EVALUATION OF GROUNDWATER RESOURCE POTENTIAL OF PALLISA DISTRICT IN EASTERN UGANDA

by

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This thesis is submitted in partial fulfilment of the requirements for the degree of

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DECLARATION

I ***JACOB NYENDE*** hereby state and declare that this dissertation/thesis "***EVALUATION OF GROUNDWATER RESOURCE POTENTIAL OF PALLISA DISTRICT IN EASTERN UGANDA***" handed in for the qualification Master of Science (Geohydrology) at the University of the Free State is my own independent work using only means and sources cited and that this work has never been presented previously for any award in any University/Faculty. All views and Opinions expressed therein remains the sole responsibility of the author.

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Kyambogo - Kampala - Uganda, May 2003.

JACOB NYENDE

Dedication

This Thesis is dedicated to my mother, Naguti Namuyonjo and my father, Nyende Jeremiah for their love, care and compassion over my life.

YOU ARE THE SOURCE OF MY INSPIRATION. "MWEBALE INHO"

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COMMONLY USED ACRONYMS

BH	-	Borehole
DWD	-	Directorate of Water Development
DWO	-	District Water Officer
ECWSP	-	Eastern Centers Water and Sanitation Project
EC	-	Electrical conductivity
EM	-	Electrical Magnetic
ET	-	Evapotranspiration
ET_p	-	Potential evapotranspiration
GIS	-	Geographical Information System
GM	-	Geoelectrical method
GS	-	Gauging station
GW	-	Groundwater
HL	-	Horizontal Lining (Dipole)
IAEA	-	International atomic energy agency
ITCZ	-	Intertropical convergence zone
LCs	-	Local Councils
NURP	-	Northern Uganda Reconstruction Project
NWSC	-	National Water and Sewerage Corporation
OBH	-	Observation borehole
PVC	-	Polyvinyl chloride
RO	-	Runoff
RUWASA	-	Rural Water and Sanitation Project
TDS	-	Total dissolved solids
UNESCO	-	United Nations Education and Cultural Organization
VES	-	Vertical Electrical Sounding
VL	-	Vertical Lining (Dipole)
WISH	-	Windows interpretation system for the hydrogeologist
WHO	-	World Health Organisation
WPC	-	Water Policy Commission

WRAP	-	Water Resource Assessment Project
WRMD	-	Water Resource Management Department
STN	-	Station
SS	-	Stainless Steel.

ABBREVIATIONS

km^2	-	Square kilometer
m^3/a	-	Cubic meters per annum
m^3/hr	-	Cubic meters per hour
m^3/d	-	Cubic meters per day
mm/a	-	Millimeter per annum
m^3/km^2	-	Cubic meters per square kilometer
mamsl	-	Meters above mean sea level
mg/l	-	Milligrammes per liter
µS/cm	-	Micro Siemens per centimeters
δ^2H	-	Change in Deuterium
$\delta^{18}O$	-	Change in Oxygen-18
Q	-	Discharge
KD	-	Transmissivity
m^2/d	-	square-meters per day
S	-	Storativity
s	-	Drawdown
N	-	Nitrogen
TDS	-	Total Dissolved Solids

CHAPTER 1

INTRODUCTION

1.1 SCOPE OF THE INVESTIGATION

1.1.1 BACKGROUND

Over 90% of the rural population in Uganda relies predominantly upon groundwater as the major source of potable water (Taylor and Howard Ken, 1995). Pallisa district in Uganda is no exception.

As much as the populations of most countries are growing, it is likely the total use of water will increase, even with conservation measures (Fetter, 1994). Groundwater has become increasingly popular in Pallisa district. Water being a finite resource, and with the increasing population in the district coupled with deficiency of safe water points, there is a need to identify more safe sources of supply of this limited resource. Therefore, due to high demand for the invaluable resource, work on providing adequate good quality water is essential. However, despite the widespread increase in development of groundwater resources, there has been a population increase that has caused an increase in several activities – agricultural irrigation, livestock and domestic water supply within Pallisa district.

This therefore, corresponds to high increase in demand for potable water to the ever-increasing population. The quantification and proper management of groundwater is therefore essential to cater for sustainable development. How best the resource can be managed depends primarily on how much the resource is understood.

The challenge facing planners, implementers and policy makers in Uganda now, is to ensure sustainable groundwater exploitation and utilisation thereby prevention of exhaustive abstraction and groundwater-related pollution.

It should be realised that the priority in groundwater is directly emphasised on the sustainability of the resources with respect to both quantity and quality. Protection and sustainable development of the groundwater resources is mandatory in framing solutions to these kinds of problems. Knowledge of the spatial and temporal characteristics of groundwater systems and their interactions with the environment provides the basis for such sustainable development and environmentally sound planning and management of groundwater resources.

None of the earlier research work has adequately covered the study area though a general overview of the groundwater assessment in Uganda has been provided. In the study area some parts lack sufficient water resources necessary for its general development especially in the alternating drying times of the year.

Presently water is obtained from rivers, dug wells, hand pump boreholes, earth dams or ponds and some seasonal springs. In some circumstances this water is not safe for human consumption.

To cater for the increasing population, irrigation of farmlands and initiating small-scale industrial projects, potable water is an obvious requirement. This study therefore, focused on an evaluation of the groundwater resource with emphasis on the assessment of groundwater availability in Pallisa and to know the groundwater resource potential in rural areas.

The field studies were conducted in the district of Pallisa in eastern Uganda and all the data collected during the project were evaluated. The results are reflected in this write-up.

1.2 OBJECTIVES OF THE RESEARCH STUDY

1.2.1 MAIN OBJECTIVE

The main objective of the study is to evaluate the groundwater resource potential for sustainable development in rural areas.

1.2.2 SPECIFIC OBJECTIVES

The specific objectives of this research are as follows:

- To determine the reliability and applicability of VES in Pallisa district.
- To evaluate the potential for sustainable harvesting of groundwater resource.
- To determine the hydrogeological properties of the aquifer.
- To determine the groundwater quality and quantity with time.
- To propose improved management strategies of groundwater resource in Pallisa district in order to avoid any possible contaminations by identifying pollution sources.
- To propose a monitoring programme in the area that includes boreholes.

1.3 SIGNIFICANCE OF THE STUDY

The growing need of groundwater in Pallisa district for public use in the development of agriculture, animal husbandry and fisheries cannot be overemphasised without leaving water required for domestic use in terms of quantity and quality.

The quantification and quality of the sub-surface waters should be ascertained for proper management of the underlying aquifer to meet the increasing demand and also to address the environmental issue, which often lead to over exploitation of the resource.

To meet these challenges, hydrological, hydrogeological and isotopic studies were therefore necessary for a viable long-term assessment and development of the sustainability and suitability of groundwater for the public. These gave in depth knowledge into the identification of the recharge source, quantities and direction of groundwater flow system.

In conclusion the study will be of significance to the following categories of Organisations and people: to the Ministry of Water, Lands and Environment, to the planners and managers of groundwater resource, to the stakeholders i.e. the rural population of Pallisa district, to other researchers in groundwater. In the first place, this study will be relevant to the Ministry of Water, Lands and Environment. It will enable the Ministry to plan for future needs of its peoples and to develop new ideas on how to manage this groundwater resource. It is well known that groundwater is generally the sole provider of potable water to the rural population in Uganda. Therefore, the proposals and suggestions of this study may form a basis of strategic planning by this ministry, the country of Uganda and the world as a whole.

Secondly, it will be relevant to the Water Resources Management Department managers because they have the social responsibility of organizing in an efficient manner and effective water services to satisfy their customers by use of groundwater. They are affected if they do not take the management option of the groundwater resource seriously.

Thirdly, the study will also be significant to the rural population of Pallisa district who are stakeholders in the entire environment at the grassroots. When the rural population get value from this resource, then they will have got the right needed material necessary for the development in agriculture, animal husbandry and fisheries since modernization is the key to successful development. This therefore demands that improper planning of the groundwater resource would affect widely the population in times of droughts. It is the aim of this study to ensure that potential of this resource is known, organised and well managed so that the rural poor benefit.

Fourthly, the study will be significant to future researchers and students on the subject of evaluation of groundwater resources. The contribution, however small this study will make, shall form a basis for all those who will seek information on this matter for consequent evaluations of groundwater resources potential to be done in other areas of interest.

1.4 CONCEPTUAL FRAMEWORK

1.4.1 Definitions

Groundwater: Is the water beneath the surface that can be collected from wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs. Or it is the water that is pumped by wells and flows out through springs.

Evaluate: It is to assess or appraise. Evaluation may be defined as the systematic and scientific process of determining the extent to which any action or sets of actions have been successful in the achievement of predetermined objectives. It involves the orderly collection, analysis and interpretation of information on the subject with a view of identifying alternative courses of current or future actions. After House (1980) defined evaluation as that leads to the settled opinion that something is the case, usually but not always leading to a decision to act in a certain way. In either case, evaluation is how one determines the quality of a product in the context of its intended use. Also evaluation is a process that is involved in many other types of academic writing, like argument, investigative and scientific writing, and research papers. When we conduct research, we quickly learn that not every source is a good source and that we need to be selective about the quality of the evidence we transplant into our own writing. The process of making a selection from among other alternatives constitutes decision-making.

Evaluation therefore, involves the following:

a) Collection of information about actions or about the subject of interest;
b) Comparison of this information with the specified norms and criteria or determined objectives and;
c) Formulation of conclusions from the comparison, and the identification of alternative courses of action.

Potential: It is the capacity for use or possible development. Here, it is the ability or capacity of a crystalline or a fractured rock formation (Basement complex) to allow infiltration and storage of groundwater and this therefore forms a major part of the groundwater supply system in Pallisa district.

Resource: Is a stock or supply that can be drawn on or a means available to achieve an end and fulfill a function. According to Santosh Kumar Garg (2000), water is the most important resource of a nation and of the entire society as a whole, since no life is possible without water. It has this unique position among other natural resources like minerals fuel etc. because a nation can survive in the absence of any other resource except water.

1.4.2 Relationship Between Concepts

The relationship between the above concepts is that the resource evaluation involves arguments, investigative and scientific facts about groundwater. It will result in knowing as to whether the aquifer has the potential or the resource can sustain the increasing population with potable groundwater supply even for long periods of drought. It should also be brought to book that effective evaluation is indispensable if success of a project or projects and of management in general is not to be left to chance. It is a powerful tool not only for improving the quality of programme planning and execution, but also for ensuring progress, for avoiding the waste of scarce resources and for deploying such resources to the greatest advantage.

1.5 PREVIOUS RESEARCH WORK

Much work has been done on water supply in Uganda. Both ground and surface water in Mukono, Bugiri and Luwero districts have been discussed in terms of the hydrological and hydrogeological aspects and groundwater quality. However, all these studies conducted did not lay much emphasis on the evaluation of the groundwater resource potential.

Morgan (1998) in her study on groundwater chemistry in the Naivasha area explained that the quality of groundwater has deteriorated due to high level of nitrate from agricultural activities as well as high-level fluoride.

In terms of evaluating the regional and hydrologic effects of global and regional climatic changes in water balance, water balance models have been developed by Thornwaite, C.W (1978), Thornwaite and Manther, J.R (1955, 1957) and introduced originally to evaluate the importance of different hydrologic parameters under a variety of hydrologic conditions. The incorporation of soil moisture characteristics of regions, annual estimate of hydrological parameters and use of readily available stream flow as well as soil and vegetation characteristics provide accurate estimates of surface run-off when compared to measured stream flow, accurate measures of relative changes of soil moisture, reliable evapo-transpiration, estimates under man climatic regimes, and estimates of groundwater discharge and recharge rates.

Groundwater evaluation and assessment of water supply (Williams M, 1998; Carter R.C, 1999; Farr, J.L, 1982) focused on the methods of evaluation and their interest lay in the pumping tests carried out. The Rural Water and Sanitation Project (RUWASA) and Small Towns Water and Sanitation Project under Directorate of Water Development (DWD) set up water supply projects that were intended to bring safe water to millions of Ugandans in the rural communities by use of groundwater. The focus however, was on delivery (construction of water systems). This has been at the expense of equity and sustainability (Gupta, 1982 and Schmitz, 1999).

The soil moisture model for the groundwater recharge was first instituted by Penman (1950). It is an application in equatorial Africa that has been detailed previously by Houston (1982, 1990) as well as Howard and Karundu (1992). The method provided periodical estimates of direct recharge (i.e. from the infiltration of rainfall) based on the changes in the moisture content of the soil. Contributions to the groundwater reservoir from other sources were not included in the calculations. Under this model, direct recharge was predicted to have occurred when soil moisture content, which was a function of precipitation (P) and evapotranspiration (ET), reached saturation and excess rainfall yielded groundwater recharge.

When the moisture content of the soil is less than 100%, a soil moisture deficit develops and recharge is prevented. ET continues, but is constrained by a "root constant" and "wilting factor", the magnitude of which each depends upon the nature of the vegetative cover.

The root constant is the product of the root depth and soil porosity and represents the soil moisture deficit beyond which ET could no longer proceed at its maximum rate, known as potential evapotranspiration (ET_P). Once this is surpassed, ET continued at 10% of the maximum rate (ET_P) until the wilting point is reached and evapotranspiration cease.

According to Howard and Lloyd, 1979 10 days or monthly intervals could lead to significant underestimation of the recharge volume. So daily recharge estimates were collected from this soil moisture balance model for two periods for which the information regarding the type and distribution of the vegetable cover existed.

The performance of the recharge estimation over the two periods enabled the effect of the changes in land-use and rainfall on the model's recharge prediction to be investigated.

Daily records of rainfall from 1954 to 1961 for Aler Station (2° 18"N, 32° 55"E) and from 1988 to 1992 for Lira (2° 17"N, 32° 56"E) were retrieved for the purposes of relating this information to Pallisa district.

For the purposes of this study, recharge calculations on the two areas above; represent the catchments' vegetation for the duration of the respective corresponding period of rainfall. After the daily values of ET_P were generated, a pan factor of 0.9 was applied and the final component in the calculation of the daily recharge(R) was surface run-off (RO) where

$$R = P - RO - ET.$$

Taylor (1996) highlighted the need for reliable estimates of groundwater recharge considering the increasing demand for groundwater that has raised concerns about resource sustainability. Recharge investigations in the study environment are typically inhibited by a shortage of good quality meteorological and hydrogeological records. Moreover, when recharge studies are attempted they tend to rely on a single technique and frequently lack corroborating evidence to substantiate recharge predictions.

In recent studies undertaken in the Aroca catchment of the Victoria Nile basin in central Uganda, the timing and magnitude of recharge determined by a soil moisture balance approach are supported by stable isotope data and groundwater flow modelling. The soil moisture balance study reveals that recharge averages in the order of 200mm/a and is more dependent on the number of heavy (>10mm/day) rainfall events than the total annual volume of rainfall. Stable isotope data suggest independently that recharge occurs during the heaviest rains of the monsoons, and further establish that recharge stems entirely from the direct infiltration of rainfall, an assumption implicit in the soil moisture balance approach. Deforestation over the last thirty years is shown to have more than doubled the recharge estimate. Aquifer flow modelling supports the recharge estimates but demonstrates that the vast majority (>99%) of recharging waters must be transmitted by the aquifer in the regolith rather the underlying bedrock fractures which have traditionally been developed for rural water supplies.

A report on the hydrogeological and socio-economic examination of the regolith and fractured bedrock aquifer systems of the Aroca catchment in Apac District and the Nyabisheki Catchment in Mbarara District in the western part of Uganda

(Groundwater Research Group, University of Toronto, Ontario, 1994) was done. It analysed the hydrological flow of groundwater in the fractures and established that the potential stores of groundwater actually lay in the fractures of the bedrock and regolith overlying the crystalline basement rocks, and in faults in the basement.

This study also aimed at developing a water resource management criterion for input into the National Water Management Policy (NWMP). Such criteria would recognise the interface nature of groundwater and surface water so as to ensure sustainable use of this essential resource. Recommendations were made in terms of borehole location and design, recharge characteristics, land use, resource monitoring and water quality.

Rural water supply therefore, occupies a significant place in development of Uganda - where the majority of the population live, and the provision of safe drinking water within a walkable distance is one of the most important basic human needs and is indispensable for sustaining and enhancing life and alleviating poverty.

Neuman (1994, personal communication) gave the following possible explanation: Consider the rock to consist of nested storage "reservoirs" comprising different scale fractures. At one end of the spectrum are a few large, permeable fractures occupying a small relative rock volume, which therefore has small porosity and storativity. On the other end are many small, low-permeable fractures occupying a relatively large rock volume, which therefore has large porosity and storativity. Close to the pumping well, pressure in the large fractures declines rapidly relative to its rate of decline in the small fractures. The latter therefore release a relatively large amount of water into the large conductive fractures due to a sizeable local pressure gradient between the small and large fracture reservoirs. Hence S is large. Far from the pumping well, the pressure gradient between the small and large fractures is relatively small. Therefore, water release from the small to the large fractures occurs very slowly. Most of the initial drawdown (in the large fractures) at a great distance is associated with water release from storage in the large fractures. Hence S is small.

With time, local pressure differentials between the reservoirs stabilize and flow everywhere within a given radius approaches a steady radial pattern. Therefore, it could be expected that S should approach a uniform value representing both reservoirs.

However, as the flow pattern is now essentially stabilized and close to steady state (even though absolute pressures may continue to decline), standard pumping tests may not reveal this fact: the flow is sensitive to S only at early times. If there were only two reservoirs with very different S values, log-log time-drawdown curves close to the pumping well would exhibit a familiar dual-porosity time inflection (of the kind analysed by Neuman for unconfined aquifers). However, if there is a continuous hierarchy of such reservoirs with a more or less continuous local range of T- and S-values, such inflections cannot be seen. The early log-log time-drawdown behaviour would then just look like a regular Theis curve. Only long pumping tests would reveal deviations from this curve, but unfortunately, storage effects during late behaviour are usually masked by large-scale heterogeneities and boundary effects.

Benson and Parsley (1984) and Everett (1984) addressed the problem of efficient monitoring of groundwater levels. As an indicator in the evaluation process, the water resource is monitored, managed and exploited in a sustainable and equitable manner, Hodgson, F.D.I (1991) and Farooq, (1998).

According to Vrba, J (2000), Groundwater quality monitoring plays an important role in the strategy of groundwater protection and quality conservation and in enforcement of an anti-pollution policy. Monitoring furthermore, emphasise the chemical and physical conceptualisation of the system, which are essential prerequisites for successful modelling (Botha and Muller, 1984).

According to Bredenkamp (1999) the study on monitoring opened up several opportunities for extending the Cumulative Rainfall Departure and Management rainfall method to other parts of the world, especially in Africa where rainfall measurements but only limited groundwater level data was available.

However, a number of well-spread monitoring points per aquifer or per selected area would provide a representative picture of the groundwater fluctuations in such an area. For many aquifers a reduction in the number of monitoring points would not seriously affect the reliability of assessments of groundwater exploitation potential, and management of the aquifer.

The variability of rainfall is probably the least reliable factor, and monitored monthly total rainfall at each monitoring station would increase the reliability of the regression between rainfall and the piezometric levels.

Bredenkamp (1999) went a head to suggest the effective monitoring and data evaluation of monitoring stations based on the following:

a) the importance of groundwater as a primary/secondary water supply;
b) the existence of exploitable aquifers for irrigation or as urban water supplies, which is generally indicated by the occurrence of boreholes with high sustainable yields;
c) the sustainability of groundwater exploitation based on the average annual rainfall-areas of high rainfall being of great importance, and because groundwater exploitation affects the base flow of streams and the ecology. However, exploitation of groundwater on a large scale also occurs in drier areas, where groundwater has been replenished over many years in the past;
d) monitoring of points already in operation and rainfall stations in the area.

Different methods have been proposed and many authors reviewed several applications on the problem of evaluation of groundwater resource potential.

Rushton and Rathod (1985) have determined the velocity components from information about the groundwater-head distribution, groundwater potential, confined and unconfined aquifers; time-variant behaviour of aquifer and hydraulic conductivity.

Serrano and Unny (1987) developed mathematical models as an innovative approach to the solution of groundwater forecasting problems where they considered the uncertainty generated by the use of data subject to environmental fluctuations and measurement errors. They have described in detail the development, solution and validation of two mathematical models describing groundwater potential at the Twin lake aquifer.

Sondhi et.al. (1989) determined the available additional groundwater potential and its distribution in many research areas; estimation of groundwater recharge from the water conveyance and distribution system and the annual water balance of the project; 'recharge distribution coefficients' are done using digital simulation models.

Chiew and McMahon (1990) estimated groundwater recharge using surface watershed modeling approach for both irrigated and non-irrigated areas. In all the above cases, they have not seen which time period will give appropriate prediction over the recharge value of a basin area. Uma and Kehinde (1992) described the analysis of the base flow characteristics of numerous small basins to estimate the groundwater in the basins.

Boonstra and Bhutta (1996) have worked on determination of seasonal net recharge considering temporal and areal recharge variations, geometry of aquifer system, historical water table elevations, drainage design and waterlogged areas, and developed numerical models for monsoon estimates, water-balance, and return period. A similar attempt is made here for estimating the ground water recharge potential of a river basin.

According to Banks (1952) and Sambasiva (1991), groundwater resource is evaluated in terms of development, assessment and its utilisation to the satisfaction of the populations' demand. However, many including the previous work on these items have been discussed under the relevant chapters in this write-up.

According to Oppong-Boateng (2001), the relatively low resistivity at the bottom layers can be attributed to clayey-rich lithology and the high values being indicative of presence of perhaps sandy or lacustrine sediment materials.

From all the above records reviewed and all that was available, there has not been any known study in Pallisa district on evaluation of groundwater potential in general. The available literature was therefore accessed from texts, journal articles and electronic format information on websites with references to other countries. This makes it a very strong case for this study to be conducted.

The next chapter 2 provides a full description of the study area.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

2.1 REGIONAL SETTING

2.1.1 LAND AREA AND POPULATION

Uganda is situated entirely within the Nile basin and part of East African countries, Kenya, Uganda and Tanzania, with a total land area of 197100 km^2. The total population of 23 million (2002 statistics) has the agricultural sector that accounts (in 1991) for about 60% of the country's Gross Domestic Product, GDP and for over 90% of the export. The average population density accounts to 117-persons/ km^2.

2.1.2 SURFACE AND GROUNDWATER RESOURCES

The internal surface water resource has 8 main drainage basins: Lake Victoria, Lake Kyoga, Lake Edward and Lake George, Lake Albert, the Aswan, the Kidepo, the Albert Nile and the Kyoga Nile. The total recharge average capacity of groundwater has been estimated to be 19.7 km^2/a. the average potential yield of the borehole is also estimated to lie between 1 m^3/hr and 4 m^3/hr.

2.2 LOCAL SETTING

2.2.1 LOCATIONS AND EXTENT OF THE STUDY AREA

Pallisa district is situated in the eastern part of Uganda and it is neighboured by Iganga district to the south-west, Kamuli district to the west, Tororo district to the south, Soroti district to the northwest, Kumi district to the north and Mbale district to the east.

It occupies an area of 1956 km^2 with a population of 357656 according to the 1991 census. The density of the area is 229 people per square kilometer. It is located between latitude 33^0 25" East and 34^0 09" East and Longitude 0^0 50'' North and 1^0 25" North. The District Headquarters are located at Pallisa, with major towns of Budaka, Kamuge, Kibuku and Butebo. A location map of the area under study is shown in Figure 1. It lies within the Lake Kyoga catchment areas of Eastern Uganda.

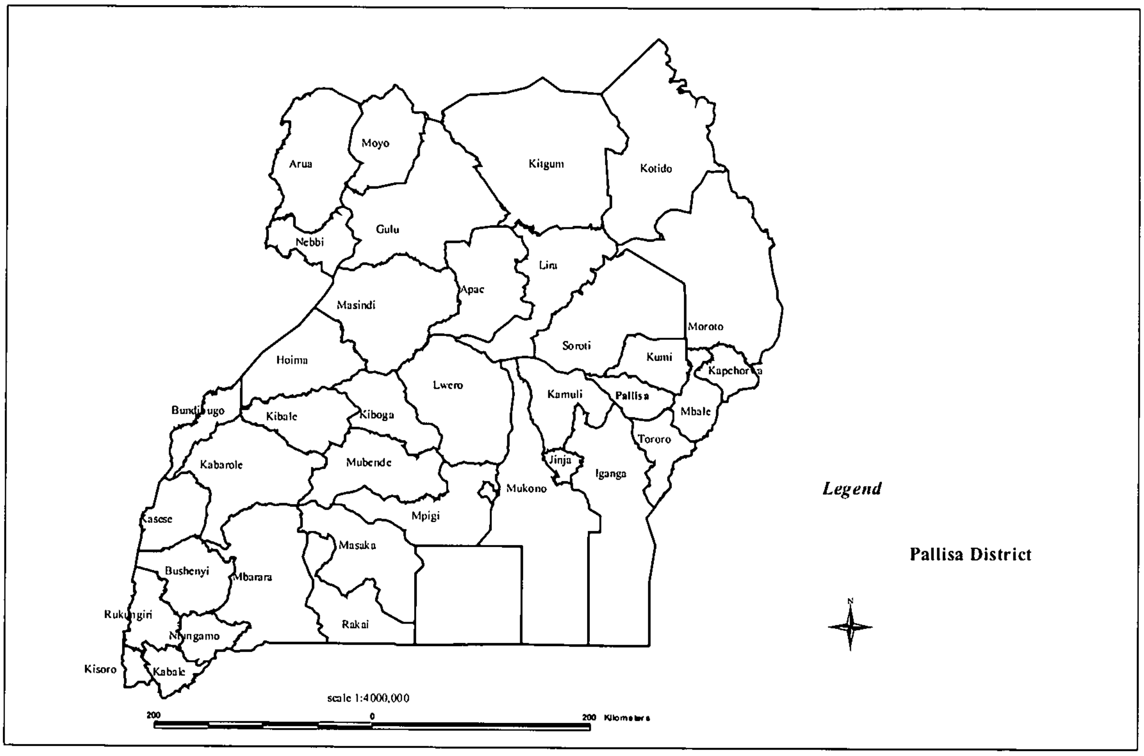


Figure 1 Location of the study area within Uganda.

2.3 PHYSIOGRAPHY

2.3.1 TOPOGRAPHY

The main topographical features of the study area can briefly be summarised as follows. The western to northwestern part, adjacent to Lake Kyoga consists of flat plains rising progressively with an elevation of less than 900 mamsl. Further to the east, which is towards Mbale, there is a progressive rise in topography from 900 – 1500 mamsl.

The main feature of the study area is granite, known as Kiryoro in Bulangira sub-county, Kakoro in Kabwangasi sub-county and Kataizula in Budaka sub-county.

2.3.2 DRAINAGE

The main arteries for surface drainage in the area are the Mpologoma River running from the east, south towards the northwest. River Manafwa in the east flowing right from the top of Mt Elgon, joining River Mpologoma, and River Dodoi in the center flowing to the west into the Mpologoma River to Lake Kyoga (Figure 13).

It should be noted that most of the study area lies within the upper part of the Kyoga basin. The present drainage pattern is as a result of upwarping and faulting along the Western Rift Valley. This caused a reversal of flow in many of the originally westward flowing Rivers as well as impeding the flow of the river draining the plateau to form extensive swamp areas and lakes. The rivers and lakes on the plateau of the Kyoga – Victoria Lake systems are as a result of impeded drainage.

2.3.2.1 SWAMPS AND MASHLANDS (WETLANDS)

Most of Pallisa district is fairly covered by wetlands and as evidenced by the large tracts of papyrus vegetation on many of the riverbanks and streams.

In general, wetlands have for long been regarded as wastelands. However, people in Pallisa have encroached on wetland areas, haphazardly draining the land for economic purposes. It should be emphasised that wetlands are a natural resource of considerable importance like any other resource.

They play a significant role in the environmental balance of this study area. Importantly the functions of these wetlands in Pallisa district include maintenance of the water table, prevention of soil erosion, reduction of extreme flows, sediment trap, wildlife habitats, nutrient and toxin retention, fishing and water supply. Above all these wetlands have played an important role in control of water quality through their buffering capacity.

However, despite the enormous direct and potential uses of wetlands in Pallisa district, extreme pressure is being exerted on wetland drainage for rice growing.

