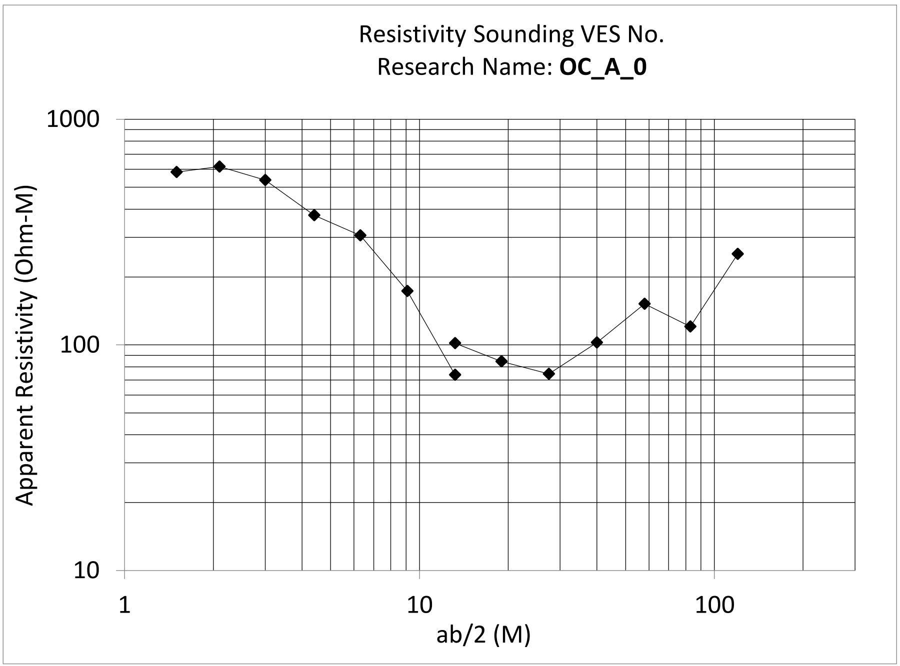
ab/2(m)	Resistivity (ohm-m)
1.5	0.754
2.1	0.489
3.0	0.199
4.4	0.129
6.3	0.100
9.1	0.028
13.2	
13.2	0.509
19.0	
19.0	0.298
27.5	0.000
27.5	0.218
40.0	0.126
58.0	0.089
83.0	0.036
120.0	0.033



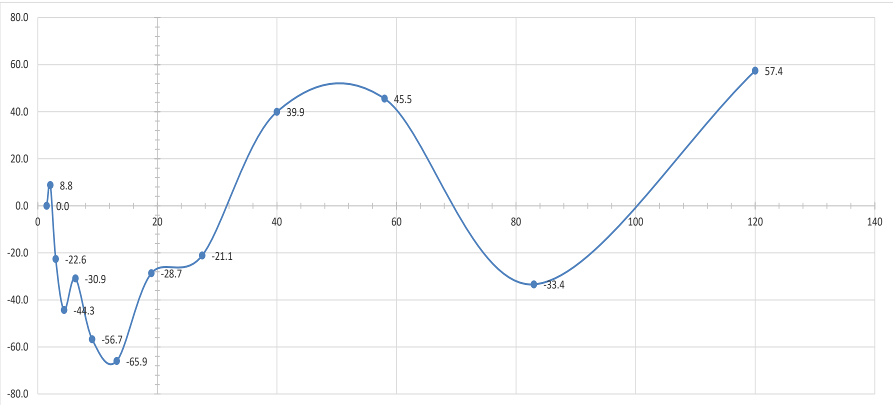
ab/2 (m)	Obyen Central
1.5	0.0
2.1	37.6
3	-25.2
4.4	43.2
6.3	48.2
9.1	-55.1
13.2	
19	34.9
27.5	48.0
40	28.4
58	45.8
83	-28.7
120	54.5

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
504517	368275		Obyen Central	OBC_K_0	Kitgum Matidi	Kitgum	Kitgum granite

	Water strike zones
	Average angles



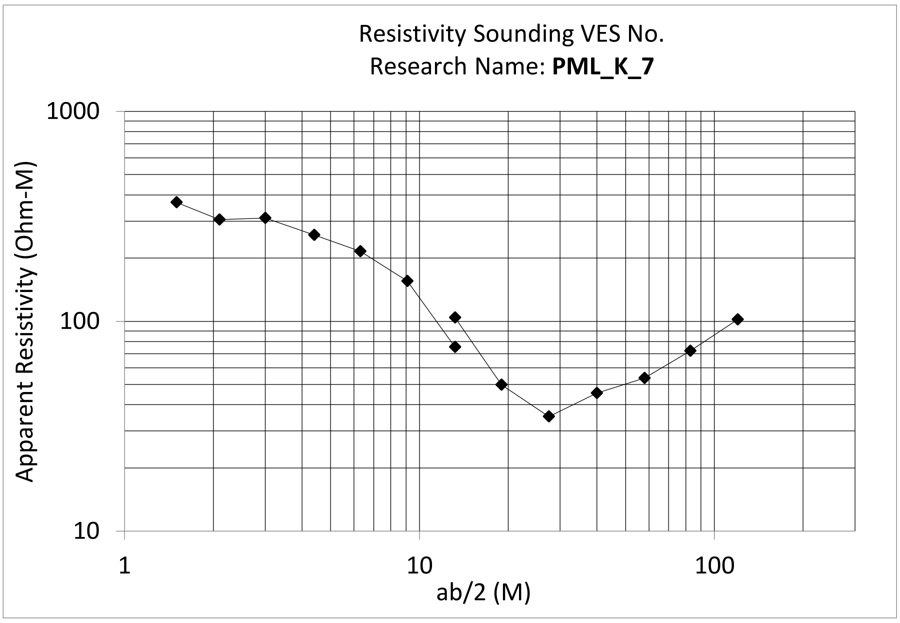
ab/2(m)	resistivity (ohm-m)
1.5	92.890
2.1	47.280
3.0	19.570
4.4	6.260
6.3	2.470
9.1	0.668
13.2	0.135
13.2	2.170
19.0	
19.0	0.802
27.5	
27.5	0.324
40.0	0.207
58.0	0.145
83.0	0.056
120.0	0.056



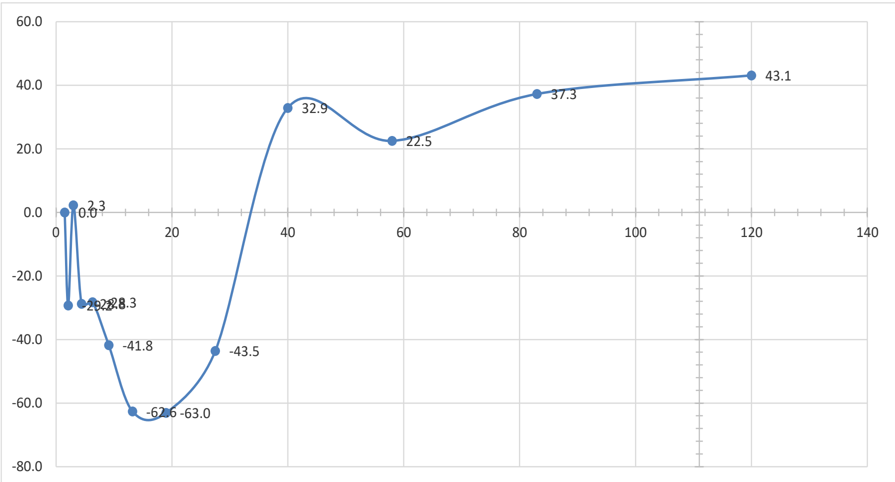
ab/2 (m)	Opiro Central
1.5	0.0
2.1	8.8
3	-22.6
4.4	-44.3
6.3	-30.9
9.1	-56.7
13.2	-65.9
19	-28.7
27.5	-21.1
40	39.9
58	45.5
83	-33.4
120	57.4

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
548287	335890	60624	Opiro Central	OC_A_0	Paimol	Agago	Migmatitic garnetiferous gneiss