2.4 CLIMATE

2.4.1 GEOGRAPHICAL RAINFALL DISTRIBUTION

For the purposes of evaluating the rainfall distribution, the following two maps representing the geographical rainfall distribution in the project area were used. One prepared by Sir Alexander Gibb and Patners, The Institute of Hydrology and Department of Meteorology, University of Reading for World Bank – UNDP; 1989 and the other by Water Resources Assessment Project, WRAP, Entebbe. The said study area lie between isohyets 1200 to 1400 mm. (Figures 14 and 15)

To supplement on the above, monthly rainfall data in and around the study area was collected from the meteorological stations that were used to determine the mean annual rainfall pattern. As a result of this, mean annual rainfall for the stations around indicated that Kayunga, Kamuli and Buwenge fall within 1100 mm/a, while the rainfall in mount Elgon area is much higher, exceeding 1500 mm.

Based on the two maps, the entire study area has an average annual rainfall exceeding 1250 mm/a and somewhat higher.

The rainfall stations with the longest data series were used to confirm the conclusion drawn from the rainfall maps regarding the geographic variation of rainfall over the study area. Since this serves only as confirmation for the evaluation, all years with complete records were used, while partial records were omitted.

2.4.2 RAINFALL DISTRIBUTION OVER THE YEARS

The same meteorological stations in Table 3 were used to evaluate the rainfall distribution over the years in the research area. The distributions of mean monthly rainfall for each station were plotted (Figures 3, 4, 5, 6, 7, 8, 9, 10, 11and 12). It can be seen from Figure 2 that the rainfall pattern show limited variation between the stations.

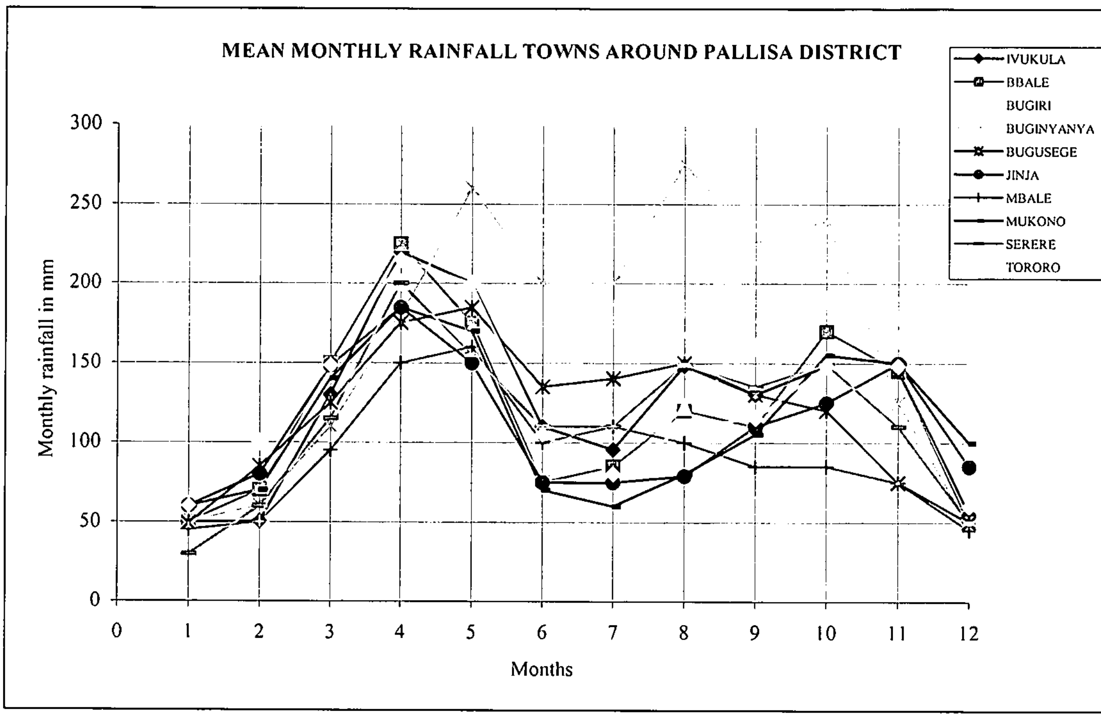


Figure 2. Graph of the mean monthly rainfall of all the towns around Pallisa district from 1956 - 1999.

In general, the rainfall is lowest in the period of December – January, and reaches a maximum in the period of April – May. For most of the stations, there is a second rainy season with a more or less pronounced peak between August and November. Only for Mbale, the second rainy season is absent, and this is probably one of the explanations for the relatively low rainfall at this station. In contrast, the rainfall is high for the whole period of April – October for the station at Buginyanya on mount Elgon.

The following computed mean monthly readings of rainfall for these different stations were done right from 1956 to 1999. The results from these readings are represented in the following individual graphs below.

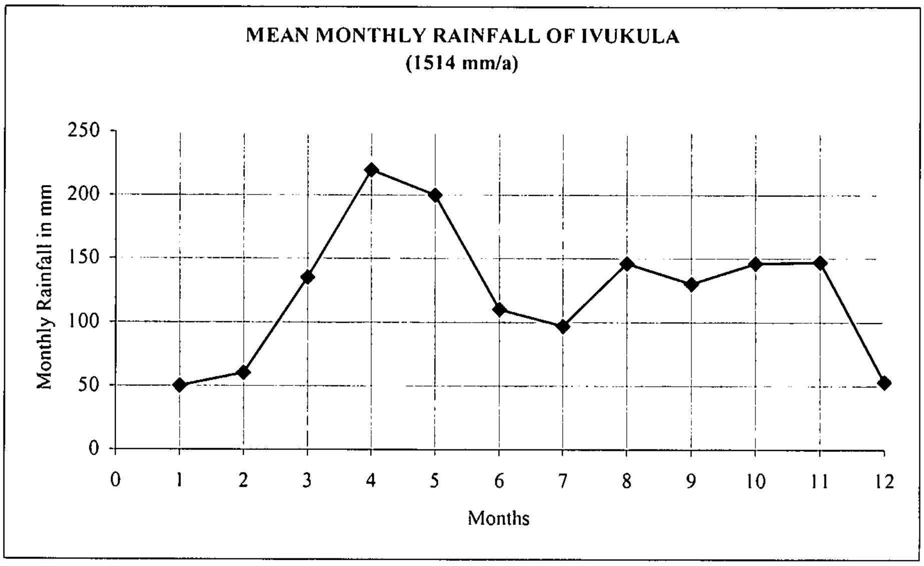


Figure 3. Graph of the mean monthly rainfall of Ivukula.

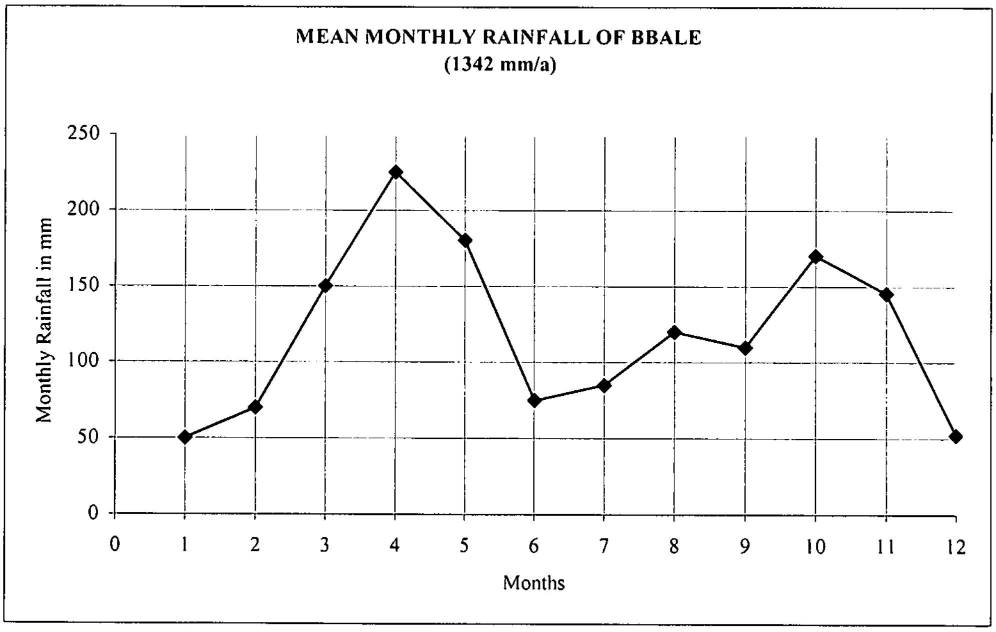


Figure 4. Graph of the mean monthly rainfall of Bbale.

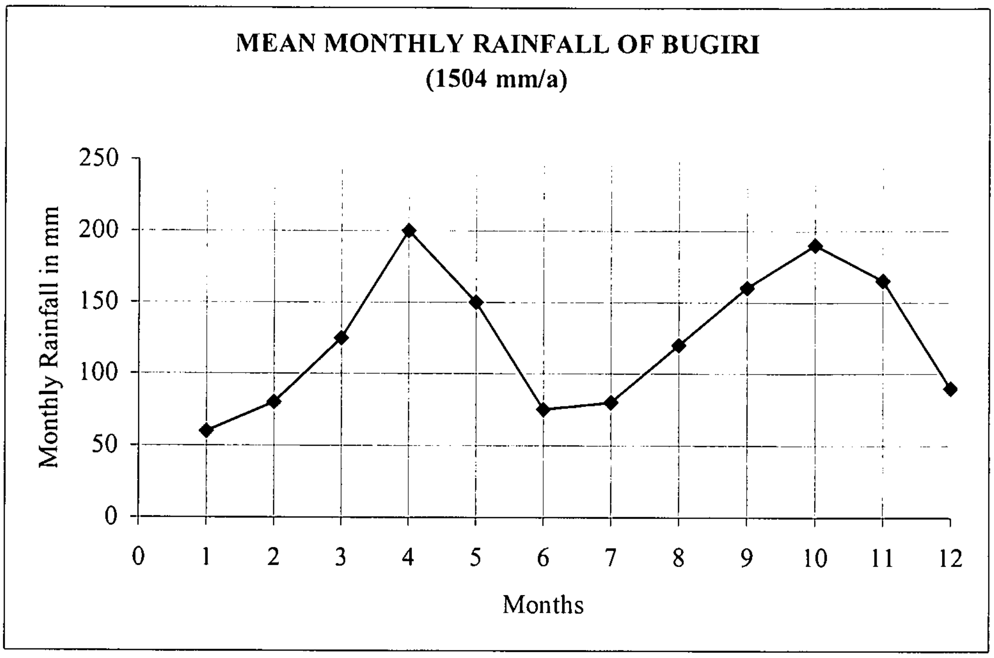


Figure 5. **Graph of the mean monthly rainfall of Bugiri.**

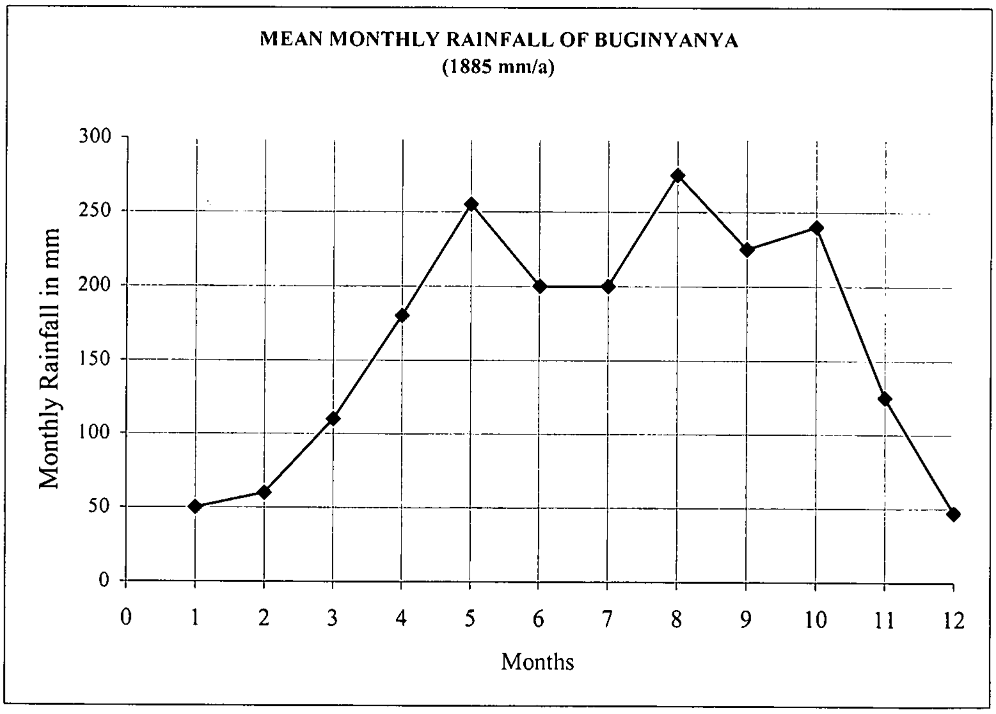


Figure 6. **Graph of the mean monthly rainfall of Buginyanya.**

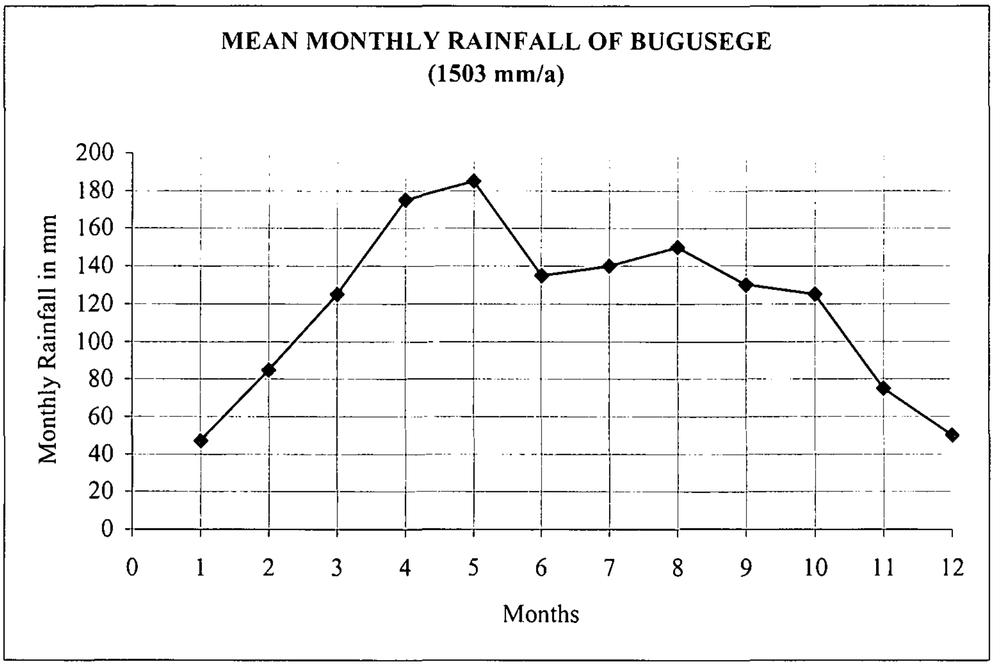


Figure 7. **Graph of the mean monthly rainfall of Bugusege.**

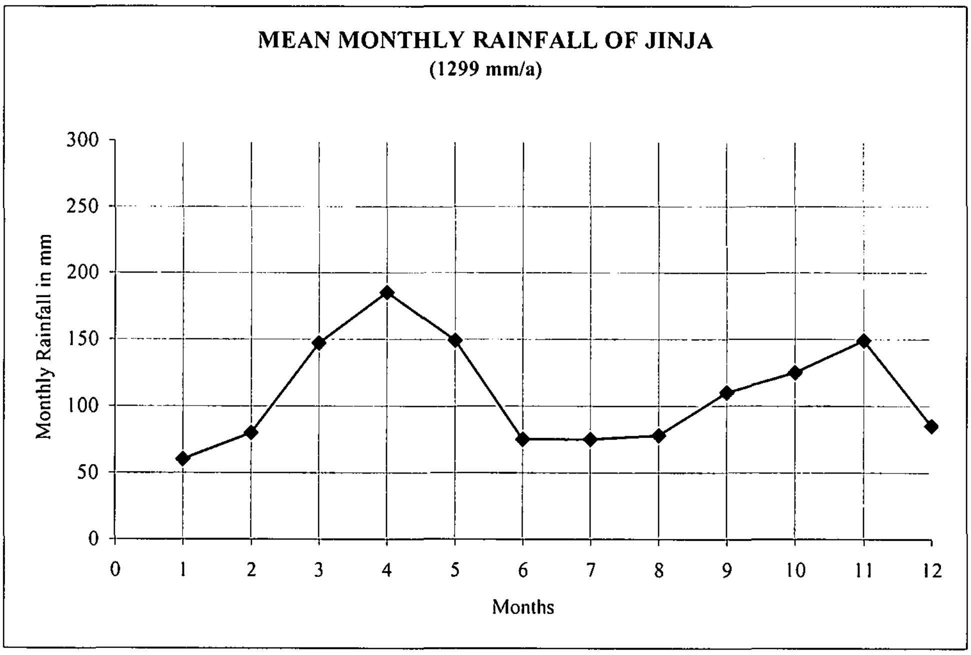


Figure 8 **Graph of the mean monthly rainfall of Jinja.**

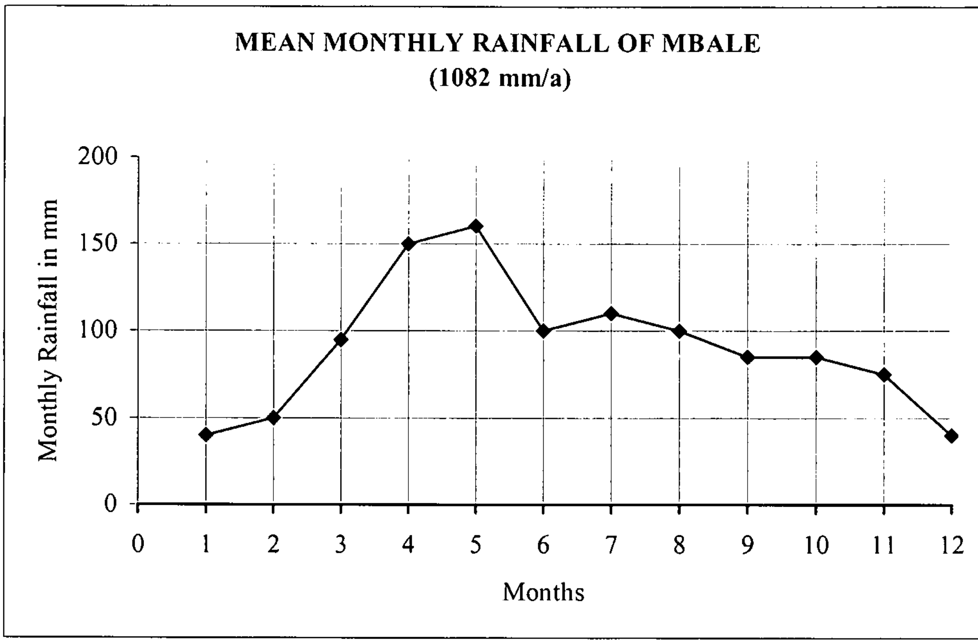


Figure 9. **Graph of the mean monthly rainfall of Mbale.**

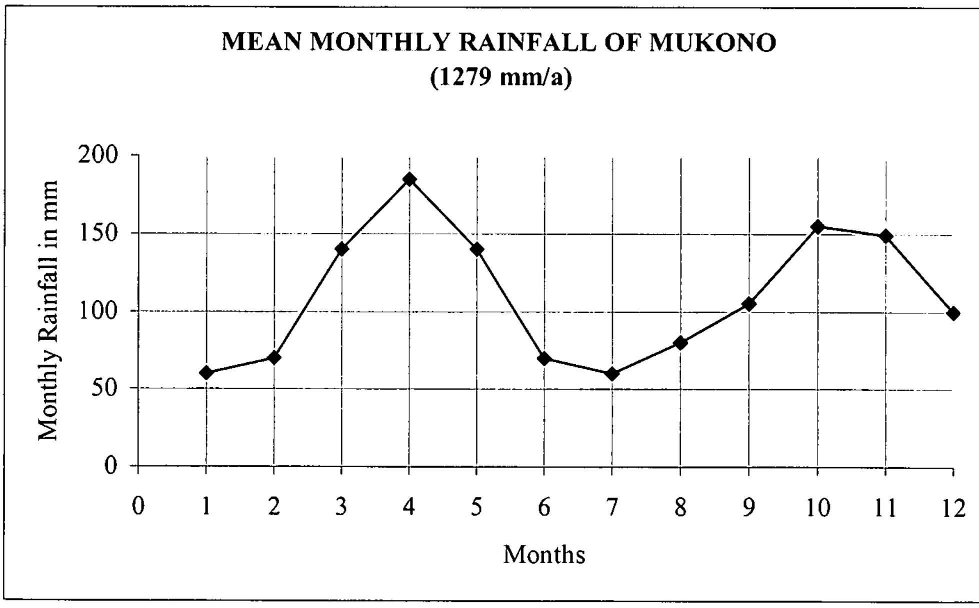


Figure 10. **Graph of the mean monthly rainfall of Mukono.**

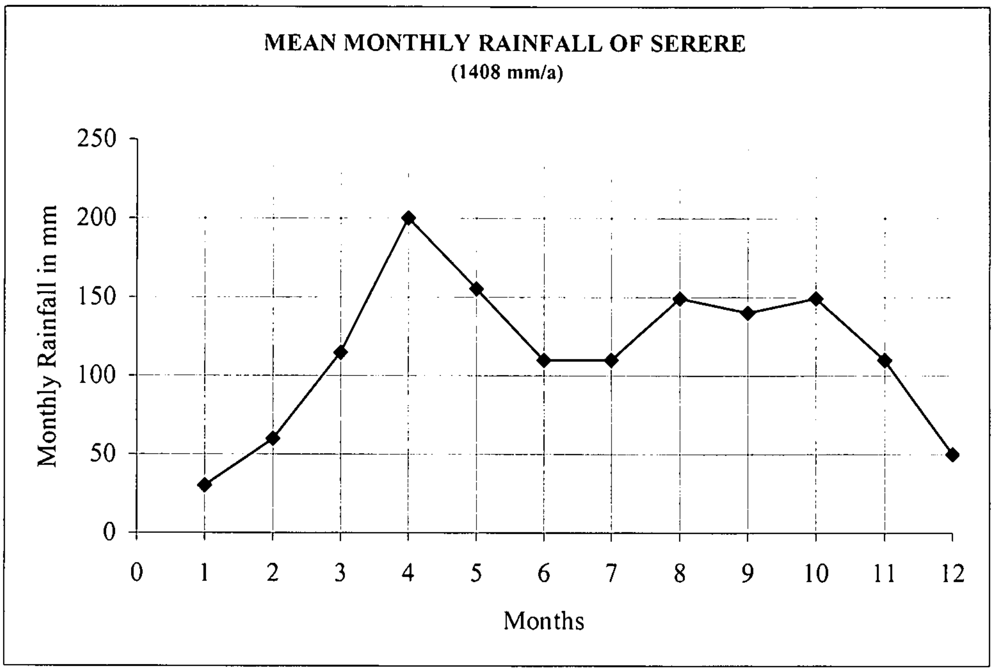


Figure 11. **Graph of the mean monthly rainfall of Serere.**

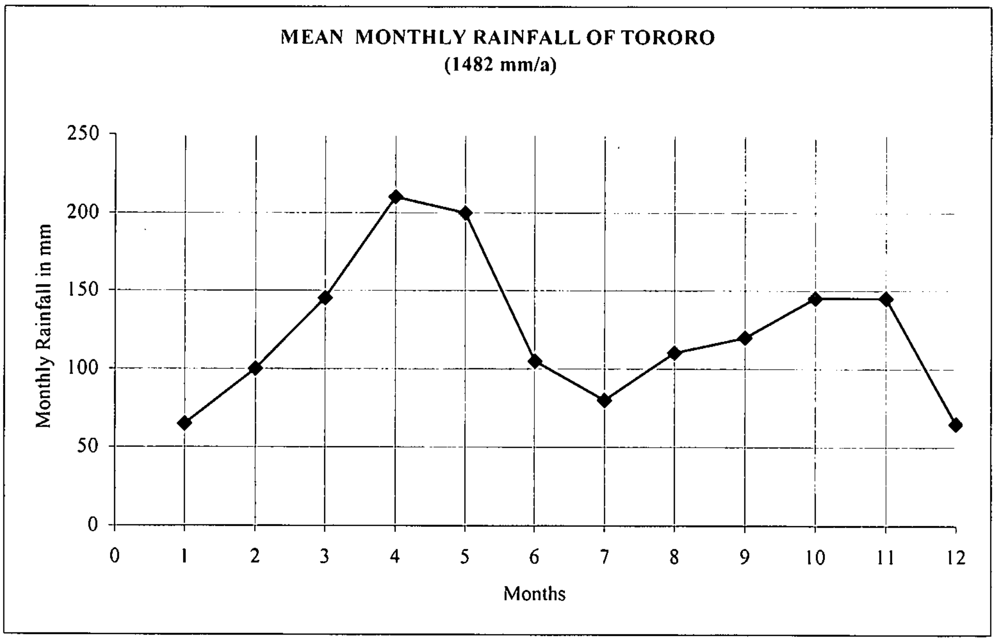


Figure 12. **Graph of the mean monthly rainfall of Tororo.**

The figures from different stations are thus not directly comparable, as they do not represent the same years. The stations used and the annual mean rainfall are shown in the Table 1:

Table 1. Mean annual rainfall for different meteorological stations around the study area (See Figure 13).

Station Name	Station No.	No. of years with complete records	Period	Mean Annual Rainfall (mm)
Bbale Gombolola	8832009	55	1942-96	1,342
Bugiri	8933036	13	1961-79	1,504
Buginyanya	8834059	12	1978-96	1,885
Bugusege	8834026	25	1961-94	1,503
Ivukula	8933014	17	1963-93	1,514
Jinja	8933043	29	1963-98	1,299
Mbale	8834002	28	1960-97	1,082
Mukono	8932030	32	1959-98	1,279
Serere	8833004	22	1963-95	1,408
Tororo	8934019	29	1963-98	1,482

Table 2. Estimated mean annual rainfall of the towns within Pallisa district and around it.