	Water strike zones
	Average angles



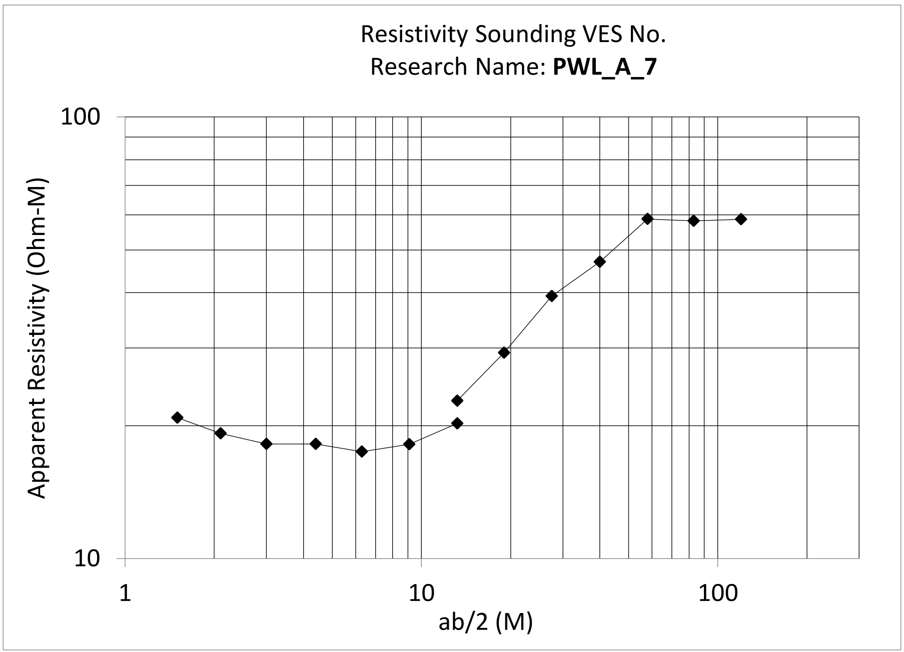
ab/2(m)	resistivity (ohm-m)
1.5	58.650
2.1	23.330
3.0	11.297
4.4	4.300
6.3	1.740
9.1	0.600
13.2	0.138
13.2	2.223
19.0	0.000
19.0	0.472
27.5	0.000
27.5	0.153
40.0	0.092
58.0	0.051
83.0	0.034
120.0	0.023



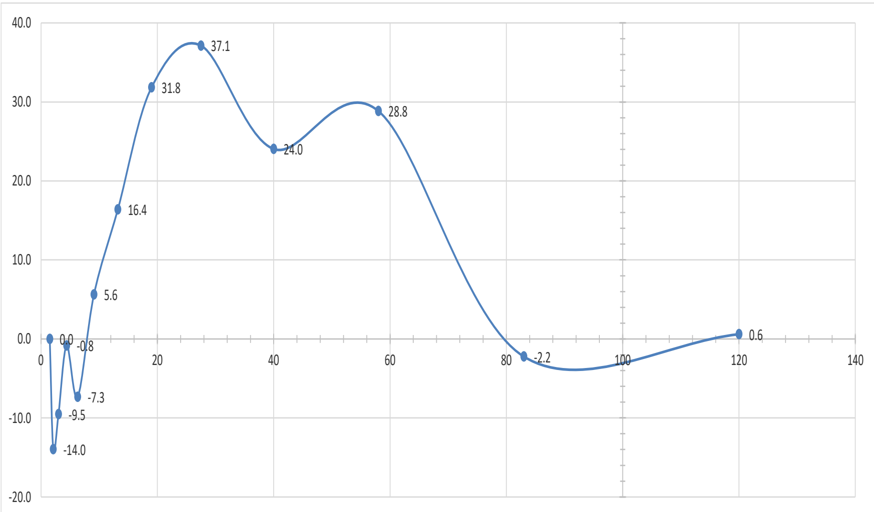
ab/2 (m)	Palamene Lwala
1.5	0.0
2.1	-29.2
3	2.3
4.4	-28.8
6.3	-28.3
9.1	-41.8
13.2	-62.6
19	-63.0
27.5	-43.5
40	32.9
58	22.5
83	37.3
120	43.1

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
520602	364123	61457	Palamene Lwala	PML_K_7	Omiya Anyima	Kitgum	Intermediate granulite Sed_Volc_Dyke_Plutonic

32	41	65	107	111	**Water strike zones**
-12	35	26	41	42	**Average angles**



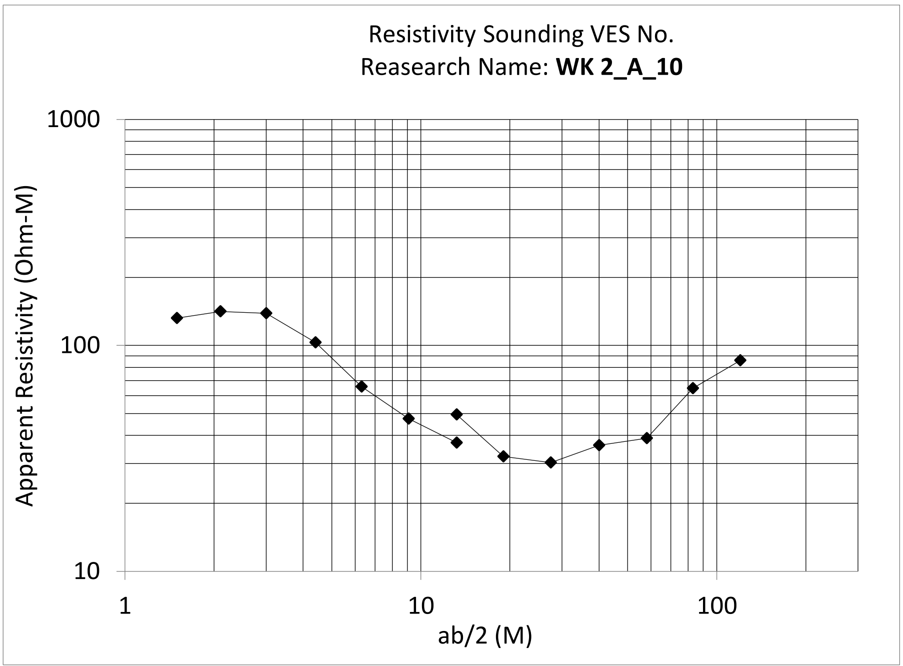
ab/2(m)	resistivity (ohm-m)
1.5	3.320
2.1	1.470
3.0	0.662
4.4	0.303
6.3	0.141
9.1	0.070
13.2	0.037
13.2	0.486
19.0	0.000
19.0	0.277
27.5	0.000
27.5	0.171
40.0	0.095
58.0	0.056
83.0	0.027
120.0	0.013



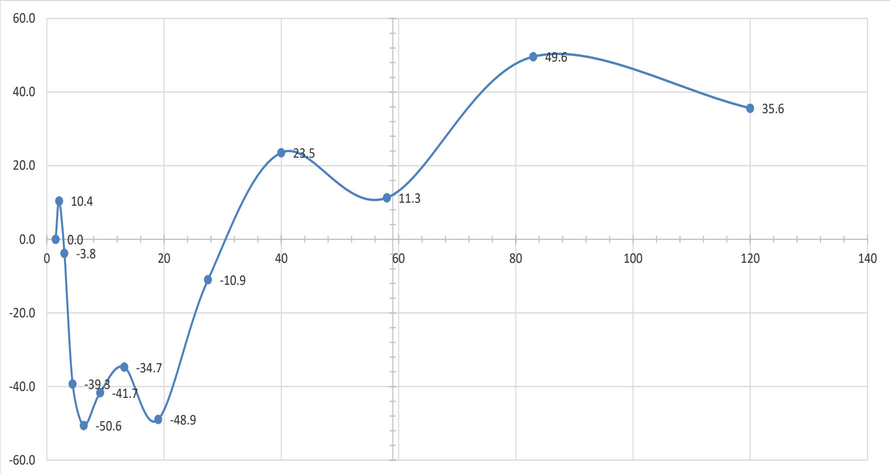
ab/2 (m)	Pawel
1.5	0.0
2.1	-14.0
3	-9.5
4.4	-0.8
6.3	-7.3
9.1	5.6
13.2	16.4
19	31.8
27.5	37.1
40	24.0
58	28.8
83	-2.2
120	0.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
546038	359434	60608	Pawel	PWL_A_7	Omiya Pachwa	Agago	Migmatitic garnetiferous gneiss

36	41	46	50	100	**Water strike zones**
27	24	26	29	-3	**Average angles**



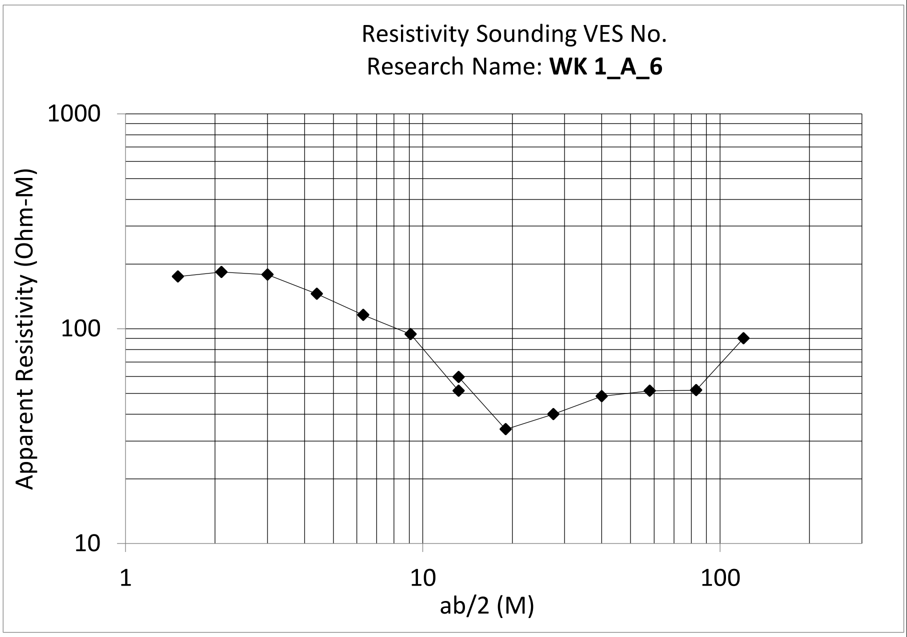
ab/2(m)	resistivity (ohm-m)
1.5	21.050
2.1	10.820
3.0	5.050
4.4	1.720
6.3	0.530
9.1	0.183
13.2	0.068
13.2	1.055
19.0	0.000
19.0	0.306
27.5	0.000
27.5	0.132
40.0	0.073
58.0	0.037
83.0	0.030
120.0	0.019



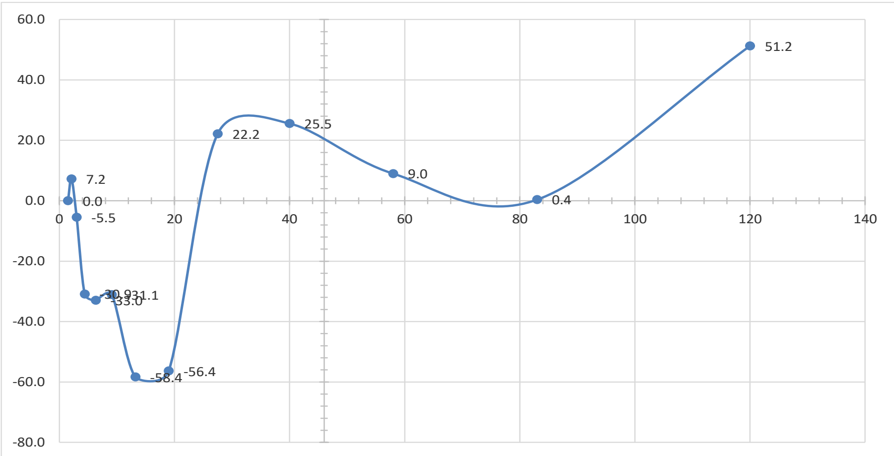
ab/2 (m)	Wang-Kenya 2
1.5	0.0
2.1	10.4
3	-3.8
4.4	-39.3
6.3	-50.6
9.1	-41.7
13.2	-34.7
19	-48.9
27.5	-10.9
40	23.5
58	11.3
83	49.6
120	35.6

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
554537	376791	60632	Wang Kenya 2	WK 2_A_10	Orom	Kitgum	Migmatitic garnetiferous gneiss

36	43	46	50	55	59	**Water strike zones**
17.0	23.8	20.0	14.5	11.0	12.0	**Average angles**



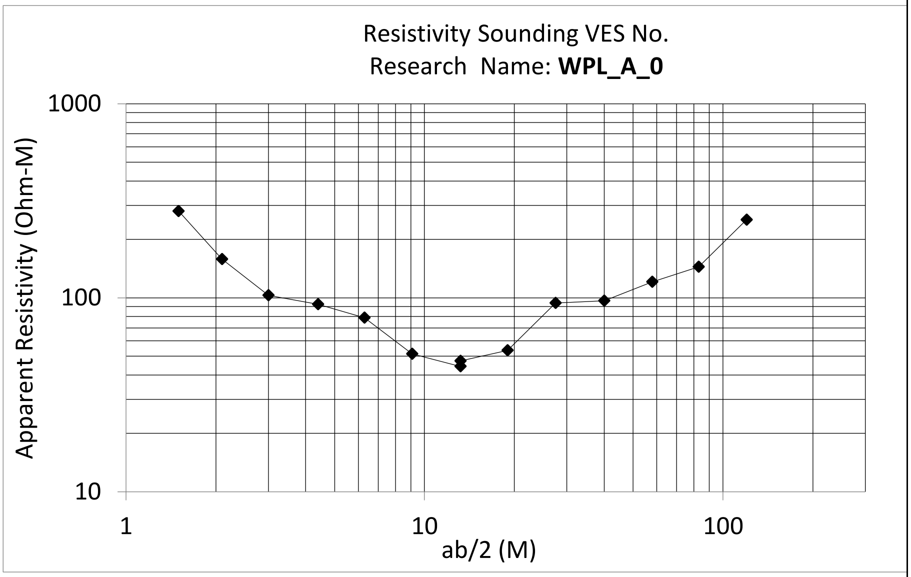
ab/2(m)	resistivity (ohm-m)
1.5	27.860
2.1	14.050
3.0	6.490
4.4	2.420
6.3	0.935
9.1	0.363
13.2	0.094
13.2	1.270
19.0	0.000
19.0	0.322
27.5	0.000
27.5	0.174
40.0	0.098
58.0	0.049
83.0	0.024
120.0	0.020



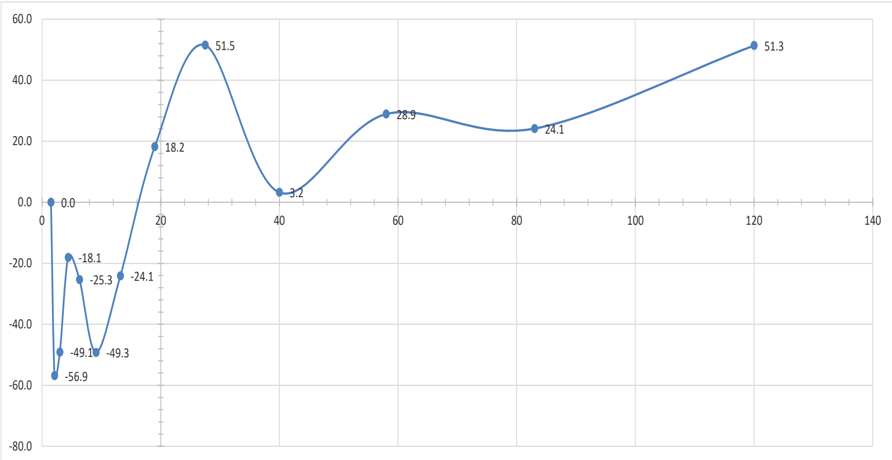
ab/2 (m)	Wang-Kenya 1
1.5	0.0
2.1	7.2
3	-5.5
4.4	-30.9
6.3	-33.0
9.1	-31.1
13.2	-58.4
19	-56.4
27.5	22.2
40	25.5
58	9.0
83	0.4
120	51.2

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
554662	377552	60631	Wang-Kenya	WK 1_A_6	Orom	Kitgum	Migmatitic garnetiferous gneiss

23	27	36	41	46	**Water strike zones**
-16	20	28	25	20	**Average angles**



ab/2(m)	resistivity (ohm-m)
1.5	44.610
2.1	12.110
3.0	3.750
4.4	1.540
6.3	0.638
9.1	0.198
13.2	0.081
19.0	0.000
27.5	0.000
13.2	1.009
19.0	0.508
27.5	0.410
40.0	0.195
58.0	0.115
83.0	0.067
120.0	0.056



ab/2 (m)	Wipolo (Paimol HC)
1.5	0.0
2.1	-56.9
3	-49.1
4.4	-18.1
6.3	-25.3
9.1	-49.3
13.2	-24.1
19	18.2
27.5	51.5
40	3.2
58	28.9
83	24.1
120	51.3

X	Y	DWD No	LOCATION	RESEARCH NAME	SUB COUNTY	DISTRICT	LITHOLOGY
547769	347188	60626	Wipolo	WPL_A_0	Paimol	Agago	Migmatitic garnetiferous gneiss

	Water strike zones
	Average angles

APPENDIX 2

Summary of Drilling data, lithologies and Pump test yields for forty wells drilled in Agago, Pader and Kitgum Districts.