Towns	Mean Annual Rainfall (mm)
Buwenge, Kamuli, Kayunga	1200-1300
Budaka, Busembatia, Busolwe, Kaliro and Pallisa	1300-1400
Budadiri, Lwakhakha.	1400-1800

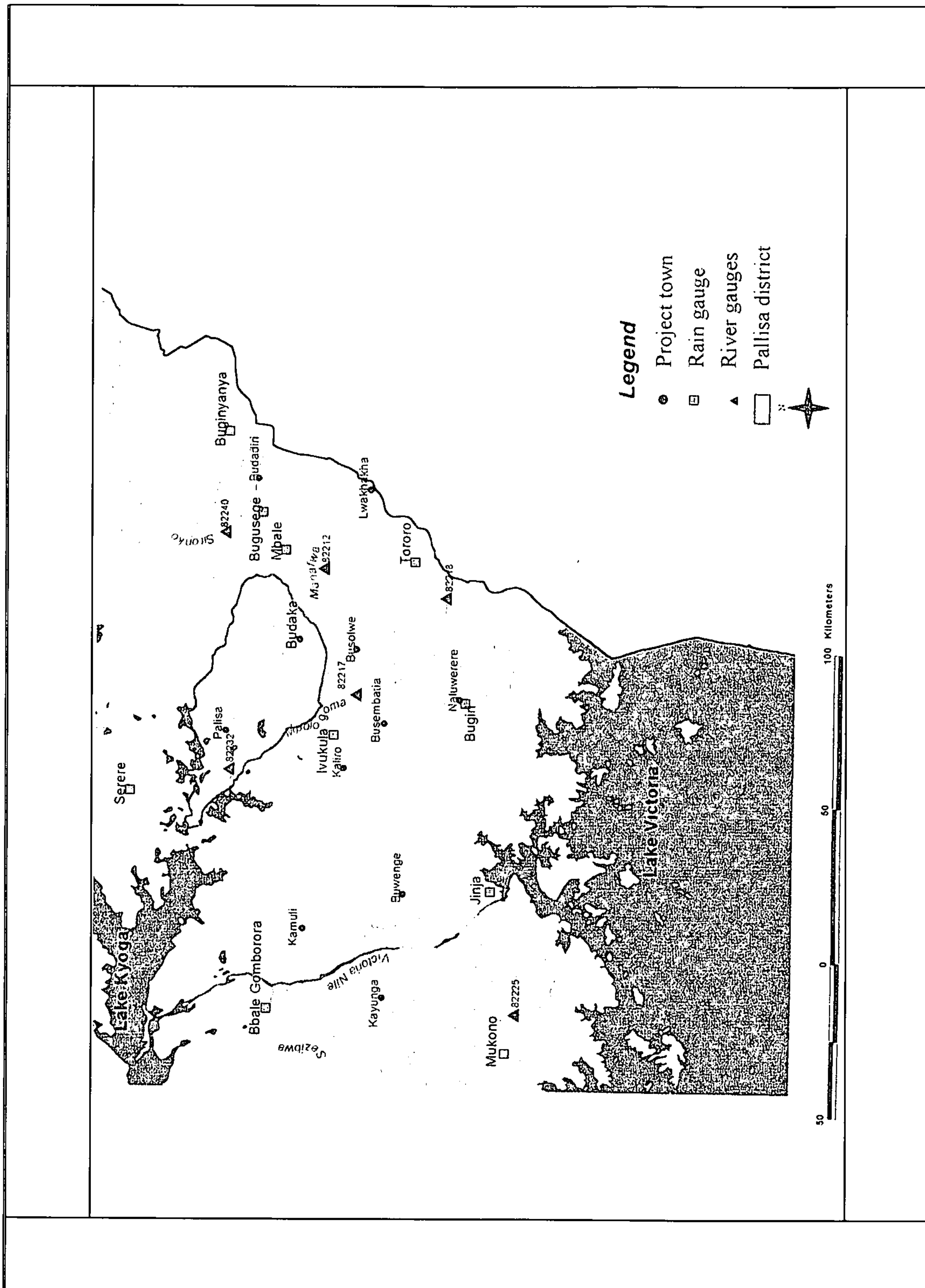


Figure 13. **Location plan of different towns and gauging stations around Pallisa district. Source: GIS, Entebbe.**

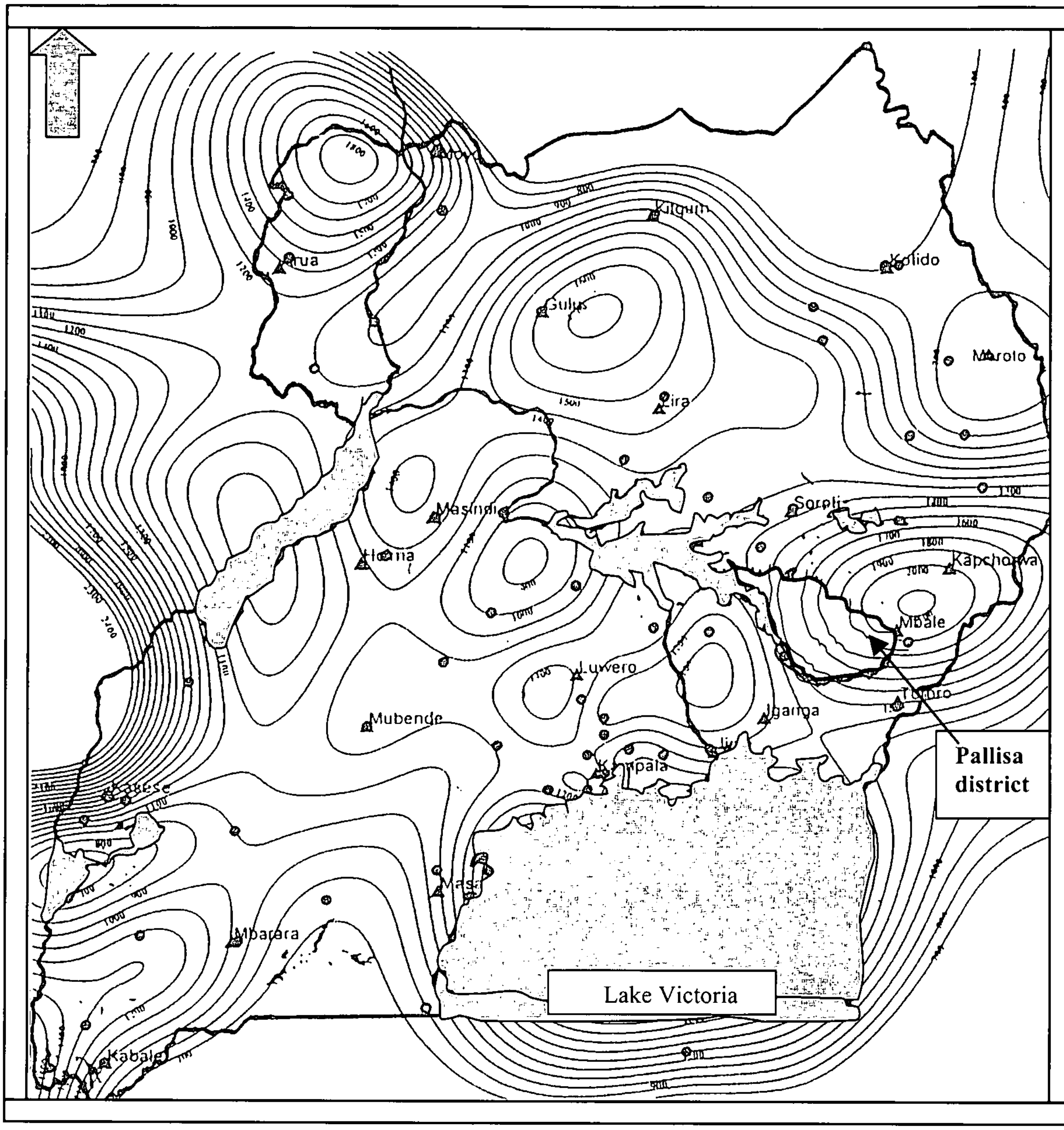


Figure 14. **Isohyets of mean annual rainfall in Uganda for the period 1950–1980. Note Pallisa district. Source: Water resource assessment project, Entebbe. (Scale 1:400 000)**

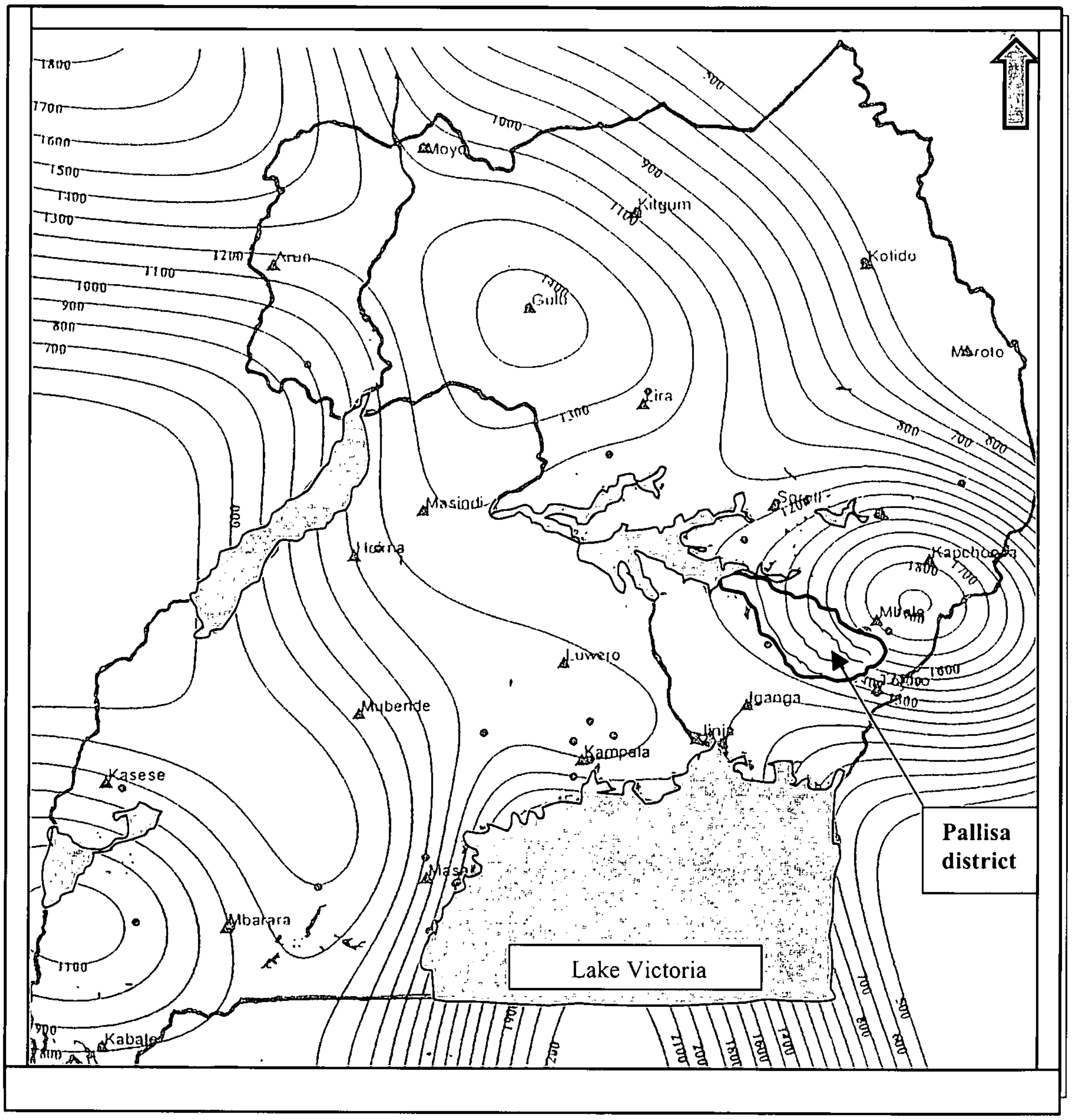


Figure 15. **Isohyets of annual rainfall in Uganda at 20% non-exceedence probability. Note Pallisa district. Source: Water resource assessment project, Entebbe. (Scale 1:400 000)**

Pallisa district has fairly well marked wet and dry seasons, related to the movement of the sun across the equator and influenced by the south-east and north east monsoons. The climate is also affected by the moderating influence of Lake Victoria and Lake Kyoga, the altitude of the country and areas of high relief. The driest months are usually December to January. Particular features of the climate, which are of importance to the occurrence of groundwater and resource potential, include the following climatic zones, Figure 16:

a) Rainfall of about 1030 to 1570 mm/a occurs in a zone of about 50 to 80 km inland of Lake Victoria.

b) The central area of Uganda around Lake Kyoga, with an average rainfall of about 1400 mm/a, a single marked dry season from November to March, surface water is seasonal and groundwater sources are important in the area.

Generally in Pallisa district, the climate is characterised by two rainy seasons: the long rainy season from the end of March to the beginning of June and the short rainy season from October to the end of November (Meteorological depart. Entebbe, Uganda). The mean annual rainfall vary from 1000 mm to 1400 mm. The average temperatures ranges between 20 to 30° C, but continues with minor daily temperature fluctuations.

Recharge occurs mainly from rainfall and concentrated run-off, but infiltration is reduced by the presence of black and sometimes reddish cotton soils. Groundwater occurrence is sometimes localized and irregularly distributed at a greater depth and require detailed site investigation for achieving successful boreholes. Groundwater supplies are more widespread as a result. The area of study experiences a tropical type of climate

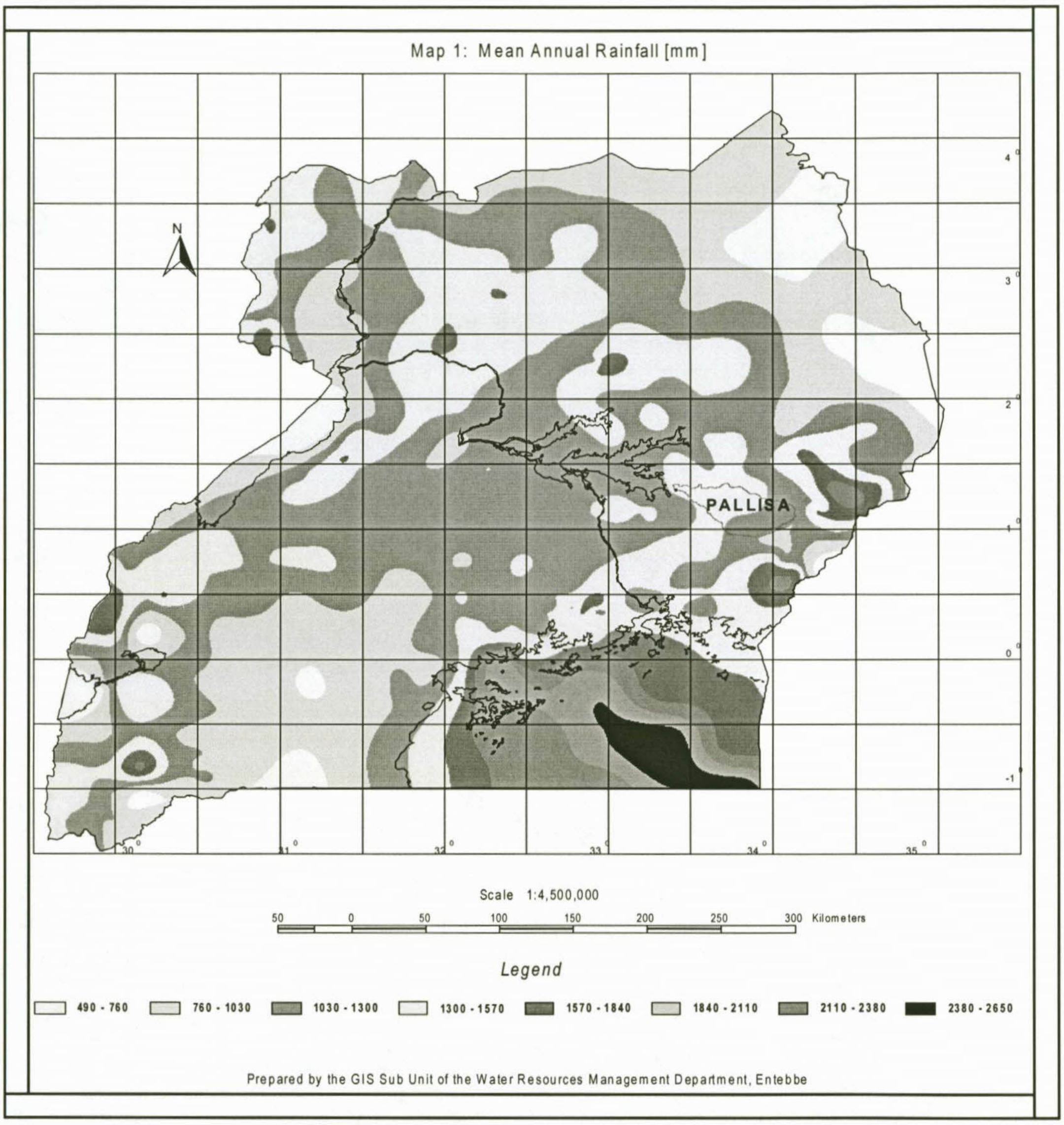


Figure 16. Mean annual rainfall distribution throughout Uganda. Note the position of Pallisa district. Source: GIS, WRM, Entebbe.

2.5 VEGETATION

Grassland savannah occupies extensively most of the eastern districts of the country. Forest savannah occurs in higher rainfall areas bordering Lake Kyoga. Seasonal and permanent swamp vegetation borders the lakes and major rivers and partly in streams.

The form of vegetation tends to develop a short root system and cover almost the whole area, in which case it contributes significantly to the infiltration of water especially in the drier months. However, the savannah forests develop deep root systems, which in turn contribute to evapotranspiration. According to Botha and Muller (1984), evapotranspiration can play a significant role in both replenishing and depleting groundwater reserves and therefore it is necessary to pay more attention for the future development of the aquifer.

2.6 SOILS AND LANDUSE

Red and yellow sandy-to-sandy clay loams, representing various stages of tropical weathering of crystalline rocks, are found in most parts of Uganda. Kaoline minerals form the clay of these soils. Black cotton soils are common in the broad valleys of Eastern Uganda and these usually restrict infiltration. Fine deposits in swamp areas have a similar effect and may have a high level of cation saturation. Locally these can be saline (mineral hydromorphic soils), such are found around Lake Kyoga, which can affect groundwater quality (Figure 17).

The detailed description of geology and geohydrology in the study area, which affect the quality, quantity and flow of groundwater, is in the next Chapter 3 of this write-up.

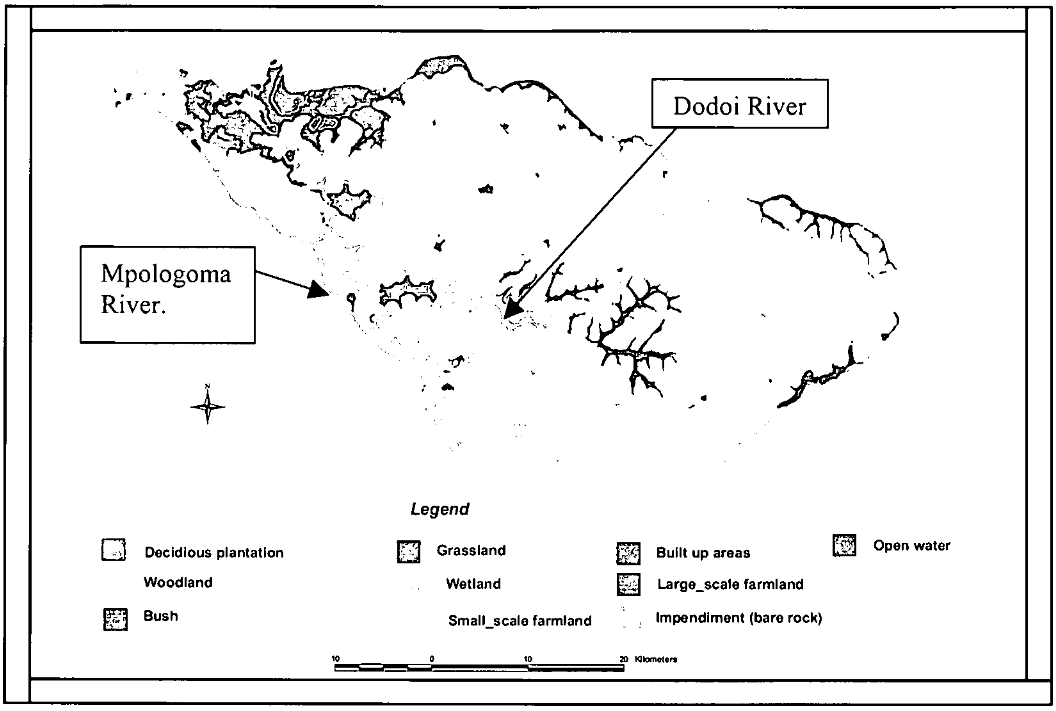


Figure 17. **Land-use map of Pallisa district. Source: GIS, WRM, Entebbe.**

CHAPTER 3

GEOLOGY AND GEOHYDROLOGY

3.1 GEOLOGY

The geology of the study area can be described as undifferentiated gneisses including elements of partly granitised and metamorphosed formations.

The geology of the study area is generalised. It consists of however, a gneissic complex formation. Gneiss and granitic formations of the Pre-Cambrian predominates (Figure 18), which are usually referred to as gneiss complex. The northern part is largely underlain by older, wholly granitised or medium to high-grade metamorphic formations.

The more hilly region of the east is underlain by young cover formations comprising of partly granitised to relatively unmetamorphosed argillites and arenites.

The various formations of the Gneiss Complex show a different response to weathering and fracturing, which have important consequences in terms of groundwater occurrence, flow and quality.

3.1.1. The Sedimentary Deposits

The sedimentary deposits of the Paleozoic to early tertiary are absent except for minor fault-bounded outliers of the ecca shales (Karoo, Mesozoic).

In the mid to late tertiary, up to 3000 m of mainly lacustrine deposits (Elgon beds) accumulated in eastern rift valley. However, thin pleistocene deposits are the most wide spread representatives of the post – Cambrian deposition.

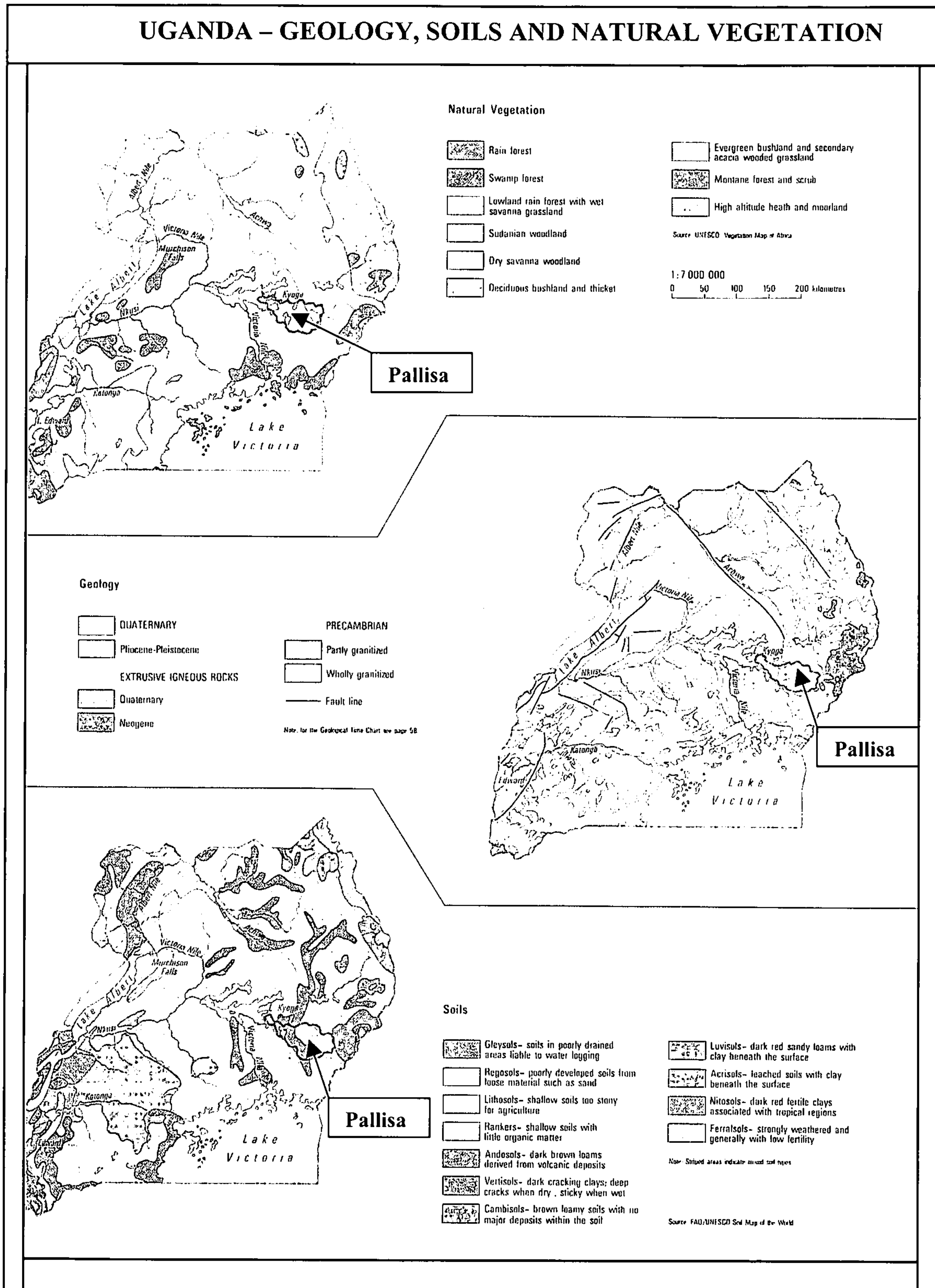


Figure 18. **Geology, soil and natural vegetation of Uganda. Source: National Curriculum Development Centre, Uganda.**

3.1.2. Volcanic Activities

Volcanic activity occurred during the Lower Miocene in eastern Uganda (Elgon, Moroto, Kadam and Napak), which in some areas are underlain by sediments possibly of cretaceous age, and during the late pleistocene over a small area.

3.1.3. Structural Geology

The structural history is complex. Major structural features include the northwest and eastern areas and the step or en-echelon faulting associated with the western and eastern rift valleys.

The rift valleys have been active tectonic areas since the miocene and tectonic movements have largely controlled depositional history of these areas.

3.2 GEOHYDROLOGY

In particular Pallisa district, fractured crystalline basement rocks of Pre-Cambrian age have long been considered the most important source of potable water supply. In much of this study area, groundwater is widely available and generally free from sediment and biological impurities that frequently plague surface waters.

Considering the rural population of Pallisa district, which relies exclusively on groundwater as the only potable water source; as a result, since the 1930s, many thousands of boreholes have been put into production. Until very recently, the preferred method of well construction has been to drill relatively deep wells that fully penetrate the overlying regolith, or "weathered zone" and rely on fractures in the competent underlying rock to provide an adequate well yield.

Throughout Pallisa district, crystalline basement rocks are extensively concealed by the regolith, which is the result of intense chemical weathering. The extent of the chemical weathering, and hence development of the regolith, depends on the nature of the basement rock including its age, structure and lithology, as well as climate and relief (Wright, 1992). According to Key (1992), it is assumed that chemical weathering is enhanced by joints, fractures and coarse grains in the bedrock that expose a greater surface area to groundwater, which is the principal weathering agent

According to Briggs (1989), the high rainfall and temperature of tropical climates serve to increase the rate at which chemical weathering processes occur as a result of hydrolysis, oxidation and dissolution.

The weathering mechanism is also encouraged by the sloping relief, which facilitates the transport of chemical reactants to the bedrock surface and the removal of weathered products. Finally the duration of which weathering has occurred and is reflected by the extent and thickness of detrital product observed in the overburden profile.

According to Taylor (2000) deeply weathered crystalline rock forms important aquifers for public water supply throughout low-latitude regions of Africa, South America, and Asia, but these aquifers have considerable heterogeneity and produce low well yields. Aquifers occur in the bedrock and overlying weathered mantle and are the products of geomorphic activity of meteoric water, principally deep weathering and stripping. The fundamental relationship between the hydrogeology and geomorphology of these terrains has, however, remained unresolved.

This study demonstrates the ability of a recently developed tectono-geomorphic model of landscape evolution in Uganda to explain the hydrogeological characteristics of two basins, as determined using a combination of textural analysis, slug tests, packer tests and pumping tests. The geopetal imprint of long-term deep weathering and erosional unloading is identified in the vertical heterogeneity of the fractured-bedrock and weathered-mantle aquifers; horizontal heterogeneity is lithologically controlled.

The two units form an integrated aquifer system in which the more transmissive (5-20 m^2/d) and porous weathered mantle provides storage to underlying bedrock fractures ($T = 1\ m^2/d$). The thickness and extent of the more productive weathered-mantle aquifer are functions of contemporary geomorphic processes. The utility of the tectono-geomorphic model, applicable to deeply weathered environments, is that it coherently describes the basin-scale hydrogeological characteristics of these complex terrains.

Generally, a lateritic, sub-humus soil horizon rests over a clay unit formed from secondary weathering of basement rock fragments. The water table tends to lie at the base of the clay where fragments of the parent bedrock pre-dominate the bedrock surface.

The weathered profile in the regolith has been shown to be uniform over a wide area Jones (1985). Acworth (1987) has described its evolution as a progressive degradation of the basement complex rock to a lateritic soil cover. This pattern has been observed over crystalline rocks in Nigeria (Omorinbola, 1984) and Malawi (Chilton and Smith-Carington, 1984). A typical cross-section of the regolith and underlying, fractured bedrock is represented in Figure 19.

Interest in the regolith has gained considerable momentum in recent years with the recognition that it may provide a more sustainable and less costly source for rural water supplies than the bedrock fractures, currently being exploited (Chilton and Smith-Carington, 1984; Omorinbola, 1984; Howard, 1989).

Acworth (1987) suggested that the hydrolysis of bedrock fragments by recharge waters, acidified through the absorption of carbon dioxide in the soil humus, is retarded below the water table by an existing calcium-bicarbonate buffer in the regolith groundwater.