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	14	2.6391	4.9273	13	-36
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	27	3.2958	4.9273	13	-7
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	36	3.5835	4.9273	13	26
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	64	4.1589	4.9273	13	-48
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	99	4.5951	4.9273	13	17
Lai Central	Paimol	Agago	60627	548557	346716	138	MGG	120	4.7875	4.9273	13	7
Opiro Central	Paimol	Agago	60624	548287	335890	151	MGG	0.0001	-9.2103	5.0173	0	0
Pawel	Omya Pachwa	Agago	60608	546038	359434	151	MGG	36	3.5835	5.0173	7	27
Pawel	Omya Pachwa	Agago	60608	546038	359434	151	MGG	41	3.7136	5.0173	7	24
Pawel	Omya Pachwa	Agago	60608	546038	359434	151	MGG	46	3.8286	5.0173	7	26
Pawel	Omya Pachwa	Agago	60608	546038	359434	151	MGG	50	3.9120	5.0173	7	29

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Pawel	Omya Pachwa	Agago	60608	546038	359434	151	MGG	100	4.6052	5.0173	7	-3
Longor	Omya Pachwa	Agago	60605	545445	360439	110	MGG	32	3.4657	4.7005	22	32
Longor	Omya Pachwa	Agago	60605	545445	360439	110	MGG	36	3.5835	4.7005	22	28
Longor	Omya Pachwa	Agago	60605	545445	360439	110	MGG	40	3.6889	4.7005	22	26
Longor	Omya Pachwa	Agago	60605	545445	360439	110	MGG	101	4.6151	4.7005	22	21
Kalongo TC/Ongom	Paimol	Agago	61453	542782	335363	120	MGG	27	3.2958	4.7875	13	21
Kalongo TC/Ongom	Paimol	Agago	61453	542782	335363	120	MGG	35	3.5553	4.7875	13	20
Kalongo TC/Ongom	Paimol	Agago	61453	542782	335363	120	MGG	61	4.1109	4.7875	13	34
Kalongo TC/Ongom	Paimol	Agago	61453	542782	335363	120	MGG	101	4.6151	4.7875	13	-10
Lawiye-Odunyo	Omiya Pachwa	Agago	61464	547900	354662	120	VDG	74	4.3041	4.7875	8	-39
Lawiye-Odunyo	Omiya Pachwa	Agago	61464	547900	354662	120	VDG	82	4.4067	4.7875	8	-58
Lawiye-Odunyo	Omiya Pachwa	Agago	61464	547900	354662	120	VDG	90	4.4998	4.7875	8	-45

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Lawiye-Odunyo	Omiya Pachwa	Agago	61464	547900	354662	120	VDG	110	4.7005	4.7875	8	36
Lakwa B	Omiya Pachwa	Agago	61465	546661	352960	120	VDG	0.0001	-9.2103	4.7875	0	0
Wipolo	Paimol	Agago	60626	547769	347188	142	MGG	0.0001	-9.2103	4.9558	0	0
Mugila	Mucwini	Kitgum	60593	494929	371302	120	MGG	18	2.8904	4.7875	10	12
Mugila	Mucwini	Kitgum	60593	494929	371302	120	MGG	23	3.1355	4.7875	10	28
Mugila	Mucwini	Kitgum	60593	494929	371302	120	MGG	64	4.1589	4.7875	10	36
Lamugo	Labong Layamo	Kitgum	60588	491033	374016	151	KG	46	3.8286	5.0173	6	-48
Lamugo	Labong Layamo	Kitgum	60588	491033	374016	151	KG	110	4.7005	5.0173	6	12
Kweyo	Omiya Anyima	Kitgum	60590	524981	361406	121	MGG	0.0001	-9.2103	4.7958	0	
Labilo B	Lagoro	Kitgum	61454	507107	363450	120	BGC	36	3.5835	4.7875	29	31
Labilo B	Lagoro	Kitgum	61454	507107	363450	120	BGC	45	3.8067	4.7875	29	31
Labilo B	Lagoro	Kitgum	61454	507107	363450	120	BGC	65	4.1744	4.7875	29	18
Labilo B	Lagoro	Kitgum	61454	507107	363450	120	BGC	81	4.3944	4.7875	29	4
Alel East	Lagoro	Kitgum	61455	511092	362875	119	MGG	32	3.4657	4.7791	7	20
Alel East	Lagoro	Kitgum	61455	511092	362875	119	MGG	46	3.8286	4.7791	7	24

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Alel East	Lagoro	Kitgum	61455	511092	362875	119	MGG	75	4.3175	4.7791	7	-32
Alel East	Lagoro	Kitgum	61455	511092	362875	119	MGG	107	4.6728	4.7791	7	20
Atocon	Omiya Anyima	Kitgum	61456	522005	363369	119	MGG	0.0001	-9.2103	4.7791	0	0
Palamene Lwala	Omiya Anyima	Kitgum	61457	520602	364123	120	IGSVDP	32	3.4657	4.7875	7	-12
Palamene Lwala	Omiya Anyima	Kitgum	61457	520602	364123	120	IGSVDP	41	3.7136	4.7875	7	35
Palamene Lwala	Omiya Anyima	Kitgum	61457	520602	364123	120	IGSVDP	65	4.1744	4.7875	7	26
Palamene Lwala	Omiya Anyima	Kitgum	61457	520602	364123	120	IGSVDP	107	4.6728	4.7875	7	41
Palamene Lwala	Omiya Anyima	Kitgum	61457	520602	364123	120	IGSVDP	111	4.7095	4.7875	7	42
Agoromin City	Orom	Kitgum	61458	552691	371163	120	MGG	48	3.8712	4.7875	32	3.9
Agoromin City	Orom	Kitgum	61458	552691	371163	120	MGG	57	4.0431	4.7875	32	15
Agoromin City	Orom	Kitgum	61458	552691	371163	120	MGG	65	4.1744	4.7875	32	27.8
Agoromin City	Orom	Kitgum	61458	552691	371163	120	MGG	86	4.4543	4.7875	32	52
Agoromin	Orom	Kitgum	61459	553099	368952	120	MGG	48	3.8712	4.7875	10	50
Agoromin	Orom	Kitgum	61459	553099	368952	120	MGG	64	4.1589	4.7875	10	36.2
Agoromin	Orom	Kitgum	61459	553099	368952	120	MGG	92	4.5218	4.7875	10	29.9

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Agoromin	Orom	Kitgum	61459	553099	368952	120	MGG	108	4.6821	4.7875	10	35
Agoromin	Orom	Kitgum	61459	553099	368952	120	MGG	119	4.7791	4.7875	10	39
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	38	3.6376	4.7875	8	49
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	42	3.7377	4.7875	8	49
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	56	4.0254	4.7875	8	14
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	62	4.1271	4.7875	8	8
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	100	4.6052	4.7875	8	32
Lapene 1/Lapeitaka 1	Orom	Kitgum	61460	558972	375602	120	MGG	109	4.6913	4.7875	8	46
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	34	3.5264	4.7875	9	30
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	45	3.8067	4.7875	9	34.5
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	63	4.1431	4.7875	9	28.1
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	66	4.1897	4.7875	9	23

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	95	4.5539	4.7875	9	19
Lapene 2/Lapeitaka 2	Orom	Kitgum	61461	558121	375549	120	MGG	99	4.5951	4.7875	9	26
Gili-Gili	Namokora	Kitgum	61462	543369	376375	120	MGG	73	4.2905	4.7875	8	-49
Gili-Gili	Namokora	Kitgum	61462	543369	376375	120	MGG	82	4.4067	4.7875	8	-56
Gili-Gili	Namokora	Kitgum	61462	543369	376375	120	MGG	91	4.5109	4.7875	8	-36
Gili-Gili	Namokora	Kitgum	61462	543369	376375	120	MGG	96	4.5643	4.7875	8	-20
Gili-Gili	Namokora	Kitgum	61462	543369	376375	120	MGG	117	4.7622	4.7875	8	64
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	36	3.5835	4.7875	9	38
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	40	3.6889	4.7875	9	39.5
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	52	3.9512	4.7875	9	43
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	74	4.3041	4.7875	9	22
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	85	4.4427	4.7875	9	
Kako	Namokora	Kitgum	61463	538635	372027	120	MGG	116	4.7536	4.7875	9	
Wang-Kenya 1	Orom	Kitgum	60631	554662	377552	151	MGG	23	3.1355	5.0173	6	-16
Wang-Kenya 1	Orom	Kitgum	60631	554662	377552	151	MGG	27	3.2958	5.0173	6	20
Wang-Kenya 1	Orom	Kitgum	60631	554662	377552	151	MGG	36	3.5835	5.0173	6	28
Wang-Kenya 1	Orom	Kitgum	60631	554662	377552	151	MGG	41	3.7136	5.0173	6	25

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Wang-Kenya 1	Orom	Kitgum	60631	554662	377552	151	MGG	46	3.8286	5.0173	6	20
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	36	3.5835	4.9558	10	17
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	43	3.7612	4.9558	10	23.8
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	46	3.8286	4.9558	10	20
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	50	3.9120	4.9558	10	14.5
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	55	4.0073	4.9558	10	11
Wang-Kenya 2	Orom	Kitgum	60632	554537	376791	142	MGG	59	4.0775	4.9558	10	12
Lakongera 1	Orom	Kitgum	60635	554687	388374	124	MGG	78	4.3567	4.8203	19	42
Lakongera 1	Orom	Kitgum	60635	554687	388374	124	MGG	82	4.4067	4.8203	19	50
Lakongera 1	Orom	Kitgum	60635	554687	388374	124	MGG	87	4.4659	4.8203	19	57
Lakongera 1	Orom	Kitgum	60635	554687	388374	124	MGG	115	4.7449	4.8203	19	79
Lakongera 1	Orom	Kitgum	60635	554687	388374	124	MGG	119	4.7791	4.8203	19	82
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	46	3.8286	4.7005	41	0
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	50	3.9120	4.7005	41	-3
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	55	4.0073	4.7005	41	-3
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	64	4.1589	4.7005	41	13
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	69	4.2341	4.7005	41	24
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	73	4.2905	4.7005	41	33

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Lakongera 2	Orom	Kitgum	60637	554052	389034	110	MGG	105	4.6540	4.7005	41	14
Lakongera 3	Orom	Kitgum	60647	554763	388389	151	MGG	0.0001	-9.2103	5.0173	0	
Lakongera 4	Orom	Kitgum	60758	551163	387772	156	MGG	41	3.7136	5.0499	9	30
Lakongera 4	Orom	Kitgum	60758	551163	387772	156	MGG	92	4.5218	5.0499	9	-52
Lakongera 4	Orom	Kitgum	60758	551163	387772	156	MGG	147	4.9904	5.0499	9	
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	18	2.8904	4.8203	20	30
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	23	3.1355	4.8203	20	36
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	27	3.2958	4.8203	20	40
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	32	3.4657	4.8203	20	39.5
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	36	3.5835	4.8203	20	37.9
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	41	3.7136	4.8203	20	38.9
Laluko	Orom	Kitgum	60639	559599	383992	124	BGC	81	4.3944	4.8203	20	13.5
Lubiri/Lokongo	Orom	Kitgum	60642	562485	384926	147	BGC	30	3.4012	4.9904	16	-13.5
Lubiri/Lokongo	Orom	Kitgum	60642	562485	384926	147	BGC	135	4.9053	4.9904	16	
Lubiri/Lokongo	Orom	Kitgum	60642	562485	384926	147	BGC	138	4.9273	4.9904	16	
Lubiri/Lokongo	Orom	Kitgum	60642	562485	384926	147	BGC	142	4.9558	4.9904	16	
Lubiri/Lokongo	Orom	Kitgum	60642	562485	384926	147	BGC	145	4.9767	4.9904	16	
Lakwanya 1	Orom	Kitgum	60648	559095	375677	135	BGC	36	3.5835	4.9053	30	-52

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Lakwanya 1	Orom	Kitgum	60648	559095	375677	135	BGC	46	3.8286	4.9053	30	-8
Lakwanya 1	Orom	Kitgum	60648	559095	375677	135	BGC	69	4.2341	4.9053	30	8
Lakwanya 1	Orom	Kitgum	60648	559095	375677	135	BGC	78	4.3567	4.9053	30	-44
Lakwanya 1	Orom	Kitgum	60648	559095	375677	135	BGC	82	4.4067	4.9053	30	-52.5
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	18	2.8904	4.8203	20	26
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	41	3.7136	4.8203	20	20
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	73	4.2905	4.8203	20	38.5
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	78	4.3567	4.8203	20	46
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	96	4.5643	4.8203	20	27
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	101	4.6151	4.8203	20	16
Lakwanya 2	Orom	Kitgum	60777	569400	387477	124	BGC	105	4.6540	4.8203	20	7
Luperu	Orom	Kitgum	60649	566953	390297	128	ASLD	36	3.5835	4.8520	19	36
Luperu	Orom	Kitgum	60649	566953	390297	128	ASLD	41	3.7136	4.8520	19	30
Luperu	Orom	Kitgum	60649	566953	390297	128	ASLD	50	3.9120	4.8520	19	14
Luperu	Orom	Kitgum	60649	566953	390297	128	ASLD	69	4.2341	4.8520	19	-15.5
Luperu	Orom	Kitgum	60649	566953	390297	128	ASLD	110	4.7005	4.8520	19	-30.5
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	30	3.4012	5.0173	15	-1
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	35	3.5553	5.0173	15	10

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	41	3.7136	5.0173	15	16
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	46	3.8286	5.0173	15	10
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	138	4.9273	5.0173	15	
Locomo Central	Orom	Kitgum	60757	573979	381334	151	MG	142	4.9558	5.0173	15	
Obyen Central	Kitgum Matidi	Kitgum	60767	504517	368275	151	KG	0.0001	-9.2103	5.0173	0	0
Dognam	Kitgum Matidi	Kitgum	60768	502312	365953	157	KG	0.0001	-9.2103	5.0562	0	0
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	36	3.5835	4.6052	37	28
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	41	3.7136	4.6052	37	27.9
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	46	3.8286	4.6052	37	24
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	50	3.9120	4.6052	37	20
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	59	4.0775	4.6052	37	15
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	78	4.3567	4.6052	37	13
Lakwere Okaro-Kabete	Mucwini	Kitgum	60772	498443	374255	100	MGG	82	4.4067	4.6052	37	15

Location	S/C	District	DWD	mE	mN	Total Depth (m)	Lithology	Water Strikes (mbgl)	LN(WS)	LN(TD)	Pump Test Yields (m^3/hr)	Average Swing Angle, ASA (o)
Abaneka	Latanya	Pader	60623	493122	355432	120	VDG	0.0001	-9.2103	4.7875	0	0
Locken	Latanya	Pader	60622	495438	353855	124	VDG	25	3.2189	4.8203	19	40
Locken	Latanya	Pader	60622	495438	353855	124	VDG	46	3.8286	4.8203	19	20
Locken	Latanya	Pader	60622	495438	353855	124	VDG	59	4.0775	4.8203	19	16
Lageng	Acholibur	Pader	60600	488595	346081	120	AGG	29	3.3673	4.7875	40	32
Lageng	Acholibur	Pader	60600	488595	346081	120	AGG	59	4.0775	4.7875	40	6
Lageng	Acholibur	Pader	60600	488595	346081	120	AGG	64	4.1589	4.7875	40	17
Lageng	Acholibur	Pader	60600	488595	346081	120	AGG	92	4.5218	4.7875	40	40
Lugede	Acholibur	Pader	60596	487386	349702	120	AGG	27	3.2958	4.7875	20	32
Lugede	Acholibur	Pader	60596	487386	349702	120	AGG	73	4.2905	4.7875	20	16
Lugede	Acholibur	Pader	60596	487386	349702	120	AGG	96	4.5643	4.7875	20	4
Lugede	Acholibur	Pader	60596	487386	349702	120	AGG	101	4.6151	4.7875	20	5