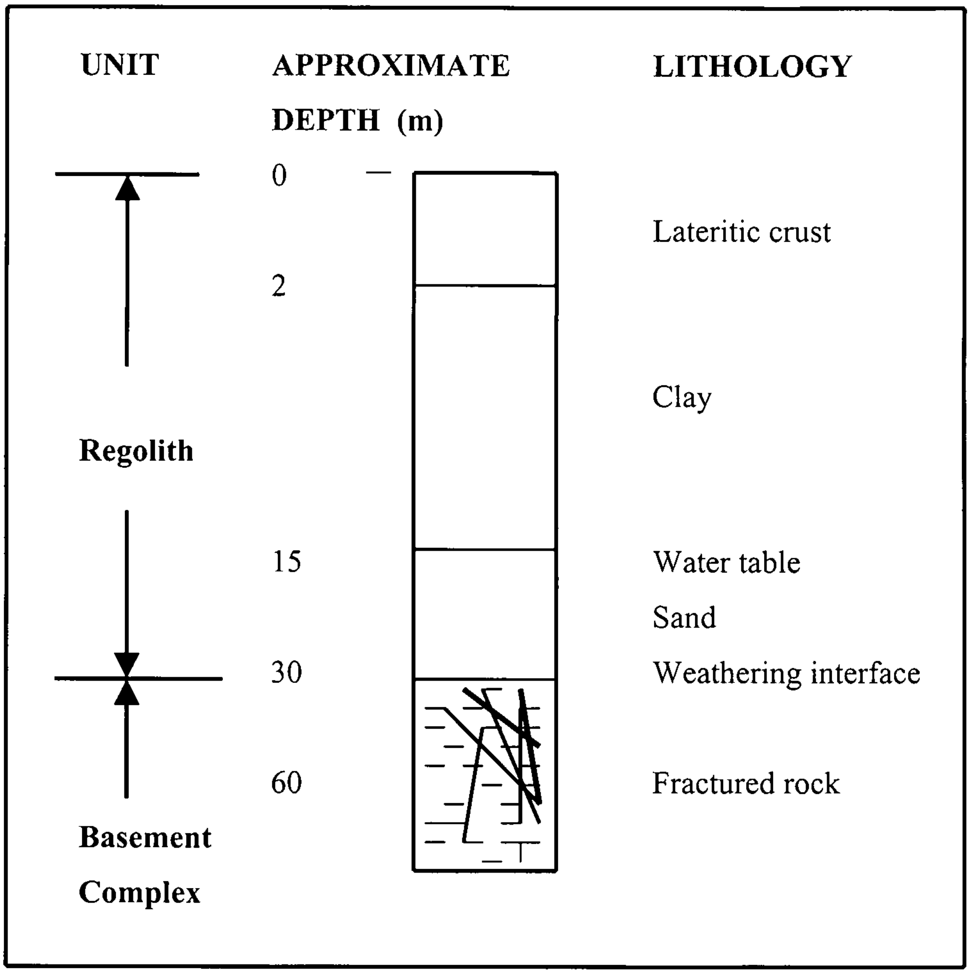


Figure 19. Cross-sectional representation of the regolith and fractured bedrock.

It was further proposed by him that this calcium-bicarbonate system stem from relative susceptibility of calcium bearing minerals such as anorthite to hydrolysis (reaction given below).

$CaAl_2Si_2O_{8\,(s)} + 2CO_{2\,(g)}$	$+\ 3H_2O_{(l)}$	$\geq$	$Ca^{2+}_{(aq)}$	$+\ 2HCO_{3\,(aq)}$
Bedrock fragments (anorthite)	Recharge		Calcium	Bicarbonate

$+\quad Al_2O_3\,(SiO_2)_2(H_2O)_{2\,(s)}.$

Kaolinite

The coincidental appearance of the water table and bedrock fragments (Figure 8) had also led to earlier theories concerning the protective nature of the water table. Further explanation on this matter is as below. According to Jones (1985), Chilton and Smith-Carington (1984); the lowering of the water table through the reduction in groundwater recharge might expose bedrock fragments to hydrolytic weathering and a shrinking in the thickness of the permeable zone of bedrock fragments could result.

Further, it is speculated that this mechanism was responsible for the absence of regolith aquifer in the more arid climate in the study area of eastern Uganda. The presence of ferromagnesian minerals in the bedrock is also believed to be responsible for reducing the permeability and thickness of the section of the bedrock fragments as these minerals tend to be converted easily to secondary, clay particles (Wright, 1992; Hazell, 1988; Acworth, 1987).

According to Norconsult (1979), the Pre-Cambrian rocks are metamorphic and have few or no pores. Groundwater therefore is confined to the weathered zones and/or to rock fractures and fissures.

The permeability of the metamorphic rocks usually decreases rapidly with depth. Such decrease is due to a combined effect of weight of the overlying rock and the tendency of surface disturbances to penetrate only a short distance into the bedrock. Joints, faults and other fractures will tend to close at greater depths because of the weight of the overlying material. Groundwater flow in the unweathered bedrock is entirely due to secondary permeability in the form of fractures.

Despite the uniformity noted in its profile, several studies have found no relationship between the thickness of the regolith and the yield of the wells drawing water from the permeable zone of bedrock fragments (Hazell, 1992; Wright, 1992; Omorinbola, 1984).

The geohydrology of eastern Uganda contains main groundwater units with major formations grouped into the following broad units:

a) Intergranular depositional aquifers: - these include the plateau sediments (Pleistocene to recent) and the eastern rift valley sediments (lower Miocene to recent)

b) The fissured and intergranular weathered aquifers: These include the extrusive volcanic (pleistocene of the east and tertiary also of east Uganda); Intrusive volucanics (cretaceous carbonatites of east Uganda,); gneiss, granulites, granites and partly granitised to relatively unmetamorphosed predominantly arenite formations (Pre-Cambrian gneiss complex) and the argillite formations (Pre-Cambrian gneiss complex).

This sub – division was intended to reflect different requirements in the borehole location, drilling methods and borehole design. The further sub-division of (b) was included to reflect likely differences in the degree of fracturing, subsequent depth of weathering and weathering products.

The weathering products can have similar aquifer properties to the intergranular aquifers of mainly depositional origin. The groundwater units and the hydrological, topographical and physiolographical features and place names for the hydrogeological units are important. Almost all the aquifers in this region were classified as poorly productive intergranular and /or fissured aquifers. The UNESCO international legend for hydrological maps was used for this study.

3.2.1. Fissured and intergranular weathered aquifers

3.2.1.1. Gneiss Complex.

The gneiss complex outcrops over some 75% of the study area and forms the principal source of groundwater supplies. Fresh, metamorphic rock is impermeable and groundwater occurs in weathered zones, joints and fissures as local, discontinuous systems.

Where weathered and fissured, the metamorphic formations characteristically have three water bearing zones:

i) An upper zone of sandy – clay with residual blocks, generally 3 to 7 m thick but usually dry except beneath 'sand rivers" or in local areas where the water table is close to the surface. Unconfined conditions generally occur in this zone. Perched aquifers are also associated with this zone.

ii) A middle zone, (saprolite and saprock), comprising an upper deeply weathered layer and a lower, less weathered but fissured layer. The hydraulic properties of the upper layer are similar to granular aquifers, but advanced alteration produces clay particles, which reduce the hydraulic conductivity.

This layer may be non-water bearing if covered by impermeable material or too steep slopes. The lower layer has fissures widened by weathering, which may be in-filled, and form the major water-bearing unit of the metamorphic rock.

iii) The lower zone of fresh, occasionally fractured rock. The occurrence of fractures is difficult to predict but fracture zones may have higher hydraulic conductivity but low storage coefficients and are generally confined.

The occurrence of groundwater in the main water-bearing horizon (the lower part of the middle zone) is rather variable, but related in a general way to geomorphology. Dry boreholes are more likely on divides, steep slopes and deep eroded pediments.

In the valley areas, recharge is derived from streams and lateral inflow from the valley sides. Higher yields are obtained where this zone occurs in between 30 to 90 m deep.

Prolonged weathering and pen plantation have resulted in extensive weathering of metamorphic formations. This depth of weathering averages 30 to 50 m, but occurs at greater depths in areas of more intensive fracturing and softer formations such as the argillite sequences.

Whilst the depth of weathering was usably shallower in the gneissic, granitic and arenitic formations, coarser weathering products give a higher hydraulic conductivity and storativity and better quality of water.

In areas where weathering has produced a high proportion of clay minerals, particularly in the argillite formations, the hydraulic conductivity is low, but even so can provide a source of water by gravity drainage to sustain borehole tapping the coarser, weathered zone usually found at the base of such sequences. Quartzite bands within the argillite sequences may be more fractured and have a higher hydraulic conductivity than in argillites.

3.3 CONCEPTUAL HYDROGEOLOGY OF PALLISA

In the study area, there are two or more, possibly interconnected aquifer units available for groundwater exploitation (Figure 20):

- The bedrock or basement rock, whose water bearing capacity is due to irregular spaced fractures in the otherwise impermeable rock;

- The overlying laterite and weathered rock often termed as 'the regolith aquifer'. The regolith aquifer is a porous aquifer, whose groundwater is stored and move in the interstices between soil grains.

As mentioned, the two aquifers are most likely interconnected, but the degree of interconnection varies considerably from area to area, and the exploitable groundwater potential largely depends on the interconnection.

While the regolith aquifer can store relatively large quantities of groundwater, it often has limited water-transmitting capability, when seen with motorised borehole. In contrast, a major fracture zone can have a good water transmitting capability, but can only store little water. Clay also can limit the transitivity capability of groundwater. Successful groundwater exploitation therefore requires a good connection between the two-aquifer units.

Notably, it has been estimated in most areas of Uganda, Pallisa district inclusive, that the groundwater recharge does not exceeds 100mm/a however; this quantity cannot be abstracted for practical reasons, and also for other reasons would be unacceptable:

- The groundwater storage in the aquifers is the source of stream flow in the dry season, and a major reduction in dry season stream-flow could have serious consequences for downstream users. If there is no recharge, and taking into consideration the increasing the water demands, abstraction of large quantities of groundwater in dry seasons affect local streams, but this could be undesirable.

- If major pumping from the aquifers is taken up in the area, it can be expected that the neighbouring boreholes, shallow wells and springs will experience a yield reduction; particularly springs might dry up in the dry season. It has also been observed that there is reduction in water levels during the same period due to lack of recharge.

Under conditions without influence of human activity, the groundwater will be recharged by rainfall, and the water will seep towards rivers, swamps and springs, where it is discharged. Towards the end of the dry period, the natural discharge will lower the groundwater table somewhat, and the spring yield will be reduced.

Water abstraction by means of boreholes affects this cycle, as the water pumped up, will reduce the naturally occurring discharge. It is evident that water intakes relying on groundwater in the upper layers of the overburden are more sensitive to an overall reduction of water table. Hence springs are more likely to dry out than even shallow wells.

The drawdown for a given pumping depends on the storage capability or capacity of the overburden. No data are available based on the direct measurements, but experience from other areas indicate it to be around 1-5%

For the regolith aquifer this is fairly correct determination. For the bedrock, where the aquifer consists of irregularly spaced fractures, the fractures might extend over watersheds.

A borehole where the main water bearing zones were to be found in the fractured bedrock, might very well rely on the overburden storage capacity in a neighbouring catchment area, if the fracture extends to this area and having good interconnection to the overburden here.

When evaluating catchment areas for bedrock boreholes it was therefore important to map the lineaments as well as the watersheds (Appendix C).

Therefore precautions were taken to minimise these unwanted side effects of the water abstraction. When siting boreholes, the catchment areas for each borehole were determined; the possible extension of the fractured zones estimated and all other water sources within the catchment areas were located and mapped.

The seasonal drawdown/decrease in yield in those sources caused by the borehole abstraction were determined. In addition, drawdown/recovery analyses were carried out to determine the aquifer characteristics and responses to long-term pumpage.

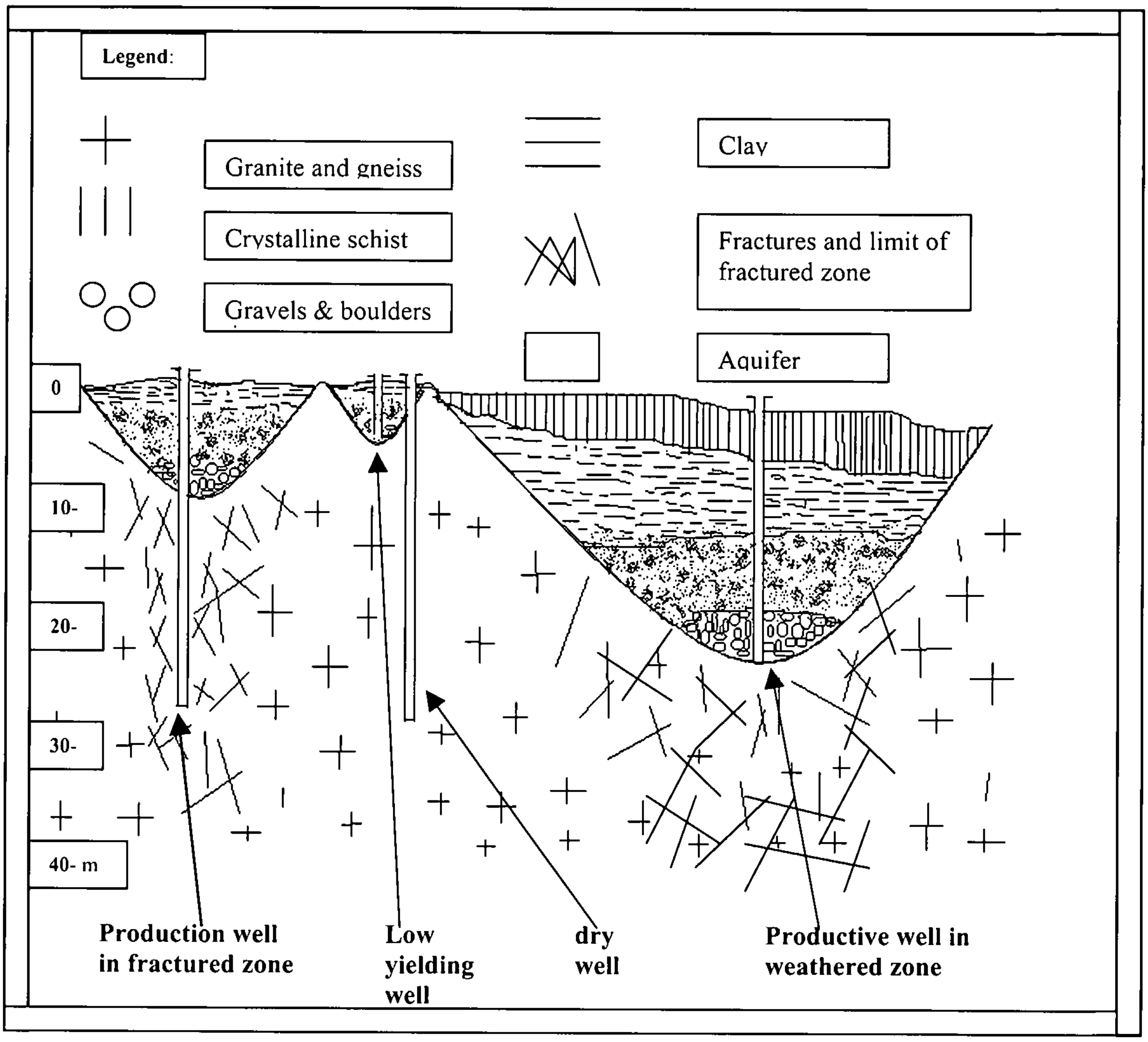


Figure 20. Conceptual lithology of Pallisa district showing positions under which water could be pumped by boreholes.

After a careful description of the geology and geohydrology of the study area, the next Chapter 4 elaborates more on the methodologies used in this research work.

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

In this chapter, various individual aspects are explained in separate sections due to diversity of all the aspects involved in the study. It discusses the study methods, the design and instruments. It also presents the methods, techniques and procedures that were used in order to gather the required data for the study. It lays out the key stages/phases and activities undertaken, besides, the major sources of information and materials used are stated. In this chapter, the layout of this thesis, *"**Evaluation of Groundwater Resource Potential of Pallisa District in Eastern Uganda**"*, and the diagrammatic representation of the methodology are presented.

Methodology being defined as a system of ways of doing or studying something, it is also the philosophy of the research process. According to Nuwagaba (1998), research methodology determines such considerations as whether to set the hypotheses or simply research questions; whether to select a relatively large representative number of elements into a sample to generalize the data; and what kind or level of evidence is necessary to make conclusions about the phenomenon under study.

On the other hand, the theoretic bases of different aspects are presented in their respective sections. The methodology followed in this study therefore, was based on the objectives stated in section 1.2 of this write-up.

4.2 RESEARCH METHODS

It is important to select and use methods that meet the objectives of a particular research. The major objective of this study was to evaluate the groundwater resource potential of Pallisa district by looking at the potential capacity of the wells, getting information about the water quality, know the aquifer extent and flow and understand the recharge potential of the study area. The quantitative and qualitative methods were used.

The research methodologies used in achieving the objectives of this study are generally as follows:

- Geophysical data collection from field and records.
- Borehole data collection or driller's logs.
- Pumping tests and analyses of result.
- Water sampling and Analysis.
- Monitoring of the resource.

The scope of this research study therefore, involved three (3) stages namely:

i) Pre-field work;

ii) Field work and;

iii) Data Processing, analysis and reporting.

The pre-fieldwork involved the identification of the available information prior to fieldwork. Compilation and literature review of previous works in the study area such as geology, structure, geochemistry, geophysics, hydrology was done. Review of geophysical methods and principles used in groundwater studies such as electrical sounding and geoelectric sounding was done and also to have knowledge on what type of anomalies and the variations that occur in these environments. Prepared aerial photographs and interpretations of them were made and acquisition of equipment for fieldwork.

The fieldwork activity involved 1) Data collection of existing geophysical data such as electrical sounding and geoelectrical sounding; 2) Measurement of physical parameters such as PH, Ec and water levels; 3) Water sampling and analyses for chemical constituents (Alkalinity, TDS, chlorides, fluorides etc.); 4) Data collection from pumping test; 5) Collection of driller's logs for recently drilled and previously drilled boreholes and; 6) Groundwater sampling for isotopic analysis.

The data processing, analysis and reporting involved 1) The hydrogeological and hydrological assessment on groundwater suitability; 2) The hydro-chemical assessment of the quality of groundwater; 3) Isotopic analysis and assessment of groundwater recharge; 4) Pumping test analyses; 5) Geophysical investigation data analysis; 6) Interpretation of results and discussion; 7) Conclusions and recommendations if any and; 8) Report writing.

4.2.1 Materials used

The following data was available and used for the research study:

- The geological map of Uganda, 1:1 500 000 by the Geological Survey Entebbe, 1995;
- The Atlas of Uganda, 1:7 000 000 by Henry Lubwama, a reprint, 2000;
- Electrical sounding and geo-electrical data;
- Topographic Maps, 1:400 000 and;
- Various Geological, Hydrological, Geochemical and Geophysical reports.

4.2.2 Survey Method

The aim of a survey was to obtain information that can be analysed and patterns extracted and comparisons made (Bell 1993). The evaluation of the groundwater resource was based on existing data and information collected, test drilling, pumping tests made, geophysical surveys and test pumping. The following methods are given in details below.

4.2.2.1 Geophysical exploration method

General

Geophysical exploration is one of the tools set at the disposal of the geologist. This can be defined as the scientific measurement of the physical properties of the terrestrial crust in order to investigate geological structure, mineral deposits or groundwater.

Geophysical investigation can provide information about the principal feature of the underground structure. This information can be used to limit the number of cores drilling to a minimum, and also to have the depth of the exploration estimated before hand (Dobrin and Savit, 1988). It therefore identifies the potential wells, locations and depths and establishes potential yields. Many geophysical techniques are available for groundwater investigations, all of which have advantages and disadvantages. Of the several geophysical methods, the electrical resistivity method is found to have had the greatest application to groundwater study. It has been used for many years with remarkable success in different regions of the world (Morris, 1964, Breusse, 1963). Recent papers and texts (Flathe, 1970; Dobrin and Savit, 1985) indicate that it is the most commonly used method in groundwater studies. This is mainly because the ability of a rock to conduct an electrical current depends almost entirely on the amount of distribution and salinity of the water in the weathered or fractured zones of the rocks. Not regarding the relatively rare cases of conductive minerals such as graphite most of the common rock forming minerals are effectively insulators.

Generally, the resistivity diminishes when the porosity, the degree of humidity or the salinity of the water a rock contains, increases. Moreover, the resistivity of the same geological horizon varies according to its degree of humidity.

Two resistivity methods were generally employed in the field.

a) Geo-electrical profiling
b) Vertical Electrical Sounding (VES)

Vertical Electrical Sounding (VES), and Geoelectrical (GM) profiling were the methods used for this study.

4.2.2.1.1 Field procedure

Resistivity methods were employed for both lateral and vertical explorations.

i) Lateral exploration (or horizontal profiling): A series of measurements were made with constant electrode spacing, moving the whole of the electrode arrangements consecutively to a number of points. Thus, the lateral variations of resistivities so detained were plotted along the profile. The method of exploration is termed as constant depth traversing.

ii) Vertical exploration (or depth sounding): Is a series of measurements of resistivity were made by increasing the electrode spacing in successive steps about a fixed point. This method of vertical exploration is known as the 'expanding electrode method' or 'depth probing'.

It is also known as Vertical Electrical Sounding (VES). The basis for making an electrical sounding irrespective of the electrode array used is that the further away from the current source the measurement of the potential difference of the electric field is made, the deeper the probing will be. In the electrical sounding with schlumberger arrays the respective electrode spacing as AB/2 increased at successive intervals and the value of appropriate apparent resistivity ρ_a was plotted as a function of the electrode spacing on the logarithmic co-ordinate paper. The curve of υ = f (a) AB/2 is called the electrical sounding curve and are well explained in the next chapter five.

The VES was based on the definition of the apparent resistivity (ρ_a) variation of the layers in relation to depth. To measure the apparent resistivity (ρ_a), at the center of each configuration, the (DC) current (I) was transmitted through the two current electrodes (C_1 and C_2) and the potential V between the two potential electrodes (P1 and P2) was measured.

Five soundings were conducted near existing boreholes in order to calibrate the resistivity value- lithological unit correlation. This geohydrological survey undertaken was to evaluate the groundwater occurrence with a view of possible regional utilisation, analysing and locating groundwater of a suitable quality and quantity for the increasing population in the district i.e. domestic use and agriculture.

The exploration consisted of the collection of geophysical data, analysed and the interpretation of enlarged aerial photographs and existing geological maps, geological field mappings around interpreted and identified structures, geophysical magnetic profiles across the lineaments and measuring the electrical conductivities and water levels of all encountered boreholes were also done. The results of the investigations are clearly shown on the profiles in Chapter 5.

4.2.2.2 Pumping test method

Pumping tests were conducted on all potential production boreholes within Pallisa district as identified by the exploration programme. Two techniques were used namely, the step drawdown and the constant rate test.

The purposes of conducting these tests are as follows:

a) Step drawdown test to determine:
   - i) The effectiveness of the borehole at different pumping rates;
   - ii) The maximum yield of the borehole and;
   - iii) The estimate of the pumping rate for the constant rate test.

During these tests, the borehole was pumped at increasing pumping rates in three to four steps, each one hour long, with the pumping rate kept constant at each step. The water level in each borehole was measured at the predetermined or predefined time intervals. The pumping rate for the lat step was chosen so that the maximum drawdown is achieved.

b) Constant rate tests were done to determine:
   - i) The geohydrological characteristics, namely the transmissivity (T) and storativity (S), of the aquifer;
   - ii) The possible (first estimate) long-term safe yield for each of the respective boreholes penetrating the aquifer.

During this test a twenty-litre jerry can was used with the corresponding time to fill it and the boreholes were pumped at a constant rate over a period of 24 hours. The water levels within the boreholes as well as any surrounding monitor boreholes were measured at the predetermined time intervals. It was very essential that the pumping rate was kept constant, as variations would result in incorrect values of the geohydrological characteristics.

Some of the definitions of the said characteristics are as follows:

Transmissivity (T) – Is the rate at which water flows through a vertical strip of the aquifer one meter wide and extending through the full thickness under a hydraulic head of one atmosphere.

$$T = \frac{CQ}{\Delta s}$$

Where; C = Constant, which is $\frac{2.30}{4\pi}$;

Q = Discharge rate (m^3/hr);

Δs = Drawdown (m).

Storativity (S) – Is the volume of water that the aquifer releases from storage per unit surface area of the aquifer per unit decline in hydraulic head perpendicular to the surface. This information together with the recovery rate of the water level within the borehole provided a reasonable preliminary indication of a long-term yield of the aquifer.

Safe yield – Is the amount of water that can be safely be pumped from an aquifer without dewatering the aquifer. Withdrawal in excess of safe yield is known as an overdraft.

The results of the pump test data collected from RUWASA project, were analysed and evaluated by both the WISH and the AQUITEST programmes using the Time-drawdown-method after Cooper-Jacob of confined aquifers. The results were used to get the possible boreholes for production.

All the boreholes surrounding were monitored during the test periods. This was done in order to evaluate boundary conditions as well as the extent of the cone of depression, and interference between prospective production boreholes along the same aquifer. The plots indicate the results obtained.

4.2.2.3 Historical Method

The desktop study with a view of getting the historical background of geological and hydrological information of the study area was done. And by utilizing this historical data, a good consistency is obtained, the likelihood is high that the reconstructed data series for even periods of missing data are reliable, if not corrections have to be introduced.

4.2.2.4 Purposeful Sampling

Enon (1998:14) describes this type of sampling as in which the researcher selects samples based on a certain purpose. The method mainly focuses on in-depth, relatively small samples selected purposively. According to Patton (1990), the logic and power of purposive sampling lie in selecting information-rich cases for in-depth study. This sampling technique helps to increase utility of findings. This study employed this method for determining the quality of water samples collected from existing and drilled boreholes, dug up wells, streams and rivers within Pallisa district as a whole.

4.3 RESEARCH INSTRUMENTS

4.3.1 Introduction

According to Marshall and Rossman (1995) the principles for data collection strategies are that the methods planned for data collection should be related to the type of information sought. They should be efficient, practical, feasible and ethical. This study relied on the qualitative and quantitative techniques but with some dimension of qualitative techniques. The instruments that were used included review of literature, interview schedule and observation.

4.3.2 Observation

According to Marshall and Rossman (1995) observation entails the systematic noting and recording of events, behaviours and facts in the social setting chosen for the study. However, Chaplain and Mbaaga (1990) define observation as a purposive or intentional examination of something, particularly for purposes of gathering data. Under this method, the information is sought by way of a researcher's own direct observations. Observing events in a natural setting is a way to establish what events, or work situations are relevant to the objectives of the study. This method has continued to characterise all researches whether historical, descriptive etc. despite the fact that it is the classic method used in experimental research.

According to Enon (1998) there are 3 ways in which observation can be used in research.

a. Naturalistic observation in which the subjects are not aware that they are being observed.
b. Participant observation in which the researcher participates together with the subjects.
c. Non-Participant observation in which the researcher is passive and merely takes note of what is being observed.

In this study, the researcher employed the participant observation method. This technique was used to observe what was going on, what existed, and how the community was behaving in Pallisa district towards groundwater resource.

4.3.3 Reliability and Validity

According to Bell (1993) validity is a complex concept which tells us whether an item measures or describes what it is supposed to measure or describe. According to Busha (1980) reliability is used to characterise stable, constant, and dependable research methods, instruments, data, or results. Reliability and validity are central issues in all scientific measurement (Neuman 1997). The two are concerned with how concrete measures are developed for a construct. Reliability is about achieving dependability and consistency of research instruments. Validity refers to the quality that an instrument used in research is accurate, correct, true and right.

Triangulation method was adopted. This is a process of viewing something from different angles. According to Neuman (1997) triangulation, in social research, means using different types of measures, or data collection techniques to examine the same variable. The measures chosen for this study, were fully supported and recommended by the supervisor, and included: observation and document review.

4.4 RESEARCH PROCEDURE

4.4.1 Introduction

The researcher carried out this study systematically to cover activities such as preliminary reading or desk study and discussion of possible topics with colleagues, selection of topic, development and implementation of the research plan and time-table, the actual data collection, analysed data and interpreted it.

4.4.2 Preliminary Reading

This was done to review secondary data about evaluations in general and in particular the evaluation of groundwater availability in Pallisa district. An examination of what is available was done and only what was relevant for the study was retrieved to supplement the explorations, drilling, and pumping and observation methods.