AGG – Awela granodiorite gneiss

ASLD – Alluvium swamp & lacustrine deposits

BGC – Banded granulite & Charnokite,

IGSVDP – Intermediate granulite Sed_Vol_Dyke_Plutonic,,

KG – Kitgum granite,

VDG - Variable deformed granitoid

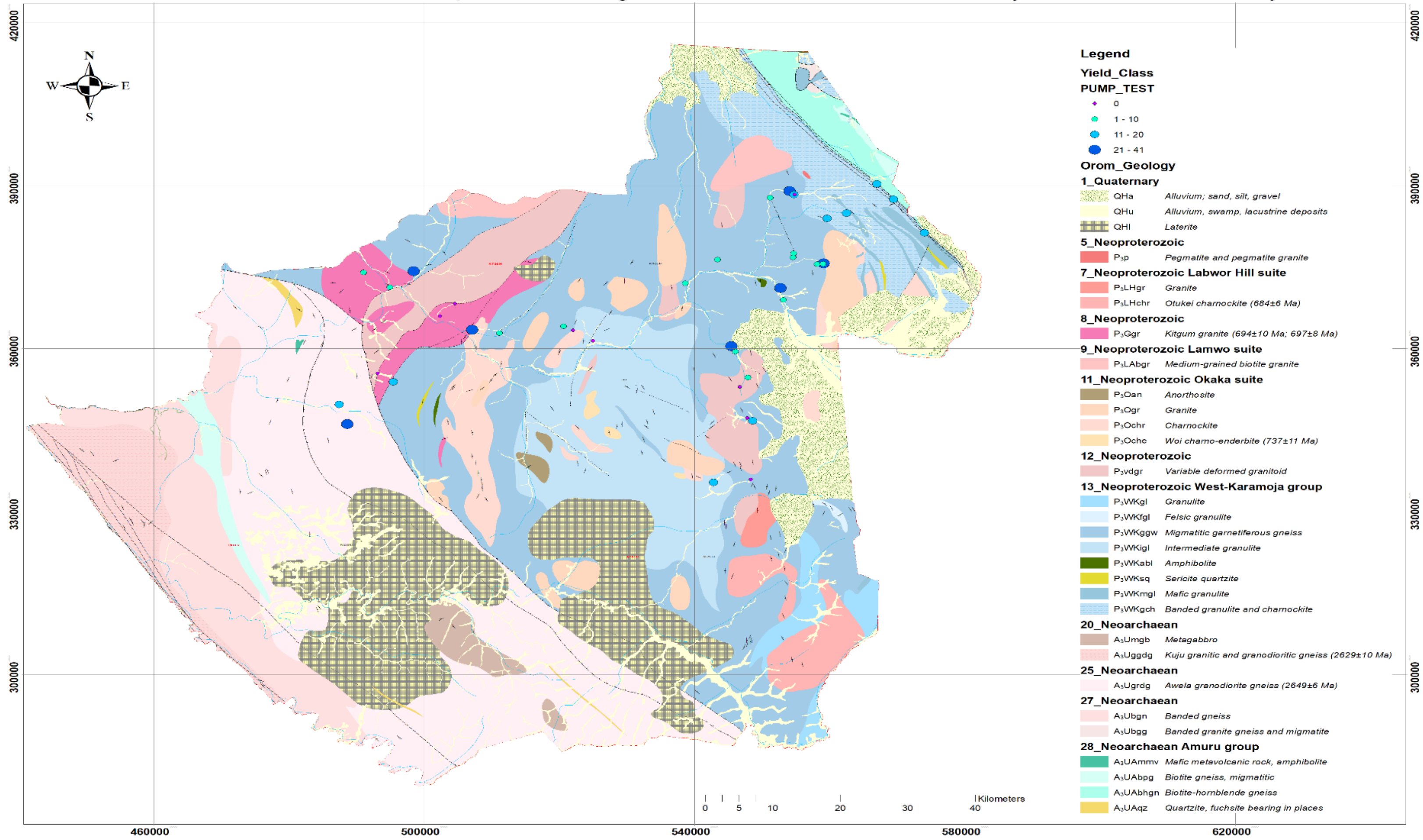
MGG – Migmatic garnetiferous gneiss,

MG – Mafic granite,

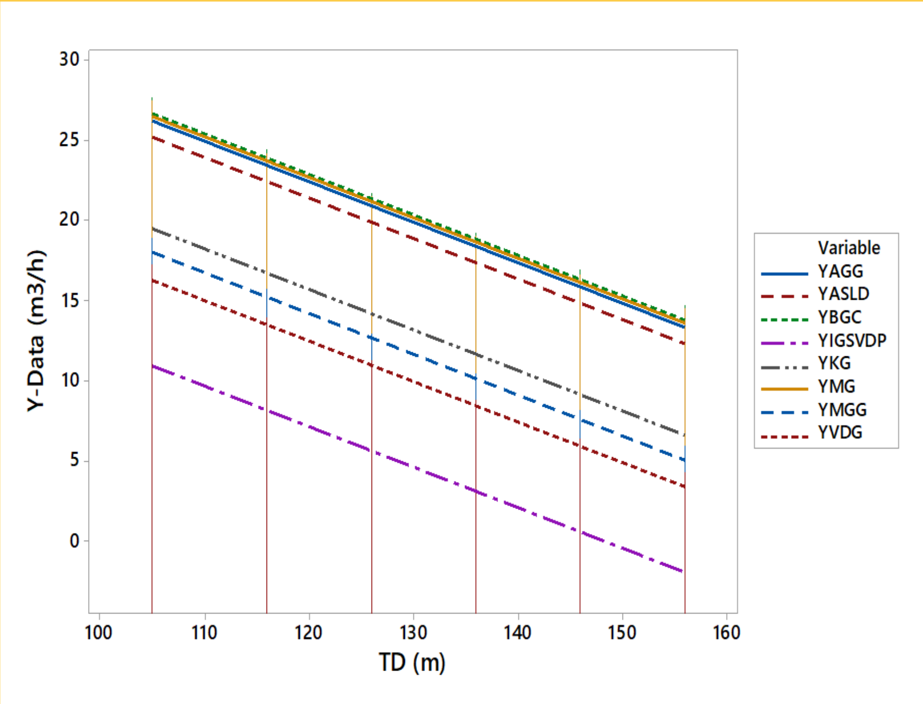
APPENDIX 3

DISTRIBUTION OF YIELDS ON GEOLOGICAL MAP OF STUDY AREA

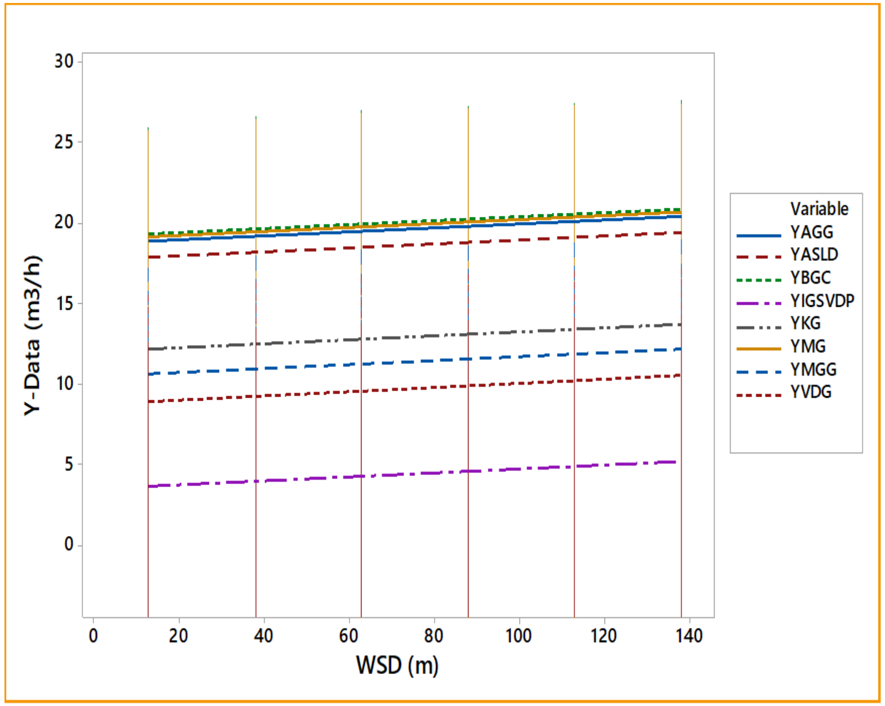
Borehole Yields and their relationship with Geological Structures from Data Analysed for Orom Study Area