4.4.3 Selection of Topic

The researcher had in mind a case study which was unfolding over some time. The problem was to know whether there was enough groundwater in Pallisa that could cater for the increasing population since most people in Pallisa depend on groundwater as their sole supply of potable water. With clear and reasonable guidance of my supervisor, a reasonable topic was arrived at.

4.4.4 Research Plan and Timetable

The research plan to guide the study was compiled in form of a Research Proposal, which was presented and approved. A detailed timetable covering the period of over one year was drawn to guide the researcher. However, due to some unavoidable circumstances, this timetable was not followed.

4.4.5 Ethical Considerations

Bearing in mind what respondents perceive of giving information to researchers, this researcher had to ensure confidentiality by assuring them that the information given is for academic purposes only.

4.4.6 Desktop Study

A desktop study was made to test the usefulness and effectiveness of the research instruments in generating the required information. It involved the development of a conceptual model, which formed the basis of subsequent stages e.g. groundwater explorations, aerial photograph interpretations etc. it was also to collate the available information and assess the likely constraints and risks involved. Fieldwork was practically done by the researcher in order to get the reliable information. But according to Yates (1981) there are many points on which decisions can be properly reached after preliminary investigations in form of a pilot survey. The aim of the pilot study is to improve the reliability and validity of the research.

4.5 DATA COLLECTION, ANALYSIS AND INTERPRETATION

4.5.1 Introduction

The extent of one's data-collection will be influenced by the amount of time he has (Bell 1993). Besides, there are other constraints. For example, if one wishes to observe meetings, he will be limited by the number and timing of meetings that are scheduled to take place during the study period.

4.5.2 Data Collection Procedures

Data was collected using document review, discussions and observation. Document review was done to acquire secondary data about the topic before field survey. Bell (1993) quotes Travers definition, which refers to a document as a general term for an impression left by a human being on a physical object. This impression thus may be on paper or set of paper, or it may be in electronic format such as films, video/audio cassettes, and etc. The researcher reviewed the contents of books, journals, Internet and Website information, and where it was possible, some documents and reports of the top administrators and managers of DWD, access to RUWASA databases in Mbale and other geohydrological publications. The objective of reviewing these documents was to get materials that contained information about the phenomena being studied. A number of government libraries

– Universities, Directorate of Water Development (DWD) - Luzira, Water Resources Management Department – Entebbe, information centres and Internet cafés were visited to access the documents containing the relevant information.

4.5.3 Data Analysis and Presentation

According to Peacock (1990), the essence of data analysis is the development of an understanding of the information it contains. Data analysis will be done to bring order, structure and meaning to data. Two types of data were generated in this study, that is, qualitative and quantitative data. Marshall and Rossman (1995) contend that qualitative data analysis is a search for general statements about the relationships among categories of data and hence it builds grounded theory. In analysing qualitative data emphasis was placed on organisation, interpretation and description. Organisation involved editing, coding and tabulation of data.

According to Nuwagaba (1998), data analysis and presentation constitute the most critical and final task in the research process. The process of analysis and presentation is premised on a number of assumptions that:

i. The sampling was adequate;
ii. The questionnaire was properly constructed;
iii. The data were properly collected and done;
iv. The data collected was correctly analysed.

Editing was done to ensure accuracy, completeness and uniformity of the data while coding was being done to determine categories under which data fell. By assigning numerical values to various categories, presentation and processing of data was made possible.

Results of the findings, discussion and interpretation are presented in detailed explanation according to themes. To ensure validity, description was done on the basis of tabulation and percentages where necessary in the next Chapter 5.

4.6 OUTLINE OF THE THESIS

The full structure of this thesis is presented as follows:

Chapter 1: It is an introduction to the research problem, provides the objectives, significance of the research study and the previous works, which are adequately elaborated.

Chapter 2: This chapter generally focuses on the description of the study area in terms of basic information such as Location, Topography, Drainage, Climate, Vegetation, Soils and Landuse.

Chapter 3: It describes in details the geology and geohydrology of the study area and the emphasis is laid on the fissured and intergranular weathered aquifer as a source of groundwater and also provides a conceptual hydrology (Model) of Pallisa district.

Chapter 4: Methodology is presented in this chapter. The materials used and briefly describes on the key sources of information and procedures followed.

Chapter 5: This chapter focuses on the results and discusses the findings of the research study from the geophysical investigation into the extent of the underlying aquifer, hydrogeological aspect based on pumping test evaluation, hydro geochemistry that emphasises on the suitability of groundwater as well as recharge estimation of groundwater using the isotope and soil moisture balance. It also discusses the management strategy of groundwater resource in the study area.

Chapter 6: This chapter incorporates the conclusions and recommendations based on the outcomes of all the findings envisaged in all the analysis that were undertaken.

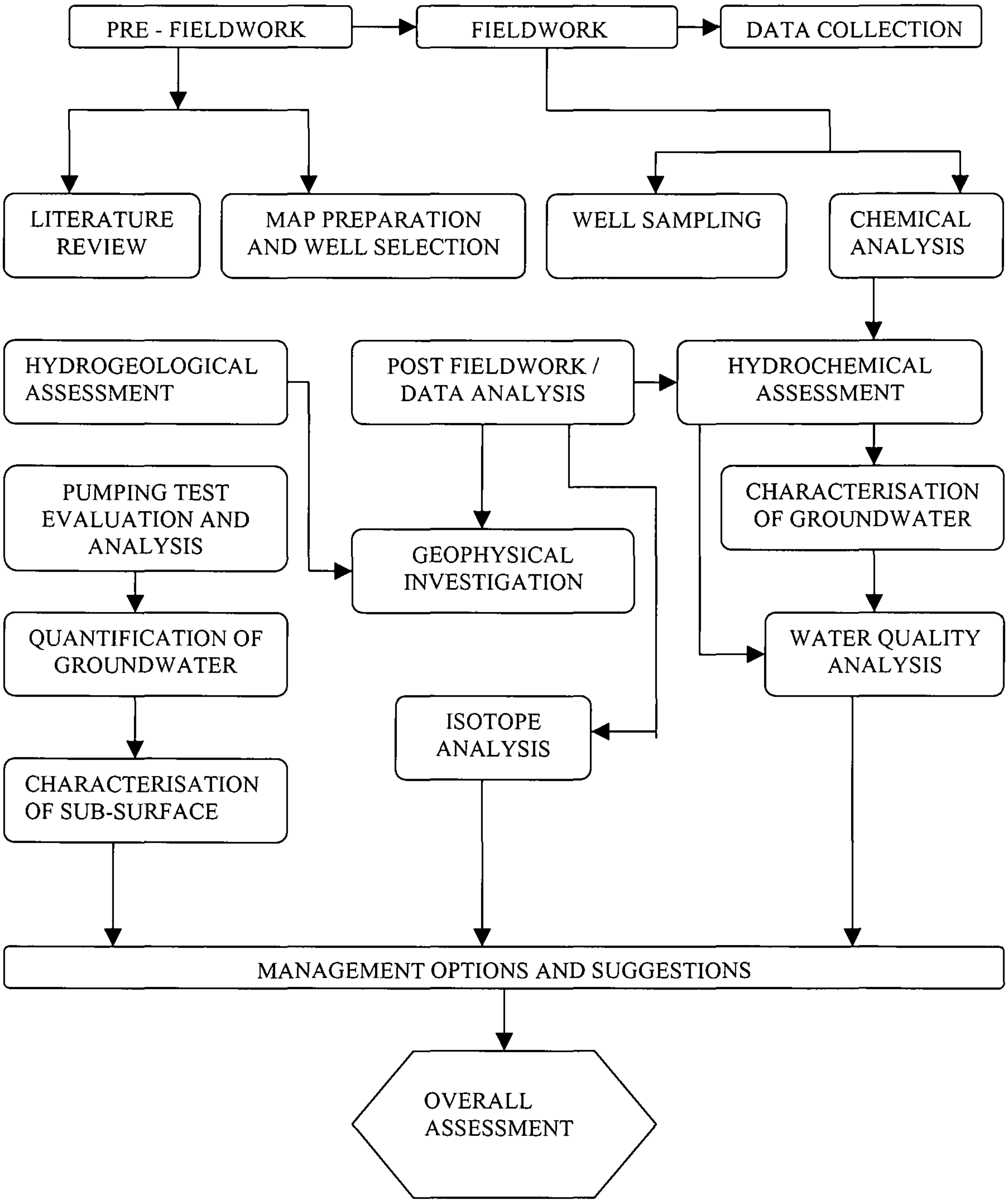


Figure 21. Flowchart of the Methodology/Procedures adopted.

CHAPTER 5

RESULTS AND DISCUSSION OF THE FINDINGS

5.1 INTRODUCTION

This chapter presents results and discusses research findings from the Geophysical survey data collected, pumping tests done, water quality analysis and observation made and it also provides suggestions to improve management of groundwater resources under the contents of this write-up. In order to maintain consistency, the results of the research findings are presented in line with the objectives set in Chapter 1, Section 1.2 and the detailed methodologies mentioned in Chapter 4.

5.2 DATA ANALYSIS, INTERPRETATION AND EVALUATION

5.2.1 GEOPHYSICAL TECHNIQUES AND DATA INTERPRETATION

5.2.1.1 INTRODUCTION

Normally, parameters determined are not necessarily unique. One problem inherent in the geophysical studies is the ambiguity of any particular geological model to a set field data. The source of the problem is that geophysical techniques measure physical property of the earth from the surface to obtain sub surface information.

The technique was adopted to determine the depth to bedrock of underlying aquifer using VES resistivity profiles. This could help to evaluate how sustainable it could be with the rapid increase in groundwater usage in Pallisa district.

VES measurements were used to assess the depth to the bedrock aquifer. The geophysical data collected in the field are shown in Appendix B. The resistivity profiles at the five locations near and around Pallisa town are depicted in Figure 22 on the next page.

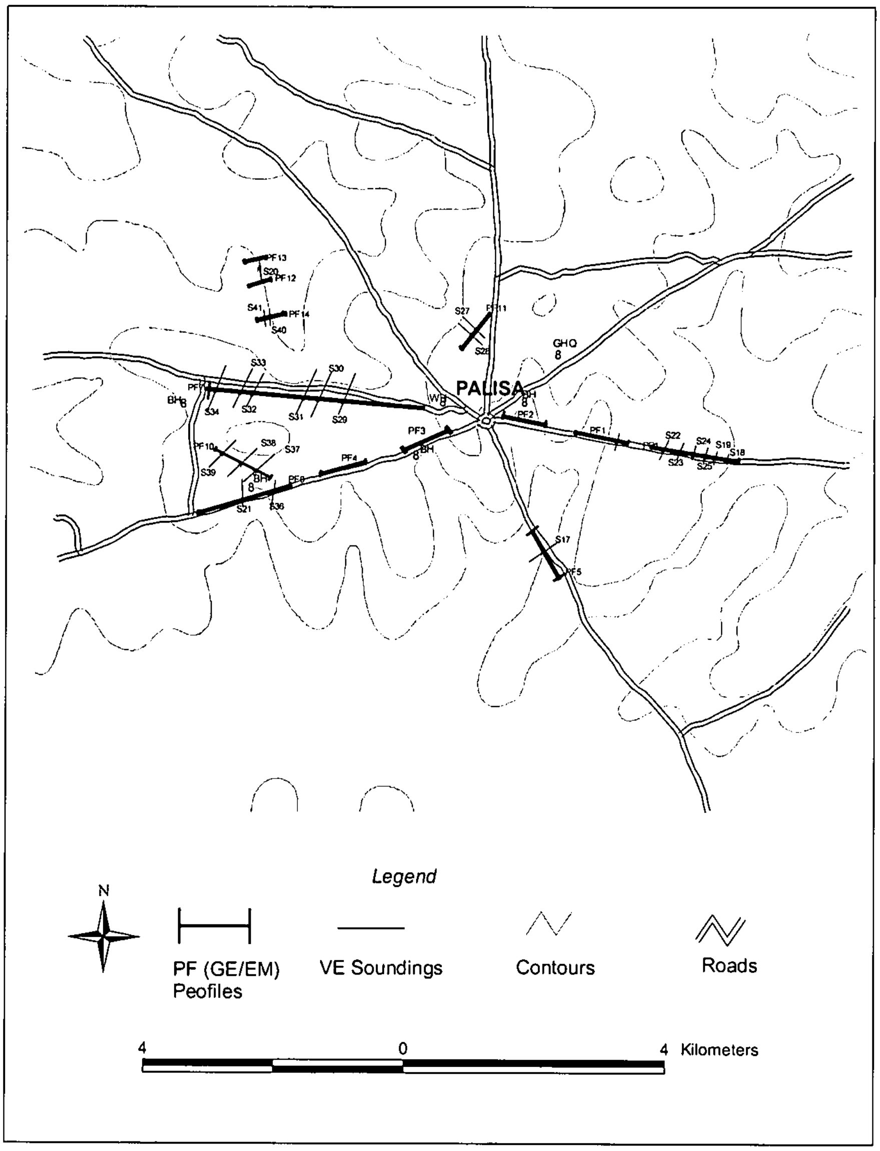


Figure 22. Positions of profiles using both the vertical (VES) and geoelectrical sounding methods.

5.2.2 AERIAL PHOTO INTERPRETATION

Stereo interpretations of aerial photographs were carried out for the purposes of identifying objects and geological fractures and judging their significance. Pallisa has poor exposures of geological expression of rock types and structure. As a result other indicators such as drainage and vegetation changes were used to recognize lineament patterns. In addition, the granitic rock types, fracturing is often reflected in the main drainage lines. Depressions formed by weathering and fractures are potential sources of groundwater in granitic and gneissic rocks.

5.2.3 FIELDWORK

The approach of this fieldwork began the investigations with the EM profiling, since it was a faster method. If the profile indicated any possibility of fractures, verification by use of geological profile became necessary. A parallel profiling laid out the same distance was used to verify the orientation of the fracture zone.

In most cases, the work was carried out adjacent to the existing wells where the regolith thickness and lithology was well known.

With an estimated thickness of the overburden at 20 - 30 m, and therefore a 40 m cable spacing was considered appropriate. This meant that information for the depth between 30 - 50 m would be obtained. And this applied to both the electrical magnetic (EM) profiling and Geo-electrical profiling. Both methods were dependent on the electrical properties of the rocks.

As a general rule, the ability of the rock to conduct an electrical current is determined by the amount of saturated pore spaces and the electrical conductivity of the pore fluid. Thus dry or low porosity rocks tend to be resistive, whilst saturated porous rocks tend to be conductive. The electrical conductivity of the rocks is especially enhanced when the pore fluid is saline, either naturally or as a result of groundwater contamination.

5.2.4 EM PROFILING

5.2.4.1 Brief overview

Traverses were conducted at different located sites. A 10-meter coil spacing and 40 meter separation, using a vertical dipole and horizontal loop to measure the apparent conductivity in mS/m was done.

5.2.4.2 Interpretation of EM profiles

The geoelectric structures beneath the study area have been interpreted.

The ability of the rock to conduct an electric current depends primarily on three factors:

i) The amount of open space between particles (porosity);

ii) The degree of interconnection between those open spaces;

iii) The volume and conductivity of water in the pores.

The presence of water and its chemical characteristics are the principal controls on the flow of electric current, because most rock particles offer high resistance to electric flow. Thus, resistivity decreases as porosity, hydraulic conductivity, water content and water salinity increase.

Several different combinations of earth material can give the same signal at the surface. The two approaches used in interpreting the resistivity data were qualitative - the interpretation of potential zones was found out by studying the nature of the field curves and quantitatively – by curve matching. By adopting these processes these profiles were constructed as seen in Figure 23.

Investigations using a 10 m coil separation showed very deep enough survey that it did not render difficulties in investigating the sub surface, an area of interest in detail. Thus, it was easy to spot out the anomaly on the curve. In terms of borehole siting, extensively weathered materials themselves were often considered as targets in their own right. Where there was a possibility of a fracture zone indicated on the profile, a geo-electrical sounding would be carried out.

Figures 23, 24, 25, 26 and 27 show the conductivity values against the station numbers at an interval of 10 m. The traverse of 10 m coil separation, both VL40 and HL40 indicated the existence magnetic data curves.

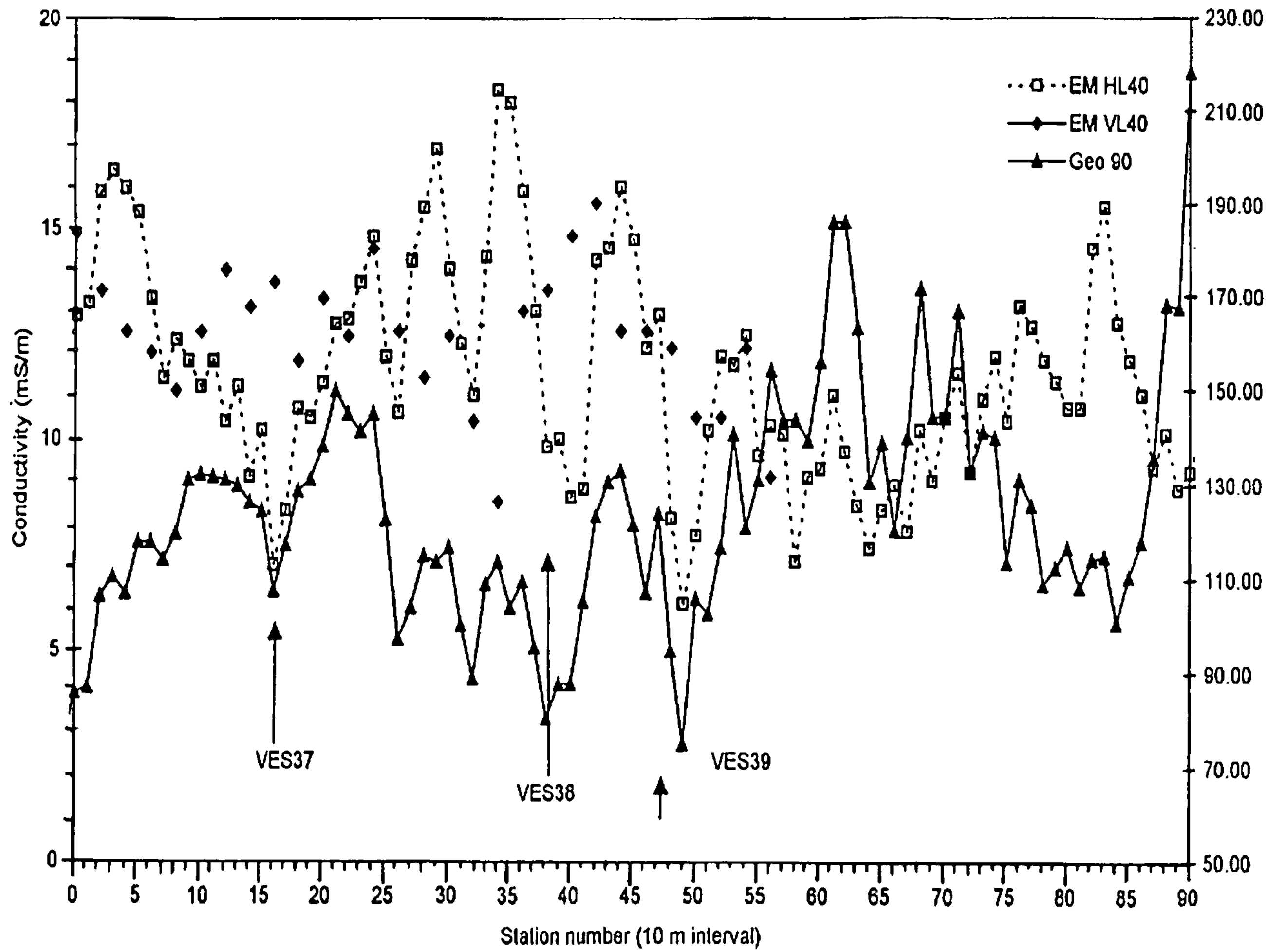


Figure 23. Graph of both Electrical Conductivity and apparent resistivity against station intervals. Note the positions of VES 37, VES 38 and VES39. Source: WRMD, Entebbe.

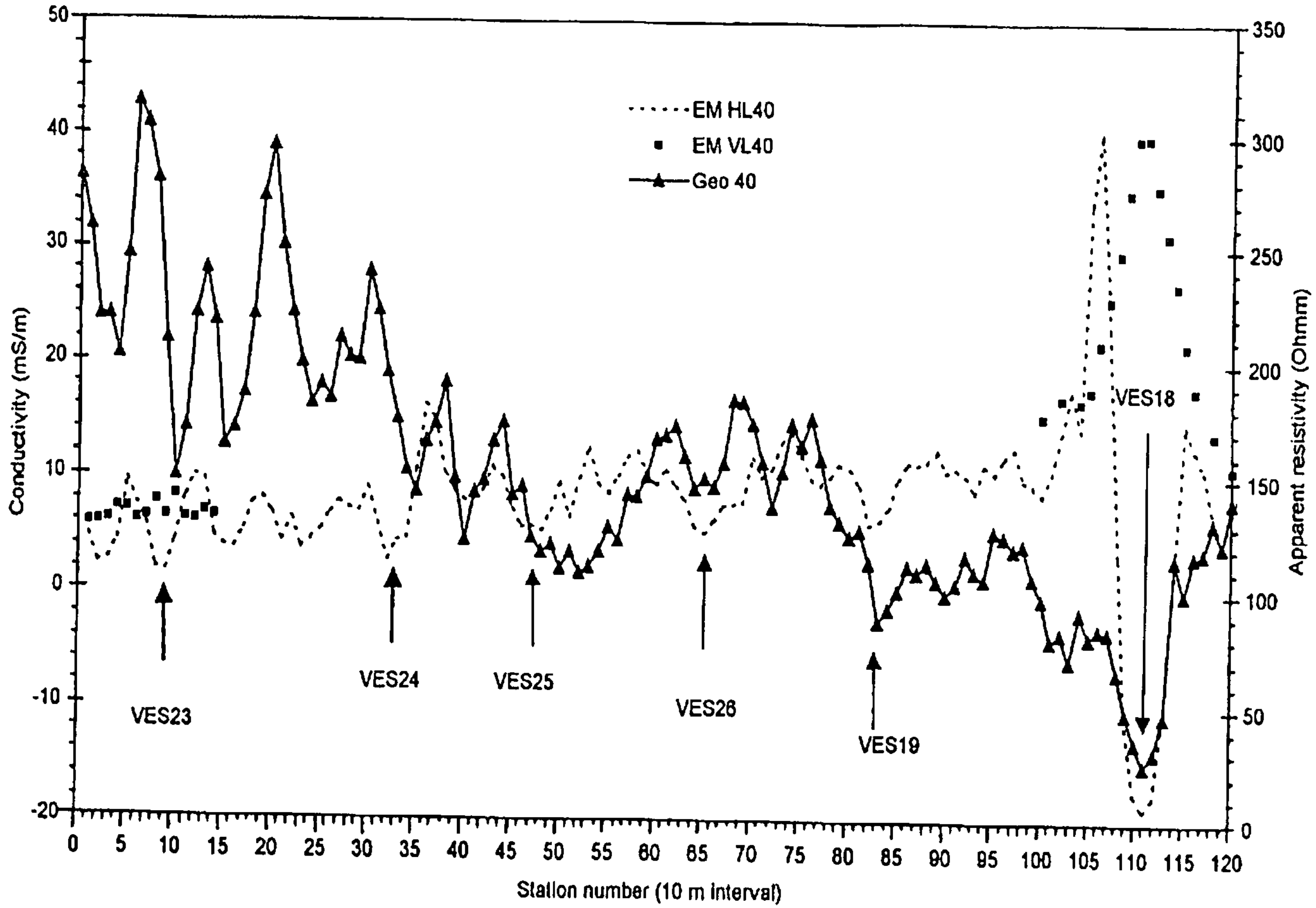


Figure 24. Graph of both Electrical Conductivity and apparent resistivity against station intervals. Note the positions of VES 18 and VES 19. Source: WRMD, Entebbe.

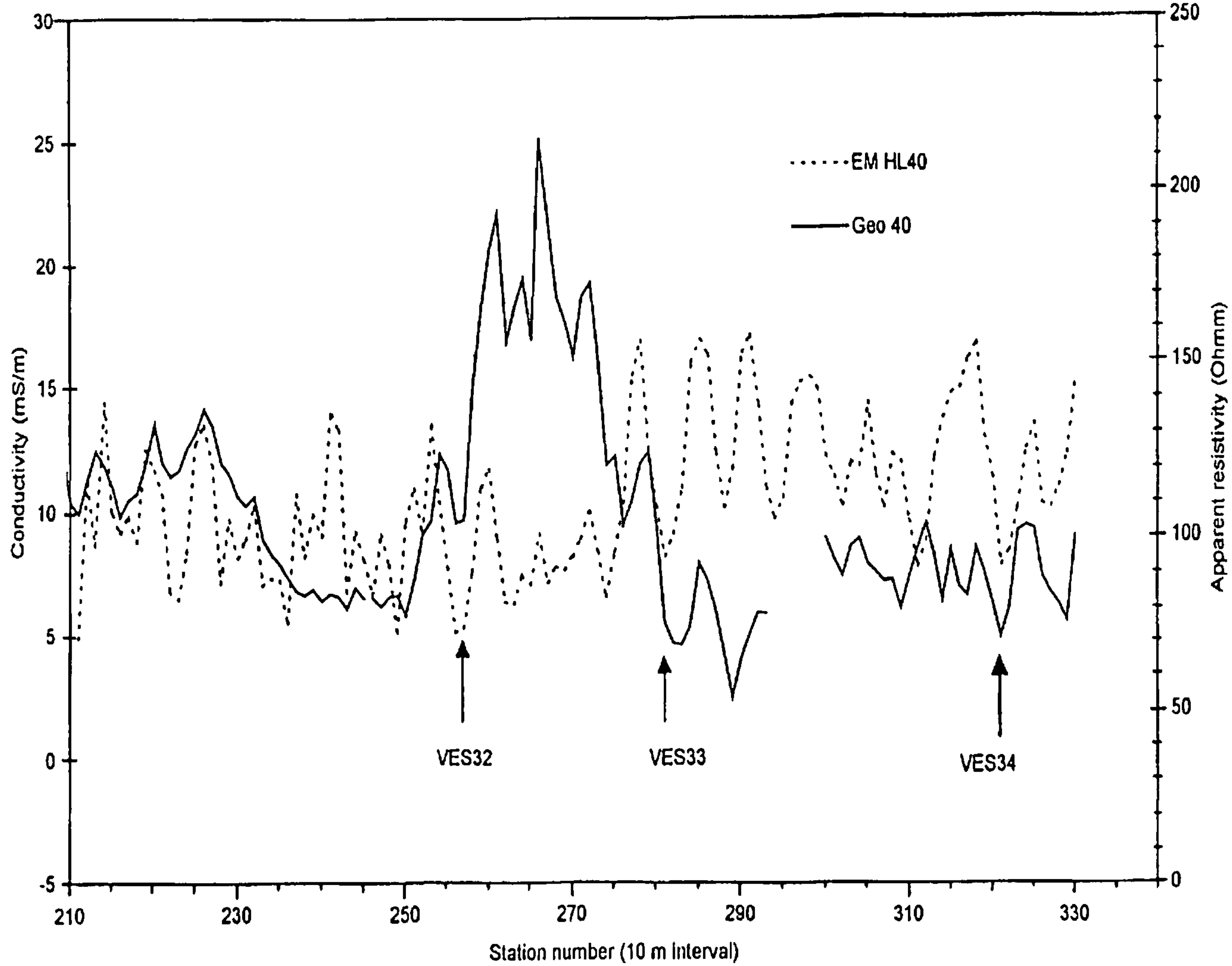


Figure 25. Graph of both Electrical Conductivity and apparent resistivity against station intervals. Note the position of VES 32, VES 33 and VES 34. Source: WRMD, Entebbe.

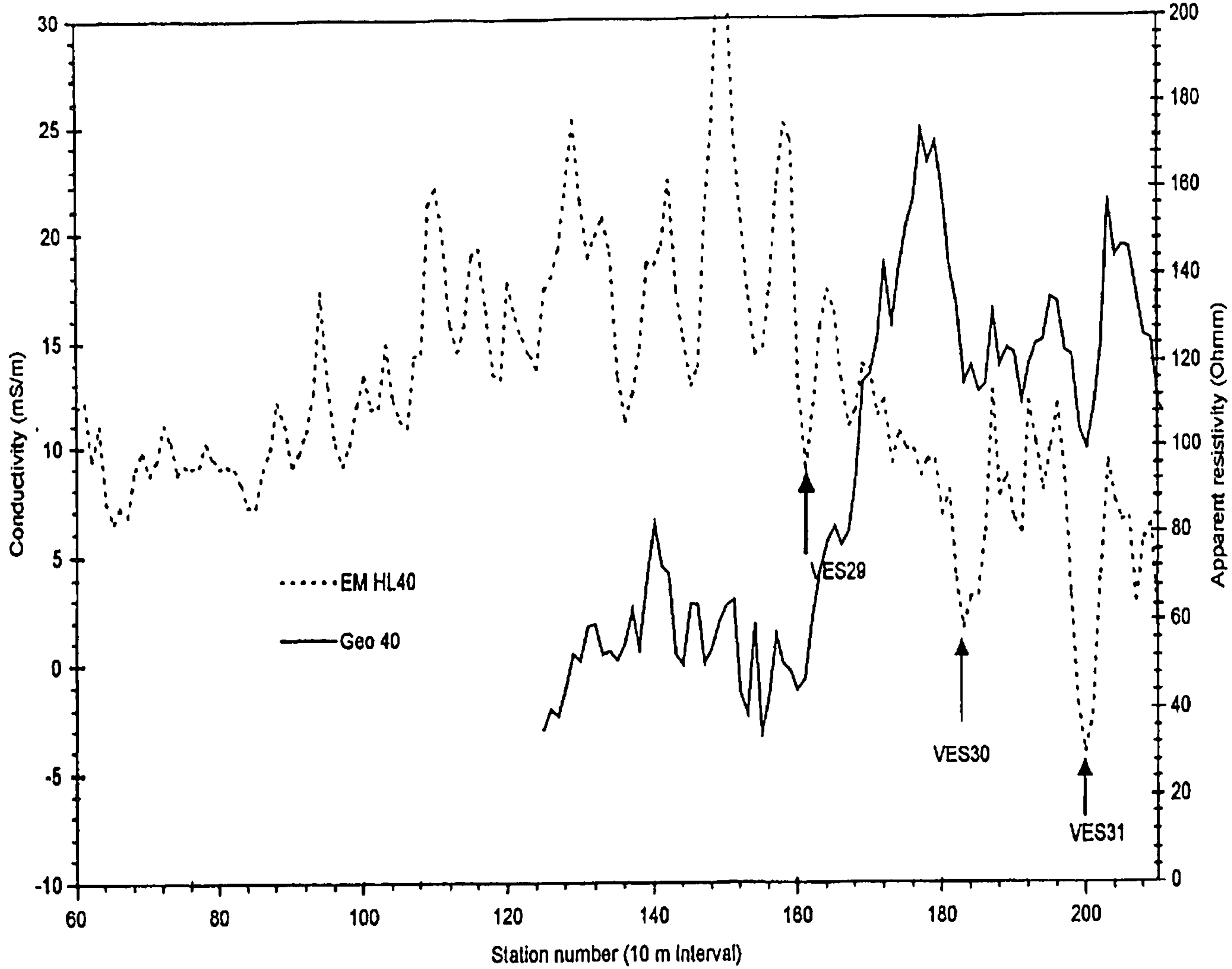


Figure 26. Graph of both Electrical Conductivity and apparent resistivity against station intervals. Note the positions of VES 29, VES 30 and VES 31. Source: WRMD, Entebbe.

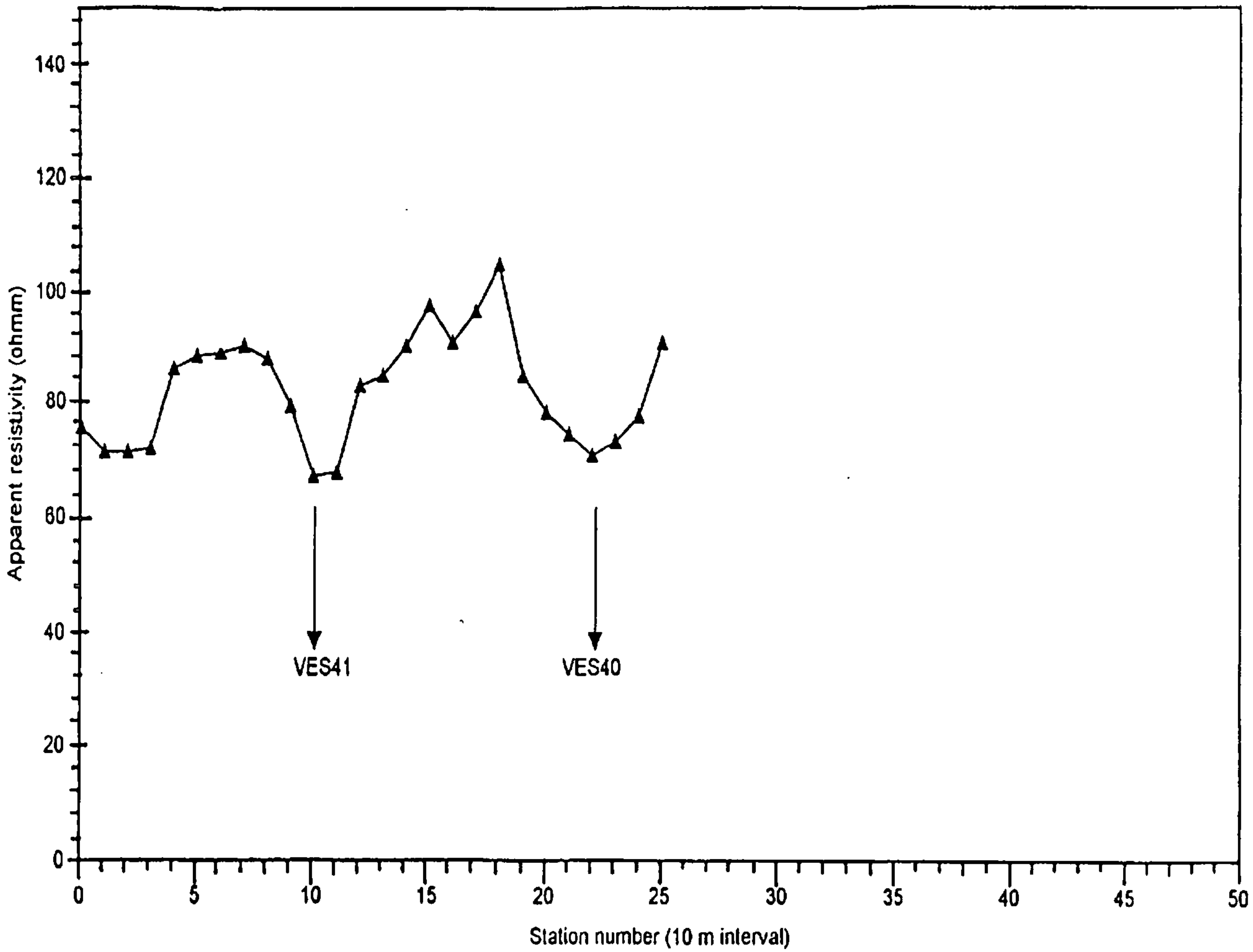


Figure 27. Graph of both Electrical Conductivity and apparent resistivity against station intervals. Note the positions of VES 40 and VES 41. Source: WRMD, Entebbe.

5.3 GEO-ELECTRICAL SECTIONS

Geoelectrical sections have been constructed with the basic assumption of horizontal layering. Lateral changes mark geoelectrical discontinuities along selected direction. These sections are useful as they enable an interpreter to see how the determined parameters correlate from one sounding station to another. More importantly, they are greatly helpful in extracting useful new geologic information from the subsurface.

Such problems as suppression, equivalence, and the location of the sounding station far from each other may mislead the interpretations. This was, therefore, where extra information to control the interpretation was found useful, thus the borehole logs data were incorporated in the correlation of geoelectrical interpretation. The geologic section interpreted from geoelectrical section may not be providing all information concerning the true geological section.

The geoelectrical boundaries were drawn to join the interpreted interfaces that agreed reasonably along the section. Where the interpretation was doubtful the interface was dashed and the most doubtful were marked with question marks.

On all the profiles three-geoelectric layers were identified. Permeability, temperature, fluid contents, salinity, structure and tectonic evolution influence the resistivities of the layer.

Faulting has resulted in the fracturing a deformation of the rock fabric. This has probably increased the permeability and porosity in the fractured zones thereby increasing fluid flow, which in effect reduces the resistivity of the formations.

In addition, the degree of alteration of the layers affects the conductivity of the layers. The high degree of alteration, the lower the resistivity of particular formation. In most cases, the top layer was thin and its resistivity was overlapping.

The surficial material mostly shows low resistivity due to clays derived from weathered pyroclastic material while in same cases show high resistivity due to dry sands and gravel.

5.3.1 SITES DONE

The potential for drilling high yielding production boreholes in Pallisa district seems good. On the basis of the results from the geophysics carried out (Figure 11), the following drill sites were identified and done.

Site1: VES 29 EM profile 7 Station 161 (Figure 28)

The site is placed on a distinctively prominent N-S lineament. The lineament is well marked by both the EM and geo-electrical profiles at station 161. The sounding curve suggests an overburden thickness of approximately 40 m and semi-weathered rock material down to approximately 60 m.

Site 2: VES 40 GE profile 14 Station 22 (Figure 29)

The site is located on an adjacent parallel lineament to that on which site 1 is found and is clearly identified on the aerial photographs. The lineament is caught by the geo-electrical profile at station 22. Right in field the sounding was carried out right at spot. The sounding curve therefore, indicates a thick, dry, hardpan top material underlain by some soft clayey material down to approximately 30 m. Fractured rock material seemed to occur between 30 - 60 m and drilling at this site would advance to a maximum depth of 90 m.

Site 3: VES 01 EM profile 6 Station 2 (Figure 30)

This site was initially picked on the geo-electrical profile. An extension of the EM profile to cover this zone produced a good match. Both the EM and GE profiles picked the anomaly. It is seen from the sounding curve that an overburden thickness of approximately 20 m with a relatively deep fractured zone from 20 to 40 m with a probable further fracturing between 60 - 110 m. The maximum drilling depth was recommended at 100 m.

Site 4: VES 39 EM profile 10 station 49 (Figure 31)

It is clearly seen that site 4 is located on a lineament that was picked by both the geo-electrical profile and EM profile. The sounding indicates an overburden thickness of approximately 30 m with a relatively deep fractured zone from 30 - 60 m. Drilling this site would advance to a depth recommended of 100 m.

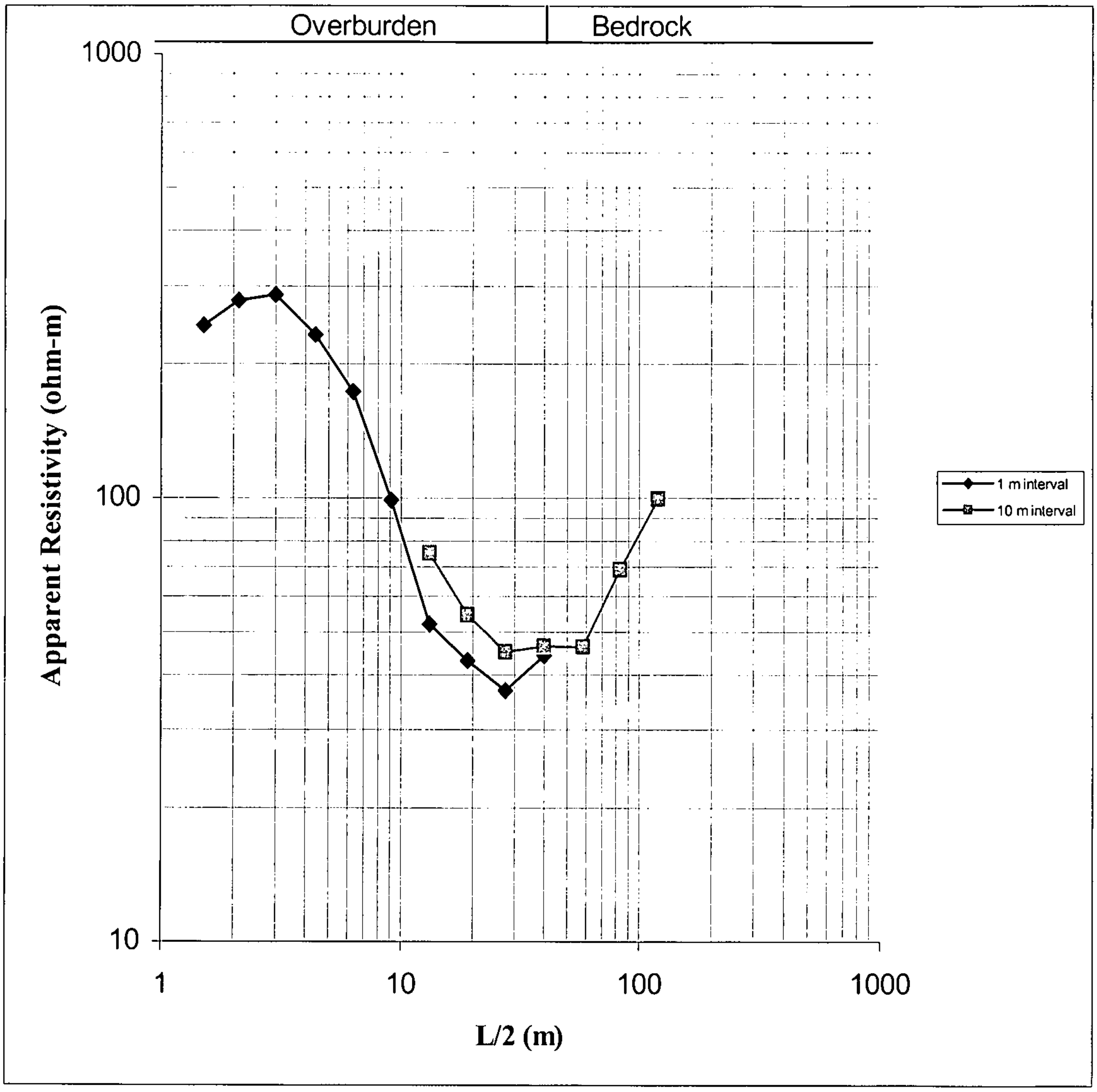


Figure 28. **Graph of Geo-electrical sounding No. VES 29 Profile 07 Station 161 of site 1, UTM coor: 36N 0576501, E 129778, Pallisa.**

Note: Both intervals as seen by the legend apply to the rest of the next profiles.

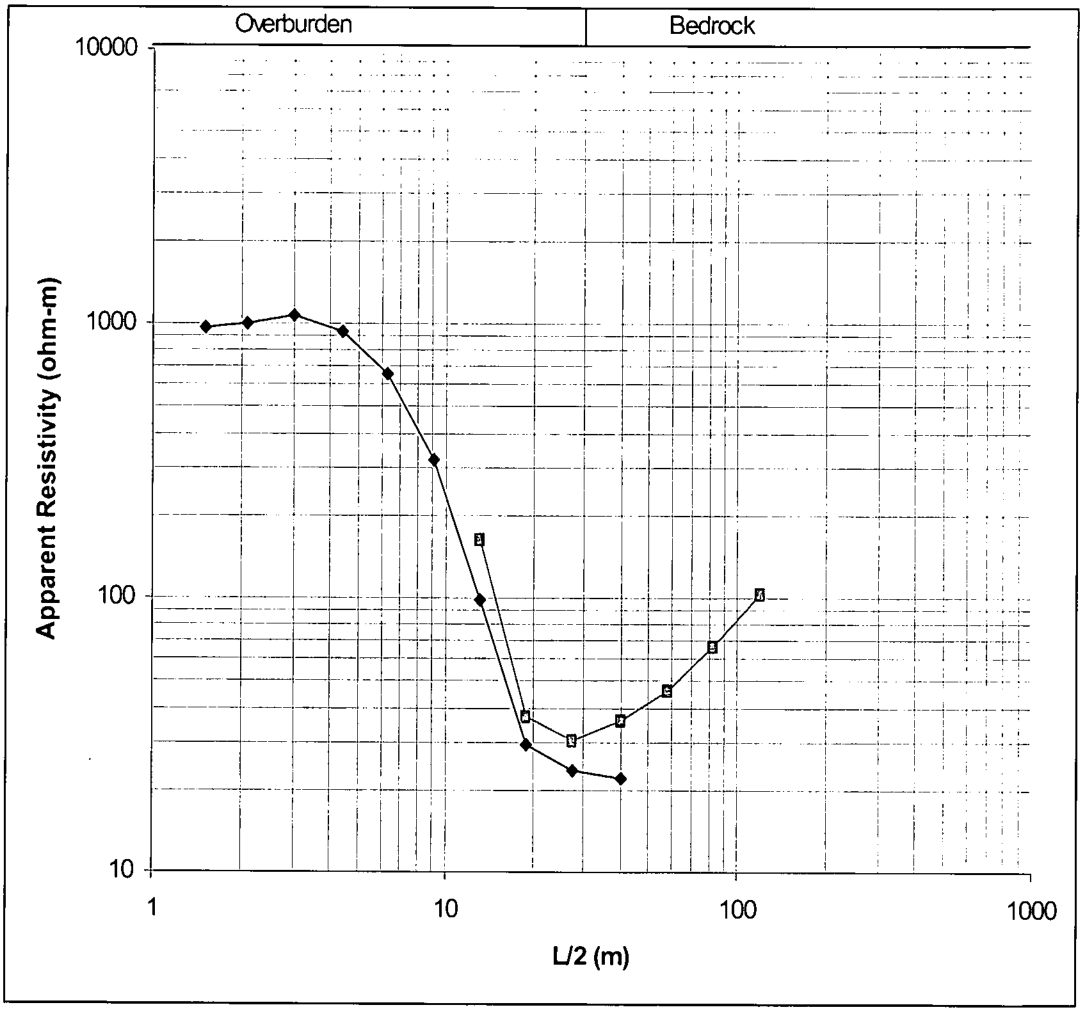


Figure 29. **Graph of Geo-electrical sounding No. VES 40 Profile GEP 14 Station 22 of site 2, UTM coor: 36N 0575803, E 130799, Pallisa.**

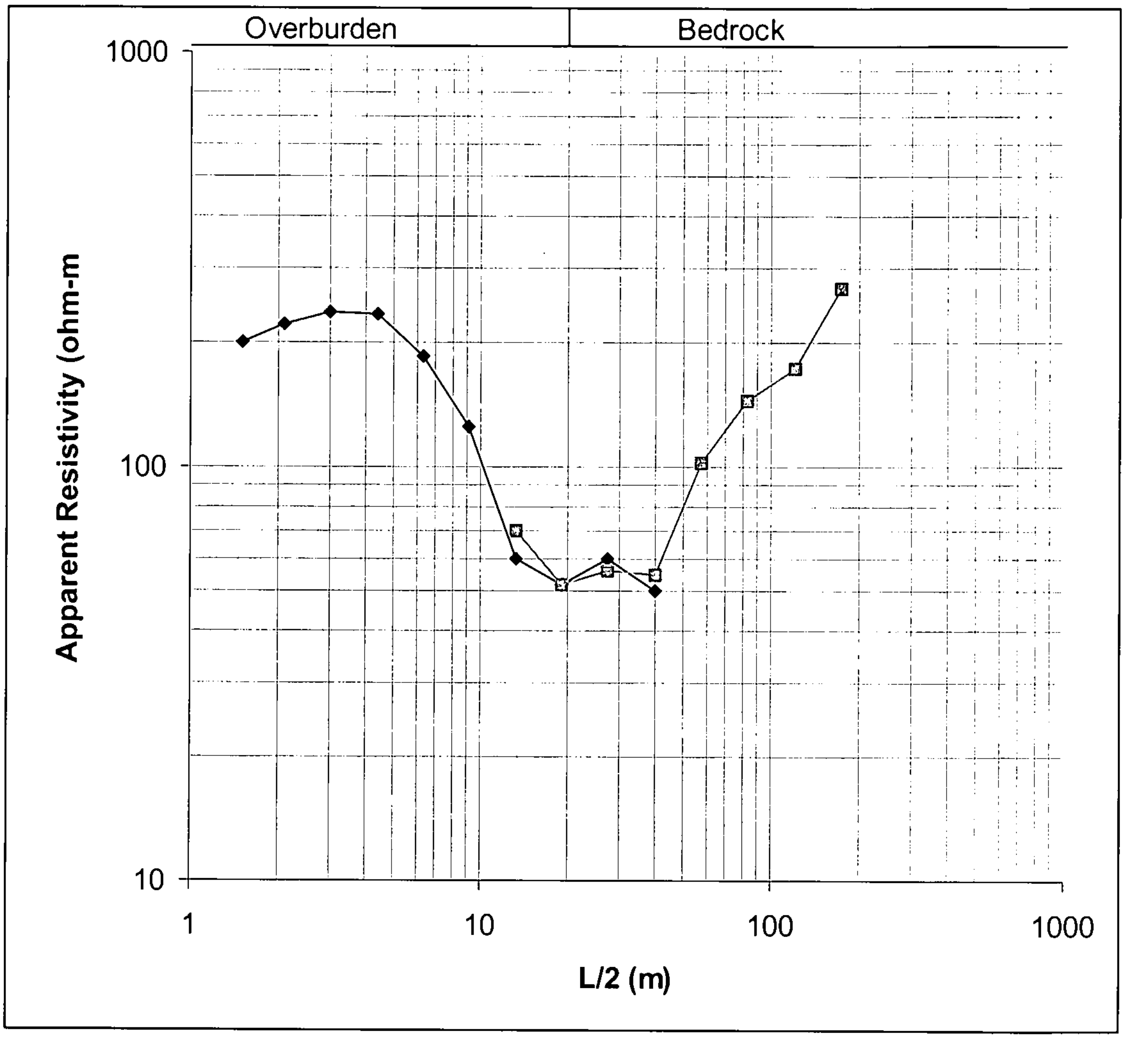


Figure 30. **Graph of Geo-electrical sounding No. VES 01 Profile 06 of site 3, Pallisa.**

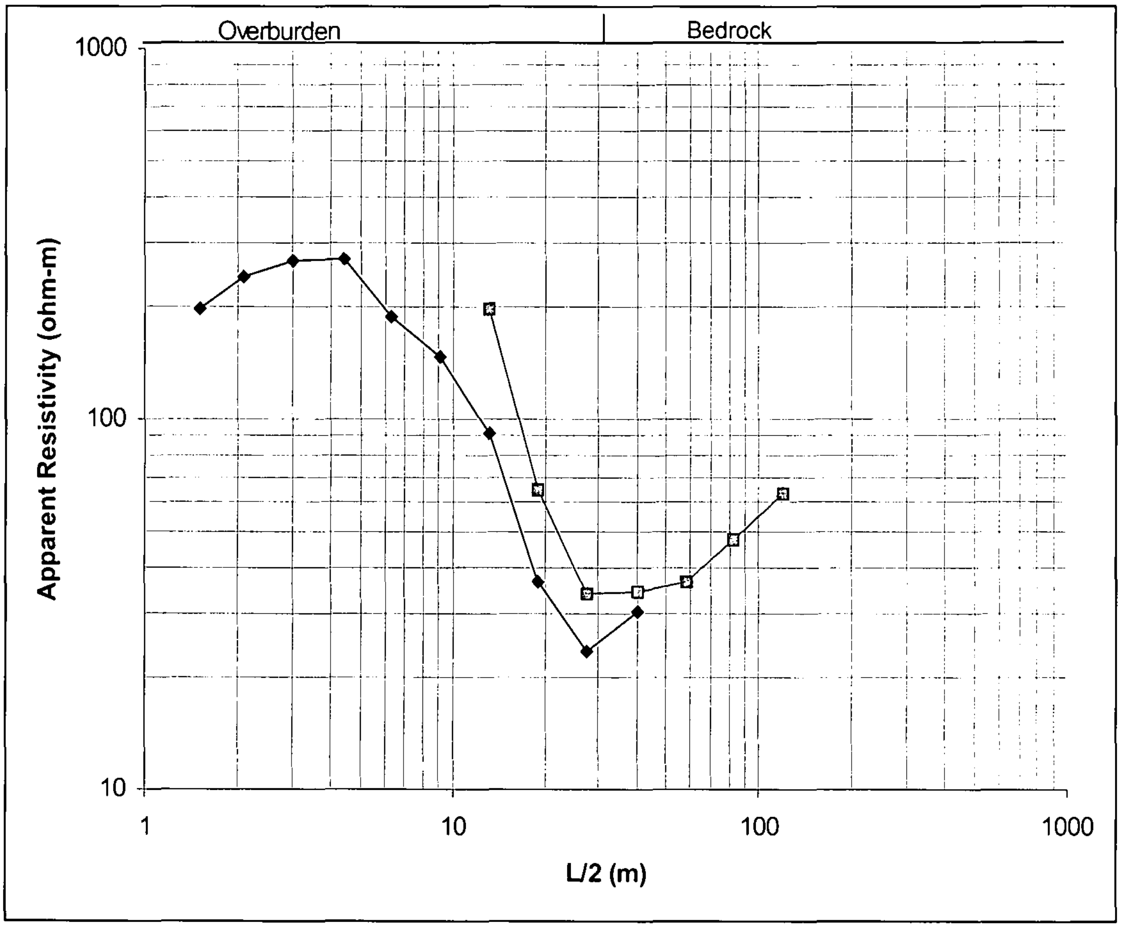


Figure 31. **Graph of Geo-electrical sounding No. VES 39 Profile EM 10 Station 49 of site 4, UTM coor: 36N 0575220, E 128705, Pallisa.**

Site 5: VES 19 EM profile 9 Station 84 (Figure 32)

This site was placed on a clearly visible N-S lineament east of Supa ginnery, which was very distinctively picked on both the EM and GE profiles. This site was picked more on the strength of the anomaly on the profile. The sounding indicates an overburden thickness of approximately 34 m with a relatively small fractured zone between 30 to 40 m. As seen the maximum recommended drilling depth would be 90 m.

Site 6: VES 18 EM profile 9 Station 112 (Figure 33)

Site 6 is located on an adjacent parallel lineament to that on which site 5 are found. It is on the strength of the anomaly on the profile that this site was selected. This lineament is clearly caught by the geo-electrical profile at station 112. The sounding curve, however, is only moderate and indicates an overburden thickness of approximately 30 m with virtually no fractured zone and it is recommended that the maximum drilling depth be 80 m.

Site 7: VES 33 EM profile 7 Station 281 (Figure 34)

Site 7 was located on the NE-SE lineament after an aerial photo interpretation. The anomaly was picked by both the EM and the GE profiles and interpreted as the NE-SE lineament. The sounding indicates an overburden thickness of approximately 37 m with a fractured zone from 30 to 40 m and a recommended maximum drilling depth of 90 m.

Site 8: VES 34 EM profile 7 Station 321 (Figure 35)

Site 8 was placed on a N-S lineament, which was identified from the aerial photo interpretation. The anomaly was picked by both the EM and the GE profiles and was interpreted as N-S lineament and confirmed by ground conditions. The sounding indicates an overburden thickness of approximately 40 to 80 m. It is however, seen that the resistivity is just below 100.