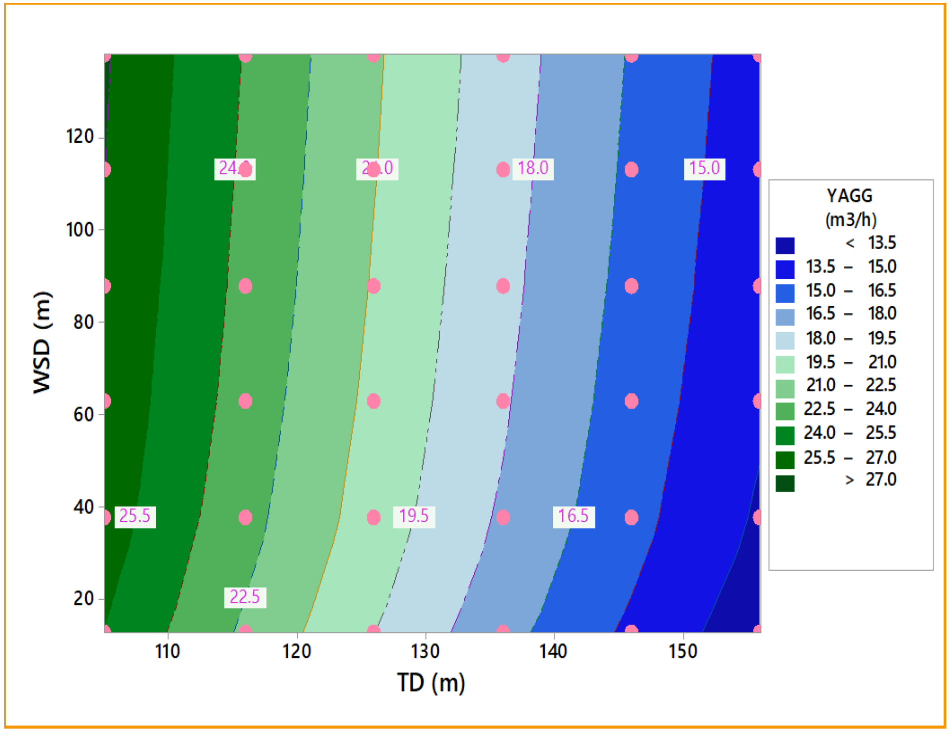
APPENDIX 4 (MODEL PREDICTED GW YIELD CURVES IN DIFFERENT LITHOLOGIES)



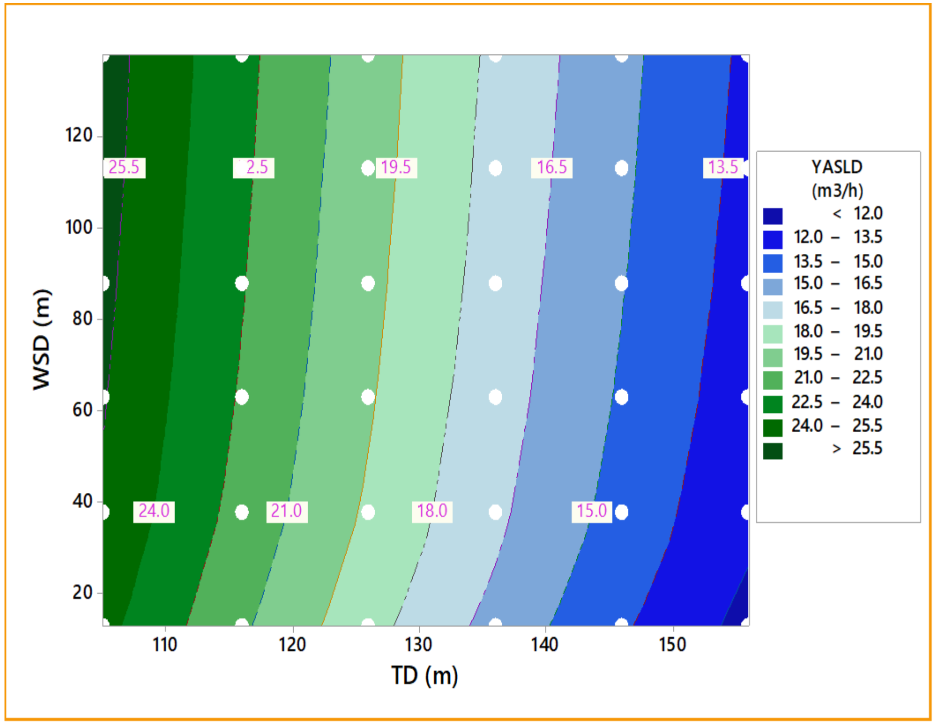
Variation of Yield with Total Depth (TD) for different geological features in the region of Agago, Pader and Kitgum, presented as linearized curves.



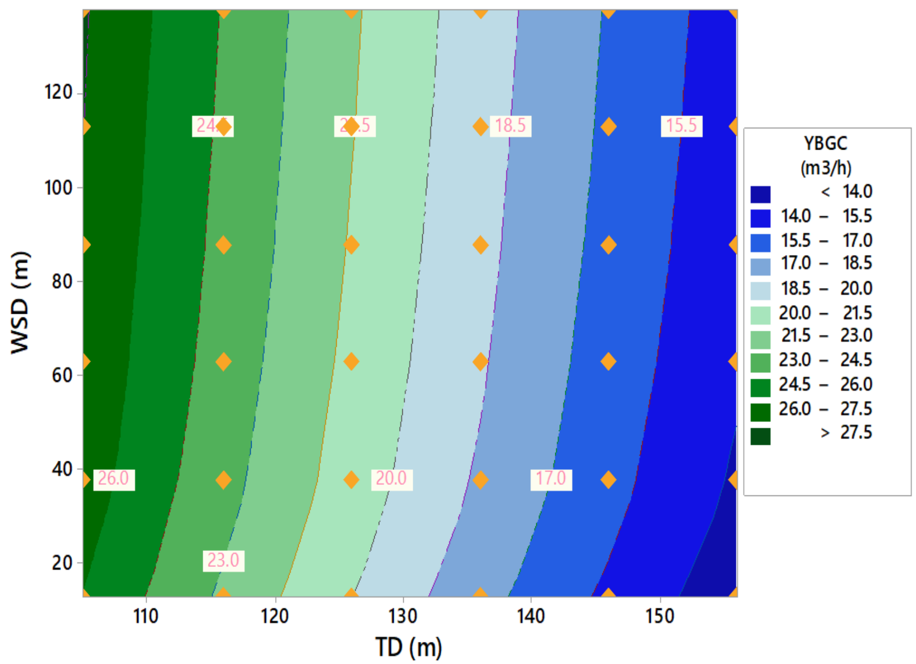
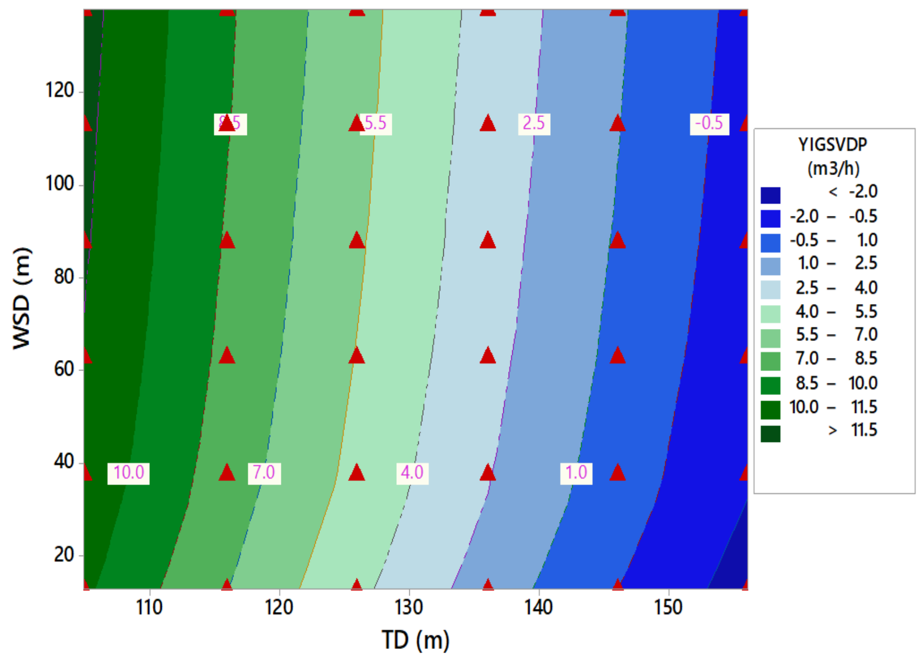
Variation of Yield with Water Strike Depths (WSD) for different geological features in the region of Agago, Pader and Kitgum, presented as linearized curves.