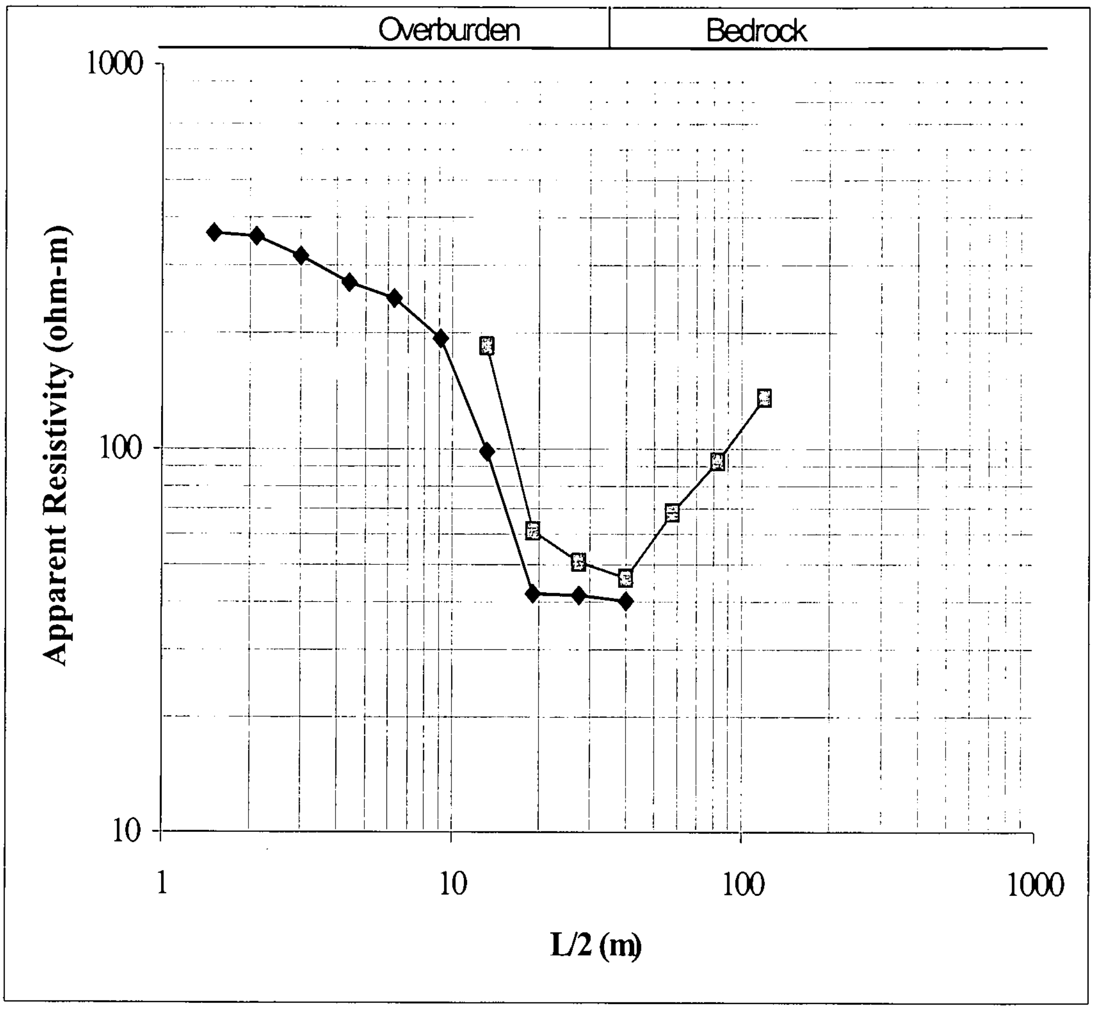


Figure 32. **Graph of Geo-electrical sounding No. VES 19 Profile EM 09 Station 84 of site 5, UTM coor: 36N 0582433, E 128714, Pallisa.**

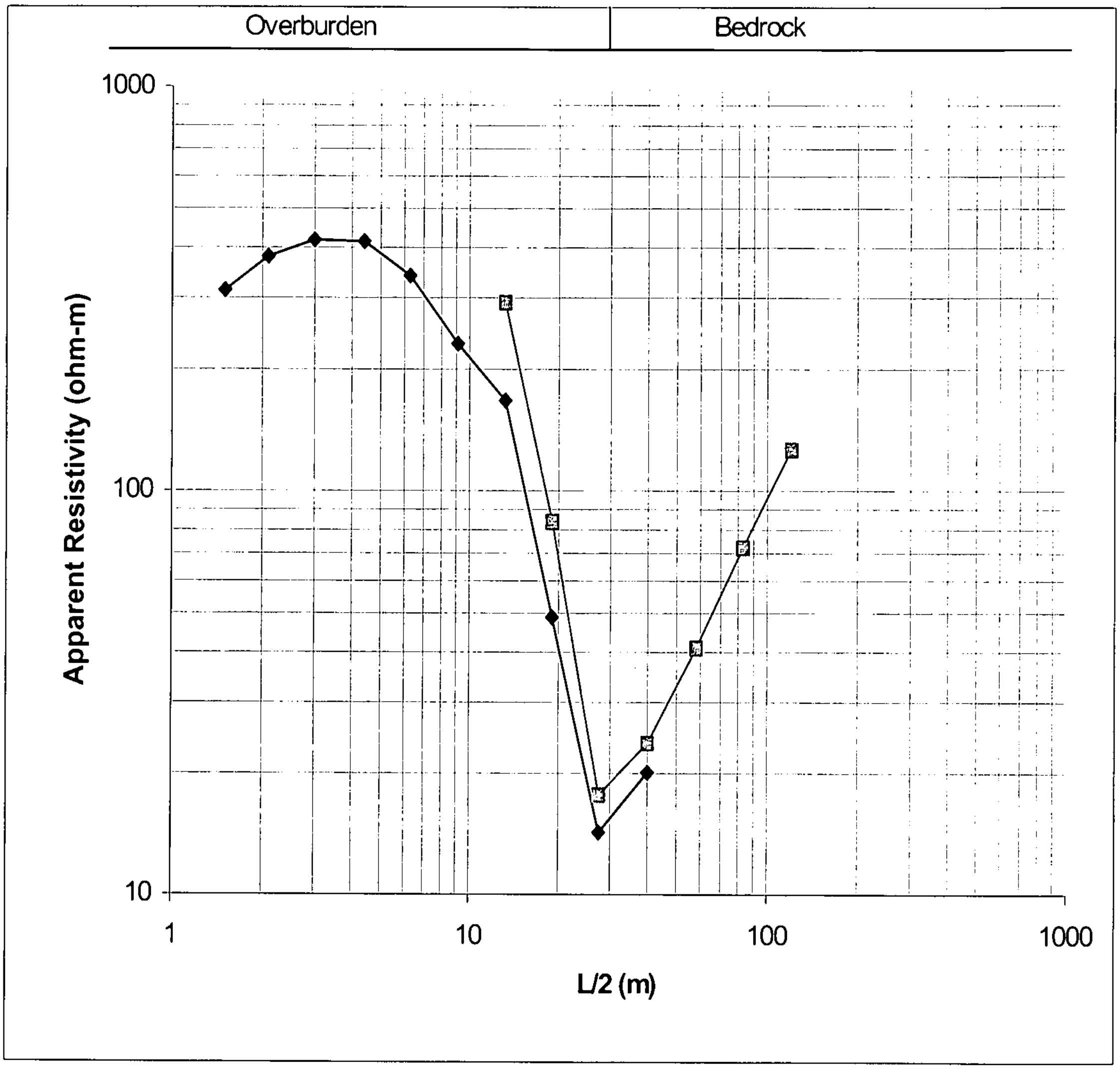


Figure 33. **Graph of Geo-electrical sounding No. VES 18 Profile EM 09 Station 112 of site 6, UTM coor: 36N 0582685, E 128637, Pallisa.**

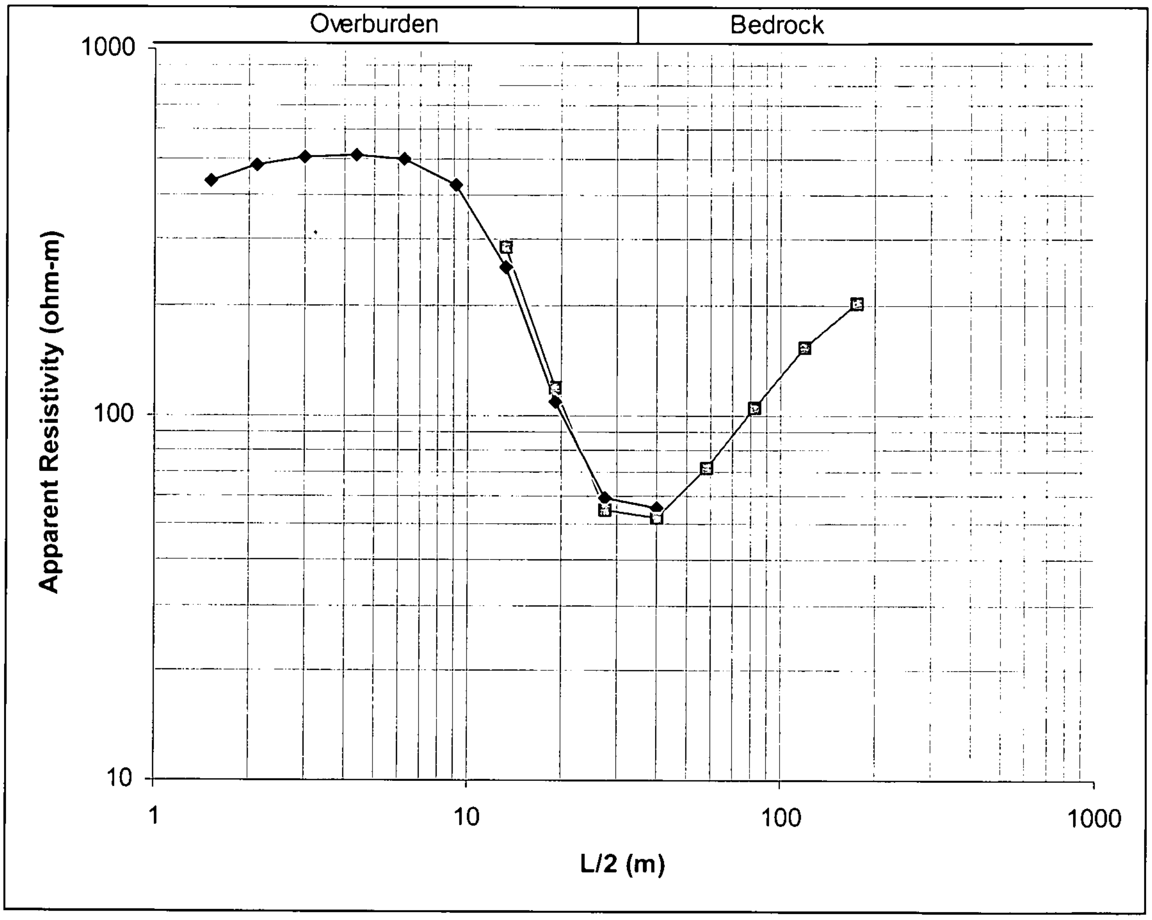


Figure 34. **Graph of Geo-electrical sounding No. VES 33 Profile EM 07 Station 281 of site 7, UTM coor: 36N 0575302, E 129830, Pallisa.**

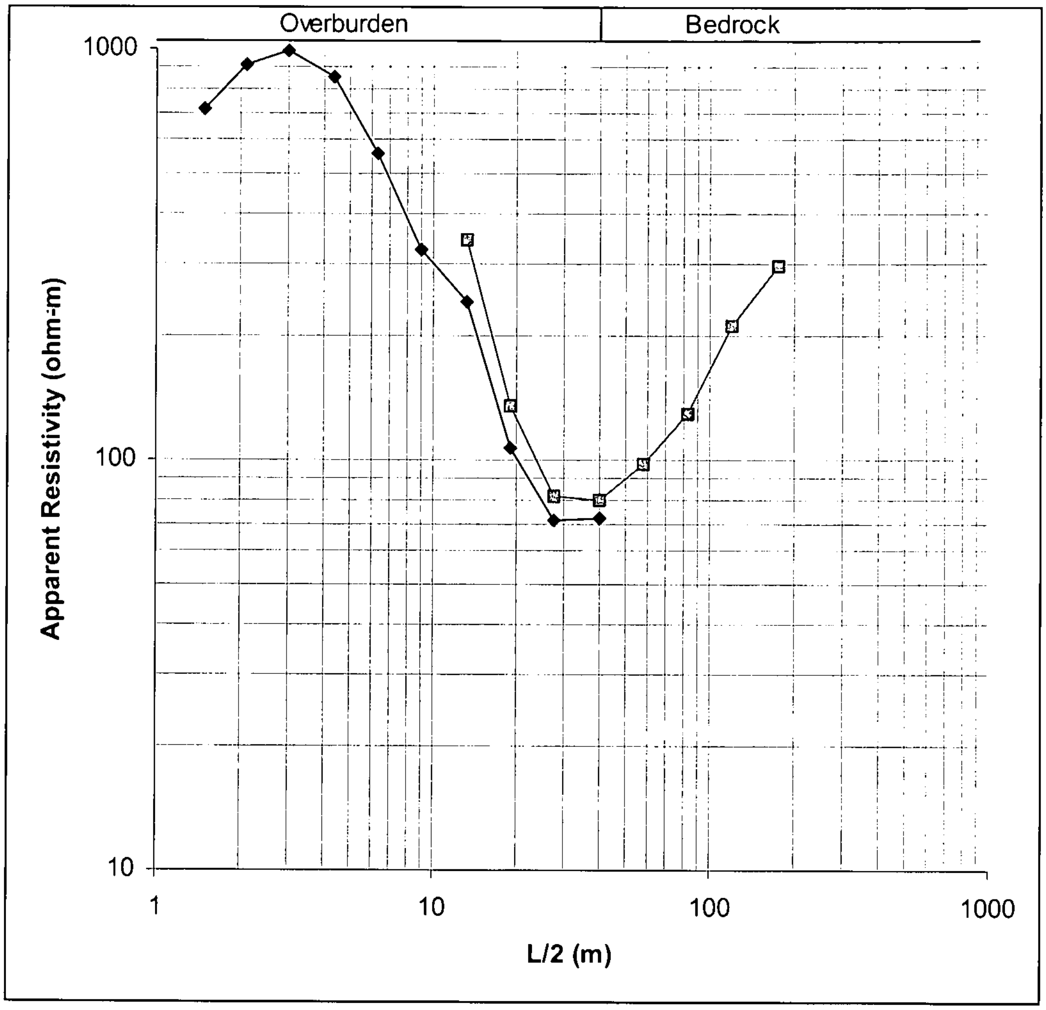


Figure 35. **Graph of Geo-electrical sounding No. VES 34 Profile EM 07 Station 321 of site 8, UTM coor: 36N 0574921, E 129854, Pallisa.**

Site 9: VES 31 EM profile 7 Station 200 (Figure 36)

It was placed on the NE-SE lineament, which was identified from the aerial photo interpretation. The anomaly was picked by both the EM and GM profiles as the NE-SE lineament. The sounding has very low values and indicates an overburden thickness of approximately 30 m with no clear fractured zone identified.

Site 10: VES 30 EM profile 7 Station 183 (Figure 37)

The site was placed on a N-S lineament and was identified from the aerial photo interpretation. The sounding curve with relatively high resistivity values indicates an overburden thickness of approximately 21 m. A fractured zone from 20 to 50 m is apparent but may not be saturated and the recommended drilling depth is 80 m.

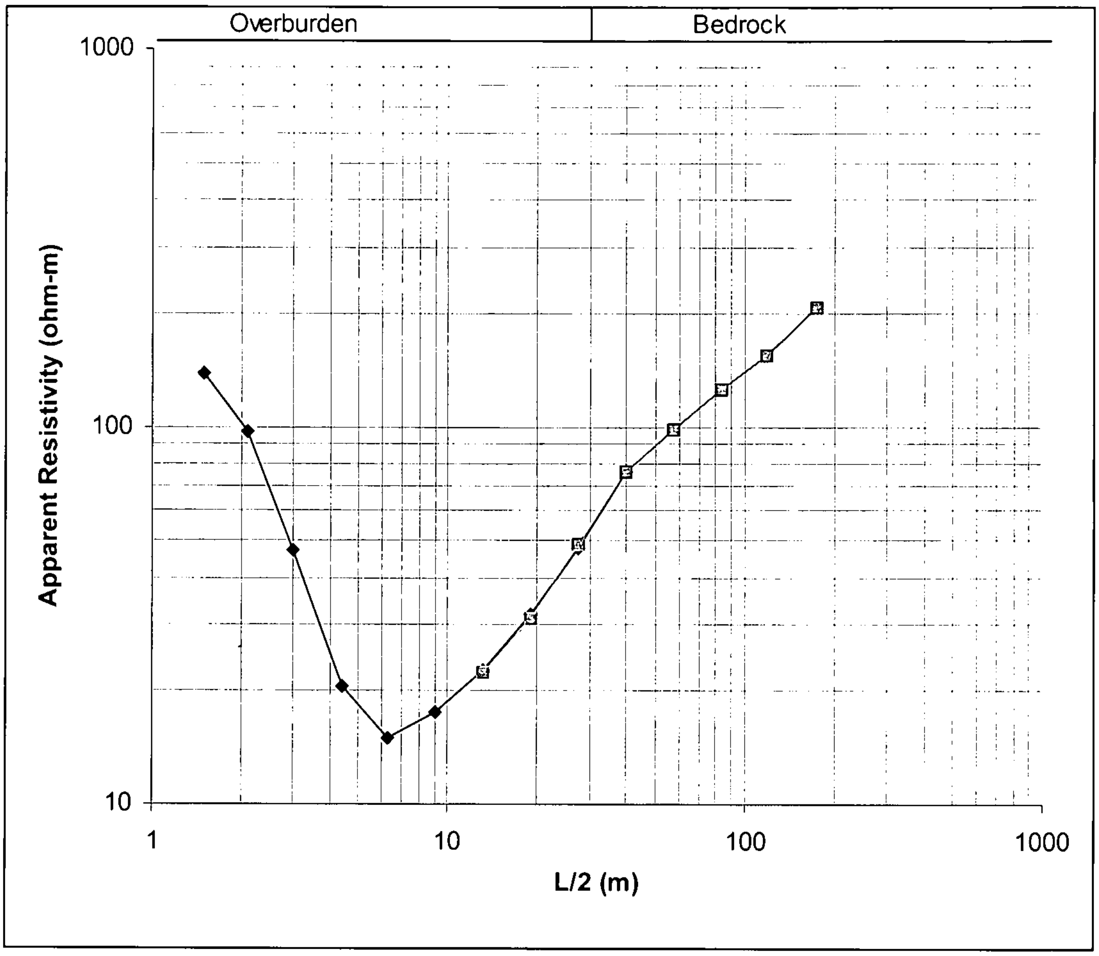


Figure 36. **Graph of Geo-electrical sounding No. VES 31 Profile EM 07 Station 200 of site 9, UTM coor: 36N 0576100, E 129793, Pallisa.**

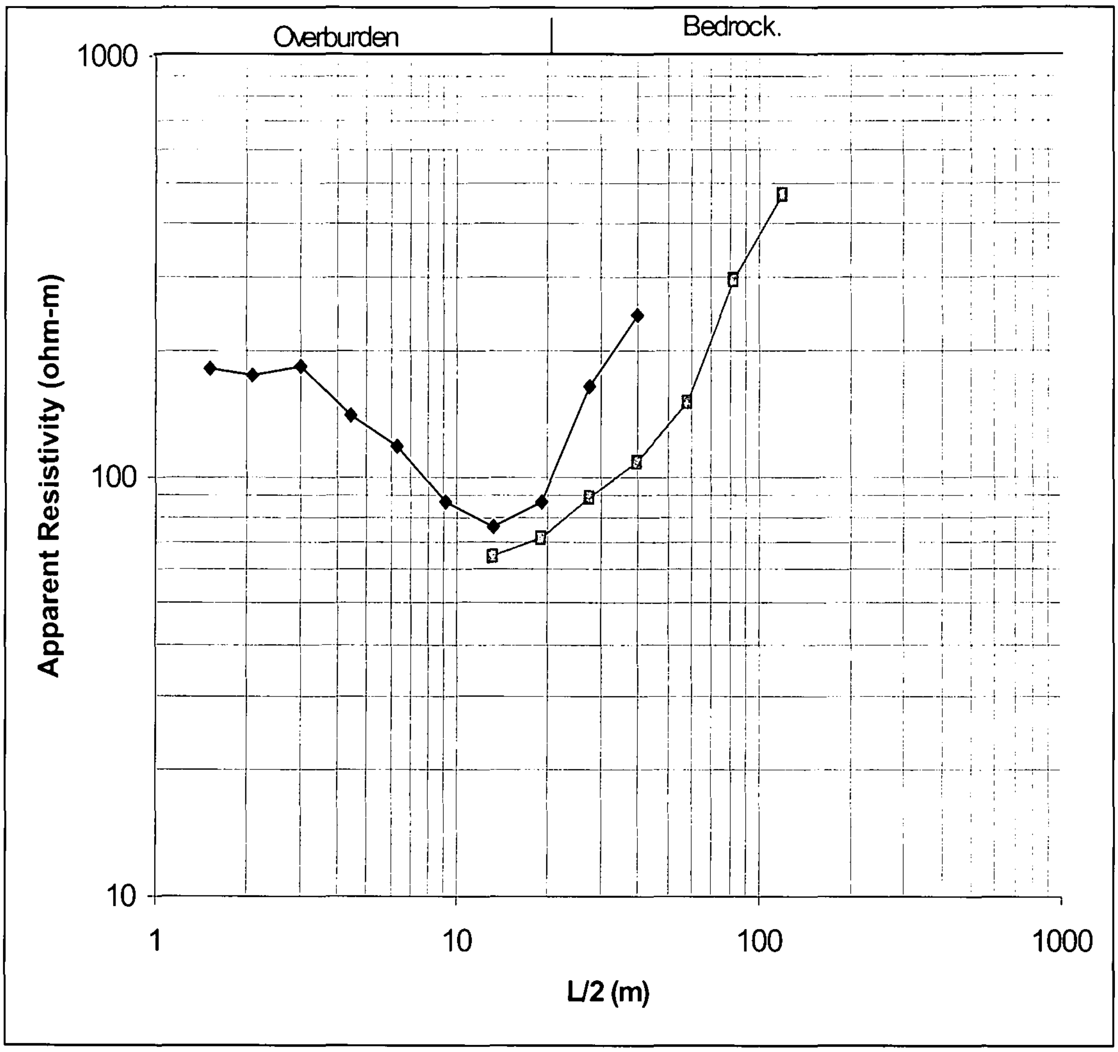


Figure 37. **Graph of Geo-electrical sounding No. VES 30 Profile EM 07 Station 183 of site 10, UTM coor: 36N 0576282, E 129792, Pallisa.**

5.3.2 RESULTS OF THE GEOPHYSICAL SURVEYS

The combined use of Electromagnetic and Resistivity surveys made it possible to determine regolith thickness and lithology. The results obtained were verified by drilling data and were found to be almost similar. Results obtained using Electromagnetic methods along transects sometimes varied as they were affected by varying depths to bedrock and lithological changes. The results of the method have therefore to be used with borehole control otherwise they may be difficult to interpret. In most cases they were found to be far different from those obtained by both resistivity method and drilling and were therefore not always reliable.

However, a generally favourable relationship is shown. Resistivity surveys gave an indication of regolith lithology since each soil type has characteristic resistivity values.

However, the aim of the extensive geophysical research, which was realised using the geo-electrical method, was:

i. The determination of the formation thickness by recording the stratigraphy of the Kyoga catchment with respect of Pallisa district;
ii. The definition of tertiary and quaternary deposits by evaluating the thickness of aquifer layers;
iii. The verification of the continuity and the relationship with aquifer layers of Pallisa district.

After data treatment, I determined three geological units:

a. The upper geoelectrical formation, which covers superficially almost the whole area, consists of lateritic crust and clays with unconsolidated water table sands. The values range between 0 - 2 m, 2 – 15 m and 15 -30 respectively with its thickness from 0 to 30 m and resistivity ranging between 150 and 1000 Ω-m was measured;
b. The second geoelectrical formation had values that ranged between 30 and 90 m, and this corresponded to the fractured lithological composition. Its thickness is up to 60 m and;
c. The third geoelectrical formation is gneiss-schist, gneiss and amphibolites. The values range between 90 and 250 m and its thickness is up to 160m.

The assessment condition of groundwater within Pallisa district therefore, resulted in the initiation of a geohydrological investigation, which included a series of explorations and drilling programmes in order to locate and develop suitable water sources for all the villages.

5.4 GEOLOGIC LOGS

It is important that complete drilling logs are obtained for the production of wells even though test drilling may have been done in advance. This adds to local geophysical information as well as providing a basis for design and development decisions for the particular wells under construction.

Geologic logs were constructed from sampling and examining of cuttings encountered at different depths of the wells. Physical properties of the rocks were measured within the boreholes, identified the lithology and boundaries between layers of the penetrated rocks. These measurements did also give indications of the fluid pore content and thus provided fundamental data for the interpretation of the surface geophysical investigation.

The geologic logs for the various boreholes within the study area were examined giving information on the stratigraphy of the area under study (Pallisa district).
The following detailed geologic logs below were produced by use of the WISH programme for the specific boreholes (Appendix E), which gave a representation of the lithology of Pallisa district (Figures 37, 38, 39, 40, 41 and 42).

The relationship between the aquifer thickness and the resistivities are shown in Table 3.

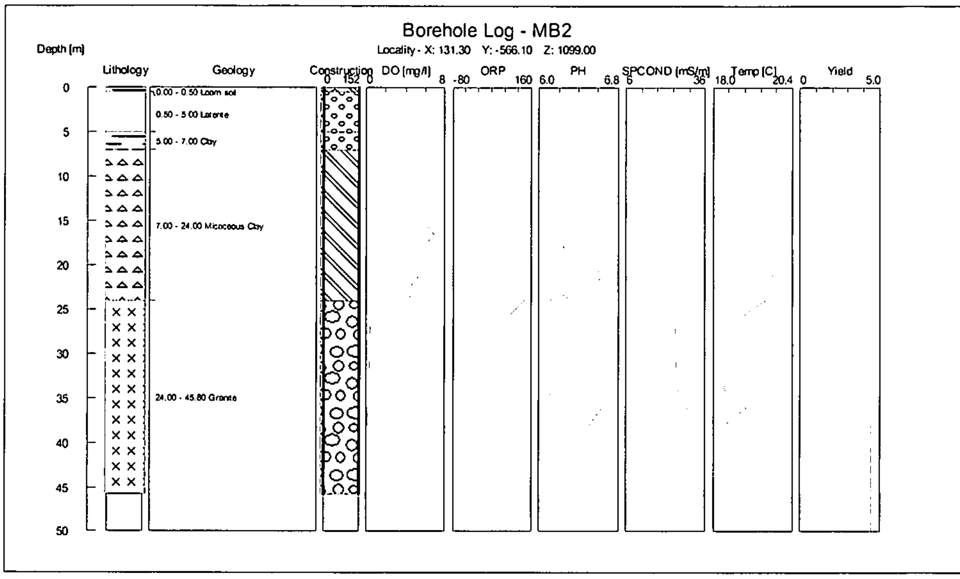


Figure 38. Details of Borehole Log of MB2 in Pallisa

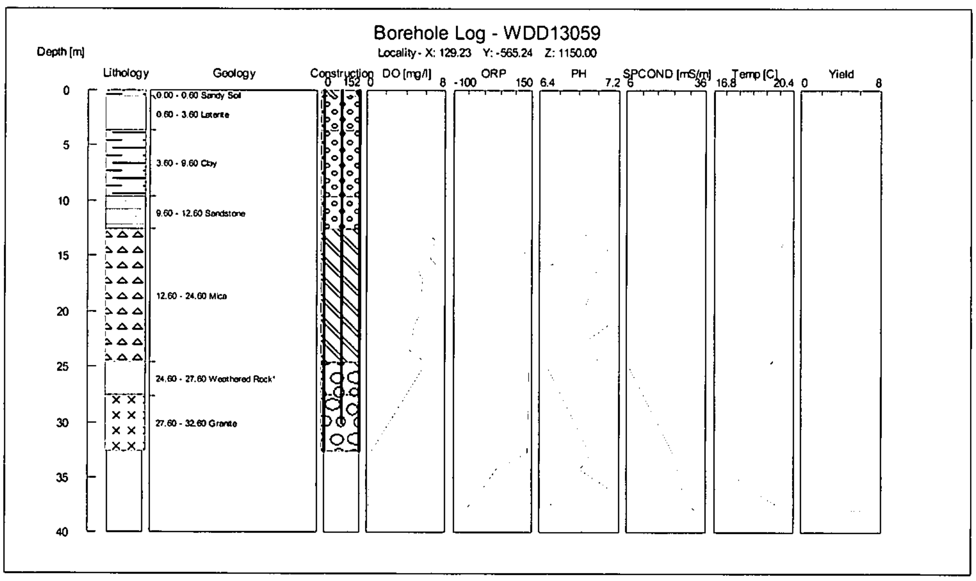


Figure 39. Details of the Borehole Log of WDD 13059 in Pallisa.