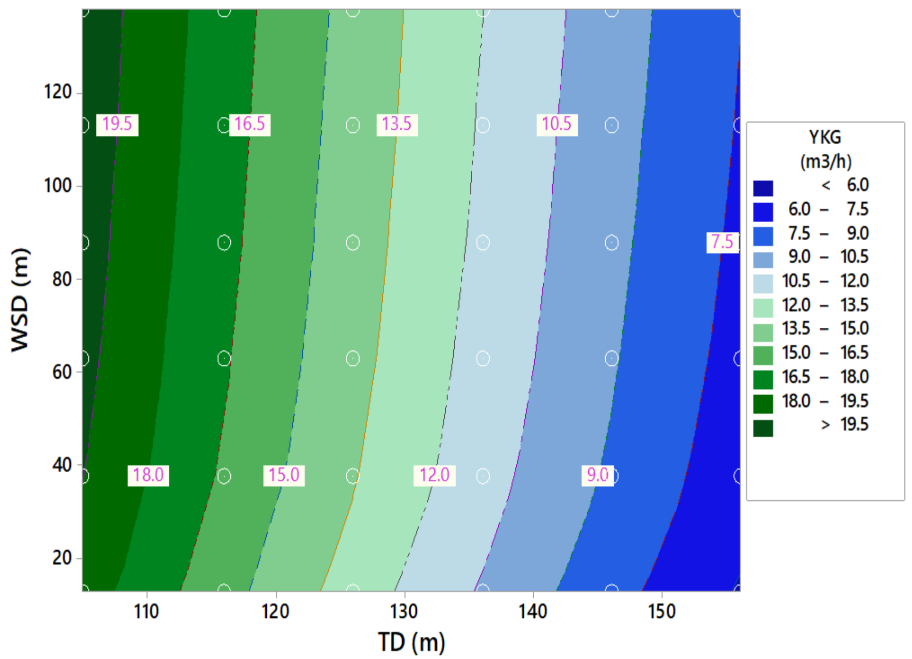
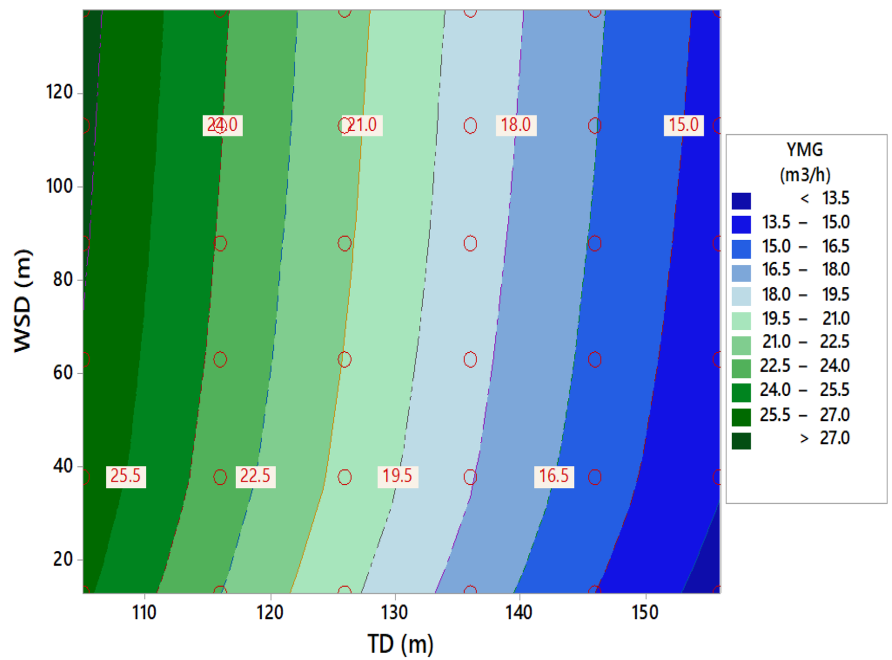


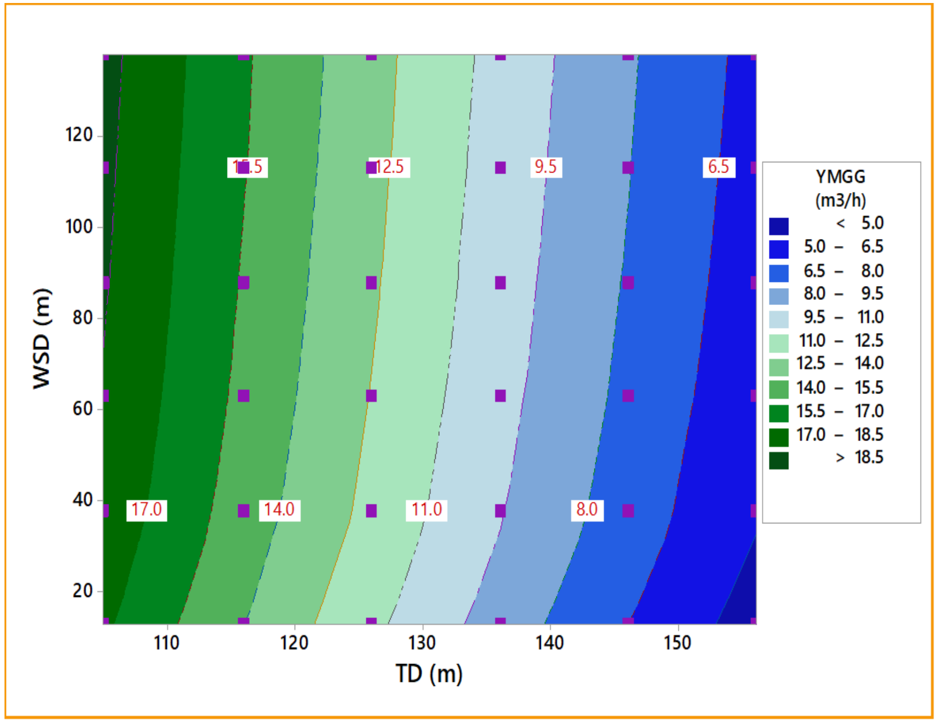
Model Predicted GW Yield (YAGG) Curves for AGG formation **(AGG** - Awela granodiorite gneiss)



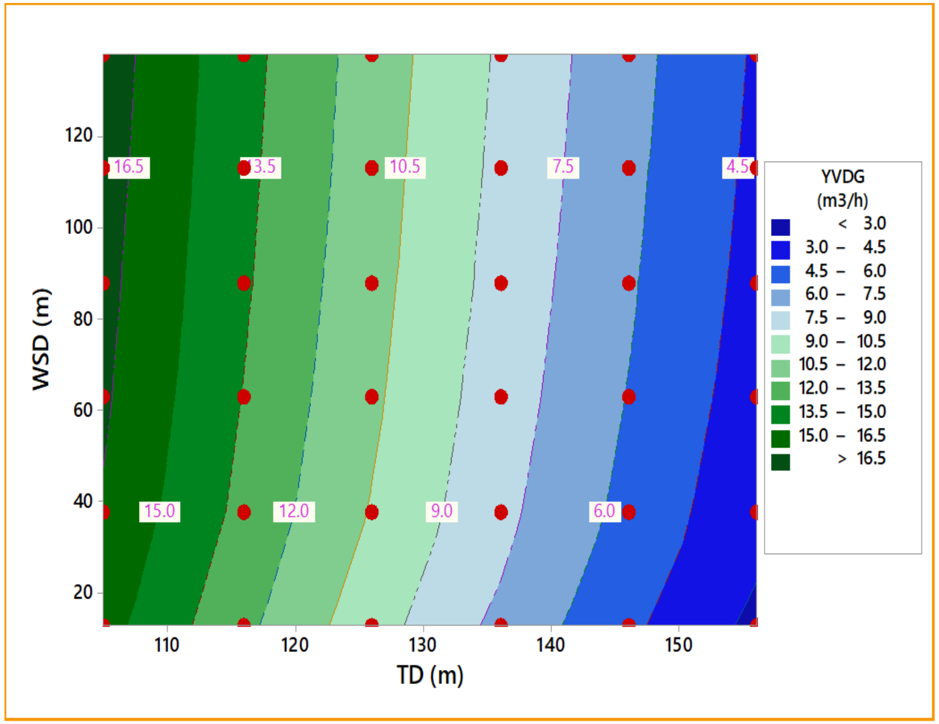
Model Predicted GW Yield (YASLD) Curves for ASLD formation **(ASLD** - Alluvium swamp & lacustrine deposits)

	
Model Predicted GW Yield (YBGC) Curves for BGC formation **(BGC** - Banded granulite & Charnokite)	Model Predicted GW Yield (YIGSVD) Curves for IGSVDP formation **(IGSVDP** - Intermediate granulite Sed_Vol_Dyke_Plutonic)

	
Model Predicted GW Yield (YKG) Curves for KG formation **(KG** - Kitgum granite)	Model Predicted GW Yield (YMG) Curves for MG formation **(VDG** - Variable deformed granitoid)



Model Predicted GW Yield (YMGG) Curves for YMGG formation **(MGG** - Migmatic garnetiferous gneiss)



Model Predicted GW Yield (YMG) Curves for MG formation **(MG** - Mafic granite)