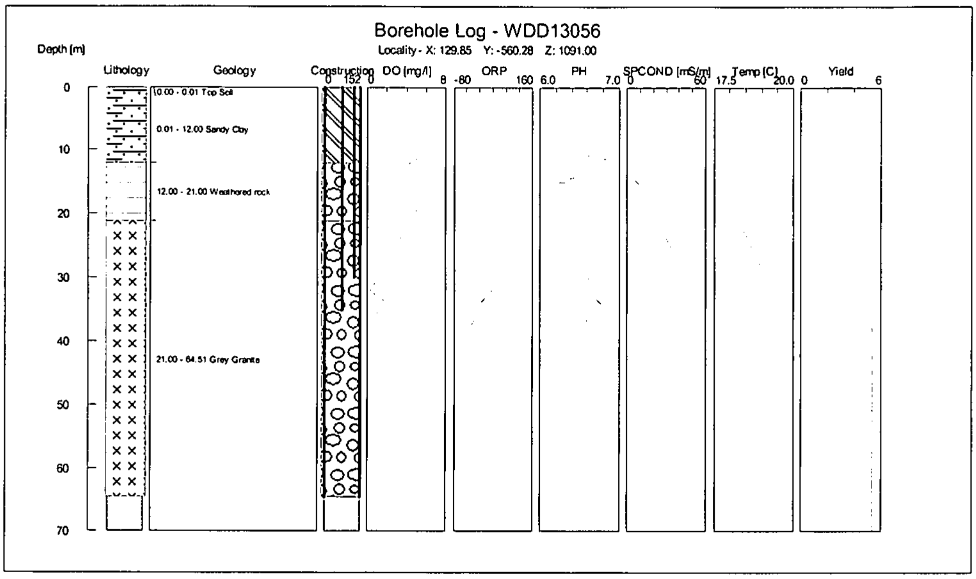


Figure 40. Details of the Borehole Log of WDD 13056 in Pallisa.

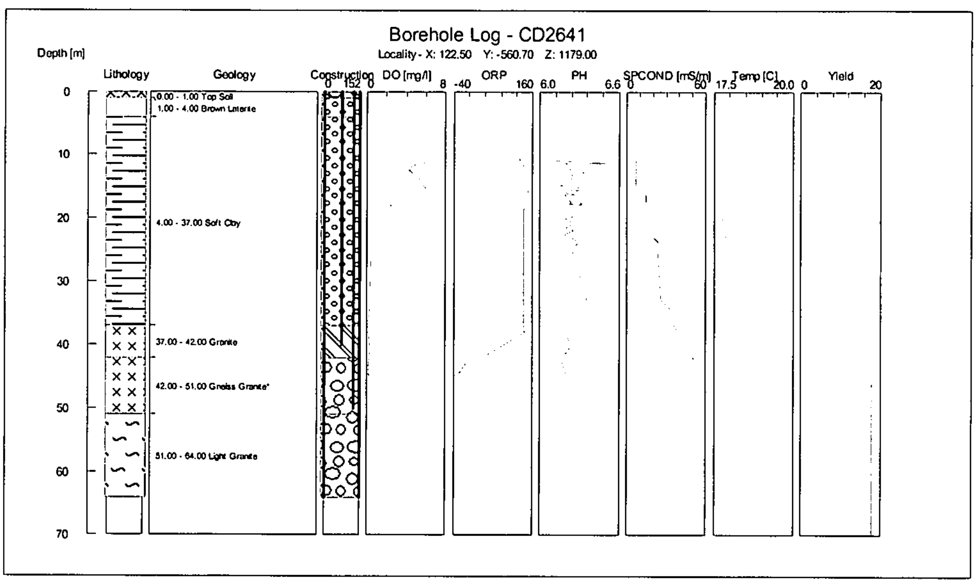


Figure 41. Details of the Borehole Log of CD 2641 in Pallisa.

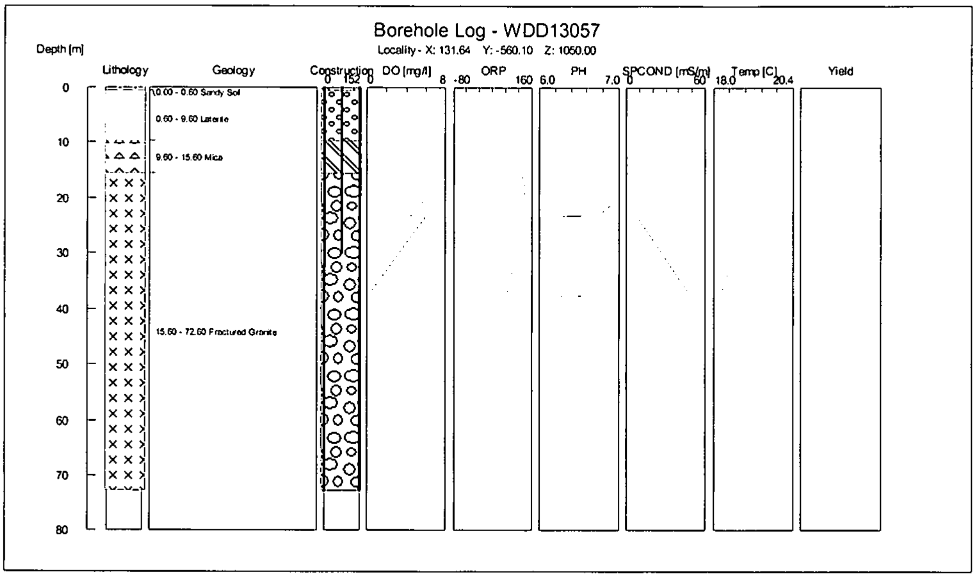


Figure 42. Details of the Borehole Log of WDD13057 in Pallisa.

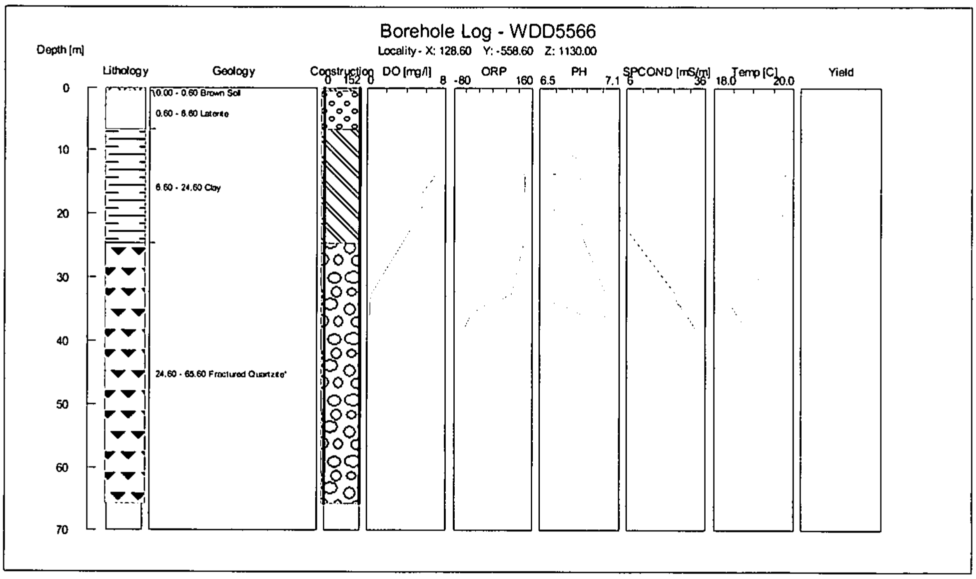


Figure 43. Details of the Borehole Log of WDD5566 in Pallisa.

Table 3. **The relationship between the regolith thickness determined by resistivity sounding and the regolith thickness as indicated by the length of the casing installed.**

Borehole Number	Regolith Thickness	
	Resistivity (m)	Casing depth (m)
MB2	53.6	55
WDD13059	33.5	35
WDD13056	65.3	68
CD2641	65	67
WDD13057	72.8	75.3
WDD5566	65	66.2

N.B It should be recognized that casing length is not an ideal measure of regolith depth as casing usually penetrates a meter or two beyond the weathered zone to permit a good grout seal to be obtained in solid bedrock

5.5 ANALYSIS AND EVALUATION OF PUMPING TEST DATA

5.5.1 INTRODUCTION

The pumping tests were carried out on the boreholes indicated in order to determine their performance characteristics and to establish the parameters of the aquifers within Pallisa district.

The sustainability of groundwater resources greatly depends on the response of the underlying aquifer to pumping. The property of the material such as the transmissivity and storativity of the aquifer influence the response and help to compute the decline in water level or drawdown. These properties are evaluated by performing test pumping on a well pumped at constant rate and the change in drawdown measured over tome (Fetter, 1994).

For the existing boreholes MB1 and MB3, a long duration pumping tests were carried out with a minimum of 72 hours recommended. Test pumping of these boreholes was conducted with some nearby boreholes as observation wells. The results of the pumping tests are summarised in Table 4.

Table 4. Pumping test results for MB1 and MB3 as reported by NURP.

Borehole	Pumping Test Results				Specific capacity at 1 hour. $m^3/h/m$	Transmissivity m^2/s
	Duration Hours	Yield m^3/h	Draw-down 1hour	Draw-down Full-time		
MB1	72	3.0	14.31	15.44	0.21	8.0×10^{-5}
MB2	60	7.2	10.12	10.55	0.71	4.6×10^{-4}
MB3	72	3.6	11.90	13.50	0.30	6.0×10^{-5}

The hydraulic conditions of the boreholes MB1 and MB3 do only justify an abstraction of 3 m^3/h to 3.6 m^3/h after 72 hours of pumping. However, since MB1, MB2 and MB3 are located in the same aquifer. The possible extraction for the combined pumping seems therefore to have been severely overestimated.

Water samples were collected from the drilled boreholes during the test pumping and analyzed at RUWASA laboratory for standard parameters, (Appendix A). For the parameters analysed there were no problems on water quality.

For the boreholes above in the table, it was however, observed that:
MB1: The well was opened twice and that there was or it has been mechanical problems with the pump. It is currently out of operation. The probable factor causing all these mechanical problems could be a side effect of corrosion.
MB2: After pumping, the yield reduced to around 4 m^3/h. implying an over exploration of the aquifer. The drilling of this borehole within the same aquifer was to establish flow of the groundwater.

MB3: There was continuous problems with this well, both mechanically and well silting up, probably caused by unsatisfactory borehole construction. This assumed a need to have hydro fracturing of the well.

It should be realised that the data given in table 9 below were measured at the time of the long duration of pumping test.

The overburden around Pallisa town and within the district seems to be fairly thin, for the boreholes included here between 8.5 and 17 meters, and consist of layers of lateritic clay. The basement rock is granite with some quartz.

For the summary of the newly drilled borehole WDD13056, MB4, MB2, WDD13057 and WDD13059, the parameters are given in Tables 4, 5 and 6.

Table 5. Summary of drilled borehole specifics.

Parameters	WDD No. Location	WDD13056 Kasodo Road	MB4 Near Police Post
Drilling Period	29.03.01 to 06.04.01	2001	06.04.01 to 18.04.01
Total depth, m.	52.7	57.6	73.2
Overburden thickness, m	17.4	-	8.5
First water struck, m	12.5	-	12.0
Main water struck, m	20/30	-	54.0
Static water level at PT, m	9.81	2.0	20.53
Yield:			
1.Driller estimate, m^3/h	7.80		3.9
2.Pump test yield, m^3/h	9.0	3.10	5.2

Table 6. Summary of test drillings.

Parameters	WDD No Location Driller No.	WDD13056 Kasodo Road DCL681	WDD13057 Nabitende. DCL 682	WDD13059 Mbale road DCL684
Drilling Period		29.03.01 to 06.04.01	07.04.01 to 13.04.01	23.04.01 to 28.04.01
Total depth, m.		52.7	60.1	89.0
Overburden thickness, m		17.4	13.1	10.4
First water struck, m		12.5	18	25
Main water struck, m		20/30	39/50	60
Static water level at PT, m		9.81	9.22	2.72
Yield:				
1. Driller estimate, m^3/h		7.8	15.6	2.0
2. Pump test yield, m^3/h		9.0	20.0	2.0

Pumping tests were performed so that the aquifer characteristics could be bettered understood and predicted. Measurements were then made at each of the pumped and observed wells, depth to water level and time of observations recorded

5.5.2 THE GOVERNING EQUATIONS

The Cooper-Jacob (1946) for confined aquifers and the Theis were used as the governing equations to evaluate the properties of the aquifer. The Cooper-Jacob method is a simplification of the Theis method, which approximates the infinite series describing $W(u)$ by the first two terms in the series as follows:

$$W(u) = -0.5772 - In(u)\,. \qquad (5.1)$$

This solution that is valid for greater time and smaller separation distance from the pumping well (smaller u values, i.e. u<0.01). The resulting equation is:

$$s = \left(\frac{2.30Q}{4\pi T}\right)\log_{10}\left(\frac{2.25Tt}{Sr^2}\right) \quad (5.2)$$

where s is drawdown, Q is the well discharge rate, t is time, r is the radial distance, and S and T are the storativity and transmissivity respectively.

The above equation plots as a straight line on semi-logarithmic paper if the limiting condition is met. Thus, straight-line plots of drawdown versus time can be produced after sufficient time has elapsed. In pumping tests with multiple observation wells, the closer wells will meet the conditions before the more distant ones. Time is plotted along the logarithmic x-axis and drawdown is plotted along the linear y-axis.

For the Time-Drawdown method, the Aquitest programme calculated transmissivity and storativity as follows:

$$T = \frac{2.30Q}{4\pi\Delta s} \quad (5.3)$$

where, T = Transmissivity, Q = Discharge and delta s is the change in drawdown over one logarithmic cycle, and t_o is the time value where the straight line fit of the data intersects the time axis.

The storage coefficient is defined by the equation,

$$S = \frac{2.25Tt_0}{r^2} \quad (5.4)$$

where r is the distance defined by the intercept of zero drawdown and the straight line through the data points.

In the analyses made below, the Cooper-Jacob solution assumed the following:

a) The aquifer is confined and has an "apparent" infinite extent;
b) The aquifer is homogeneous, isotropic, of uniform thickness over the area influenced by pumping;
c) The piezometric surface is horizontal prior to pumping;
d) The well is pumped at a constant rate;
e) The well is fully penetrating;

f) Water removed from storage is discharged instantaneously with decline in head;

g) The well diameter is small so that well storage is negligible and;

h) The values of u are small (rule of thumb u < 0.01).

The data requirements for the Cooper-Jacob solution are:

a) Drawdown vs. time data at an observation well and;

b) Distance from the pumping well to the observation well.

In addition to the Cooper-Jacob method, a well efficiency (Table 8), which is the specific capacity after 60 minutes of pumping, was divided by the theoretical possible specific capacity and calculated from the formula of Theis given by:

$$s = \frac{Q}{4\pi KD} \int_{u}^{\infty} \frac{e^{-y}}{y} dy = \frac{Q}{4\pi KD} W(u) \qquad (5.5)$$

where

s = the drawdown in meters measured in a piezometer a distance r in meters from the well;

Q = the constant well discharge in m^3/day;

KD = transmissivity of the aquifer in m^2/day;

u = $\frac{r^2 S}{4KDt}$ and consequently $S = \frac{4KDtu}{r^2}$;

S = the dimensionless storativity of the aquifer;

t = the time in days since pumping started;

$W(u) = -0.5772 - In\ u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} + \frac{u^4}{4.4!} + ...$

The *W(u)* is an exponential function which in this usage is generally read as “well function of u” or the Theis well function and its argument u are also indicated as ‘dimensionless drawdown’ and dimensionless time’.

The colleted data, (Appendix E), was analysed by the WISH and AQUITEST programmes and the results are indicated in Figures 44-71 using the Cooper-Jacob method of confined aquifer and the Theis method respectively for comparison.

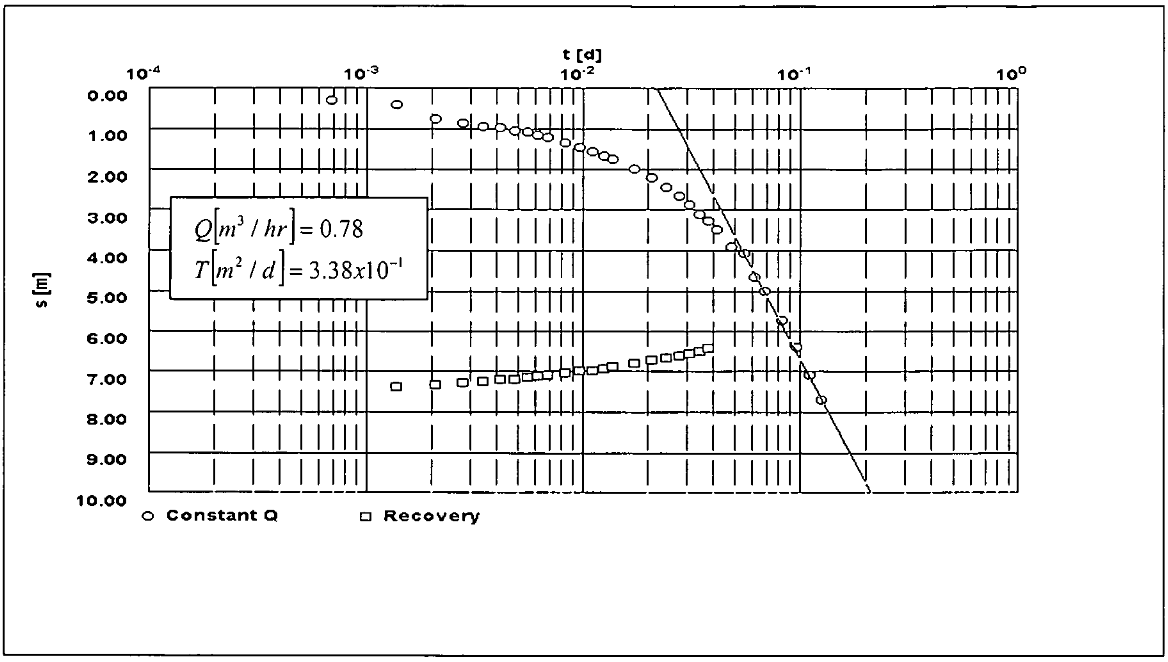


Figure 44. Analysis of pumping test data for borehole DCL1066/DWD14543 using a Time-drawdown method after Cooper-Jacob in Pallisa district.

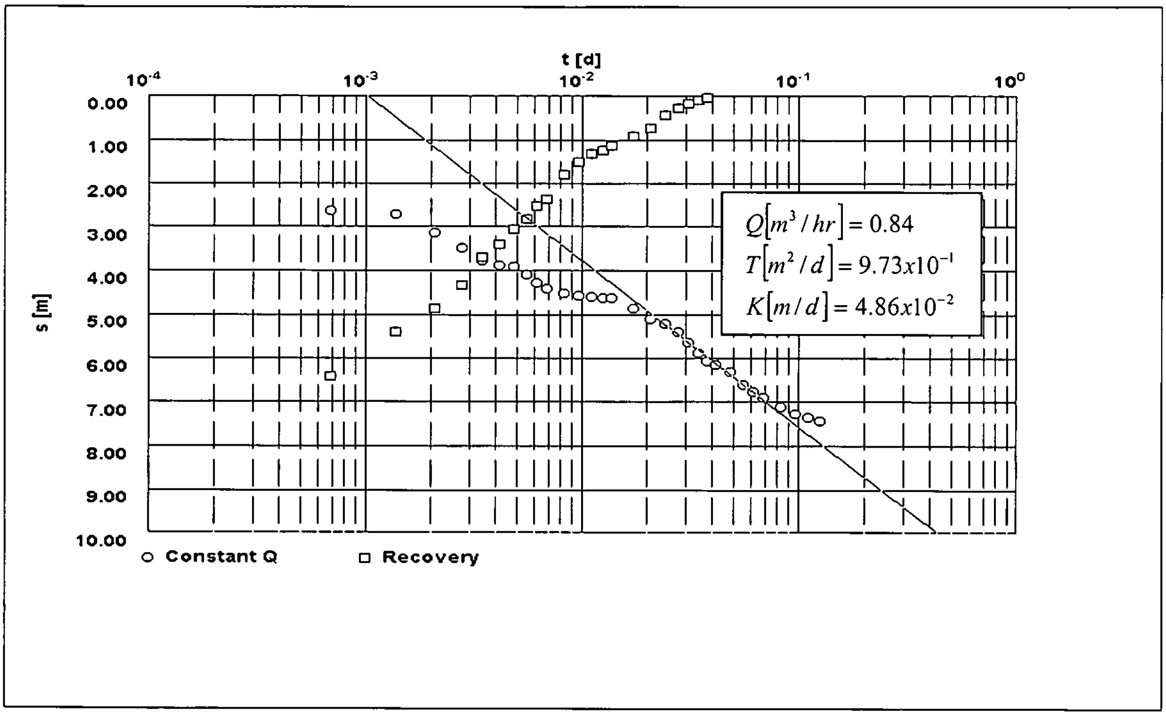


Figure 45. Analysis of pumping test data for borehole DCL1068/DWD14545 using a Time-drawdown method after Cooper-Jacob in Pallisa district.

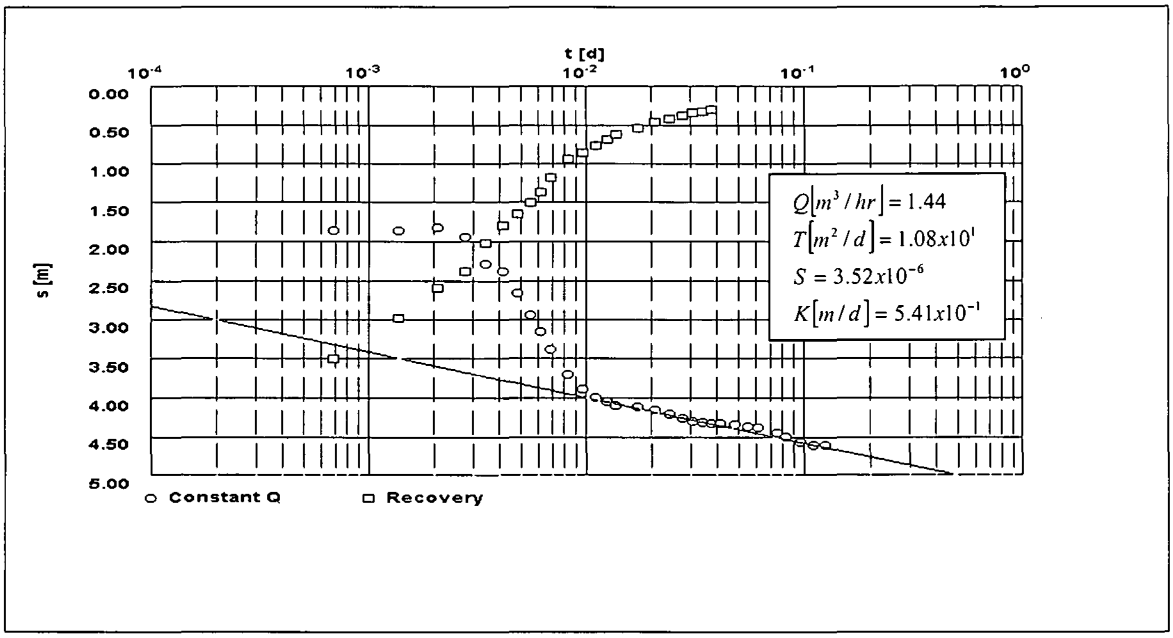


Figure 46. **Analysis of pumping test data for borehole DCL1069/DWD14546 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

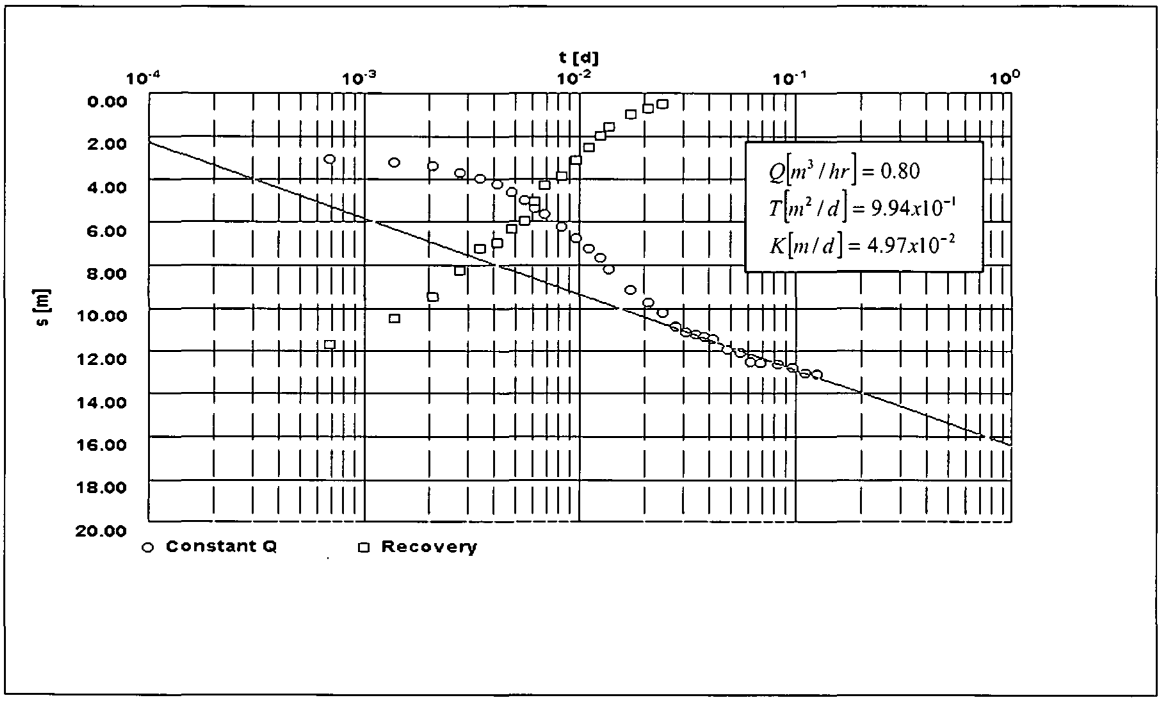


Figure 47. **Analysis of pumping test data for borehole DCL1071/DWD14548 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

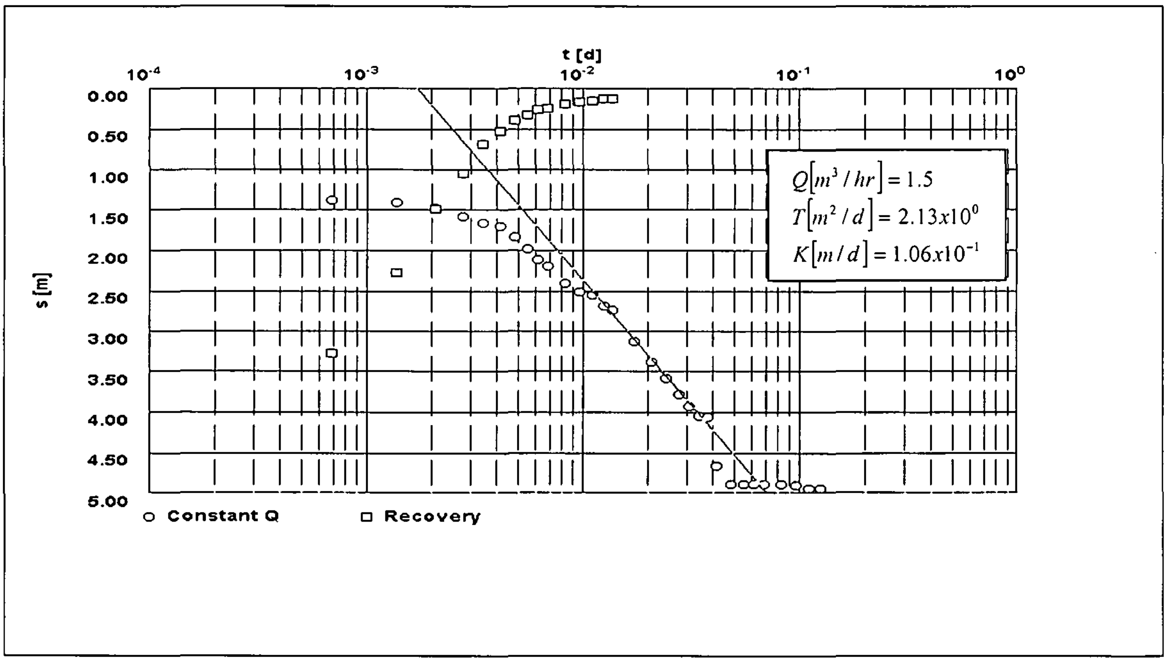


Figure 48. **Analysis of pumping test data for borehole DCL1074/DWD14550 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

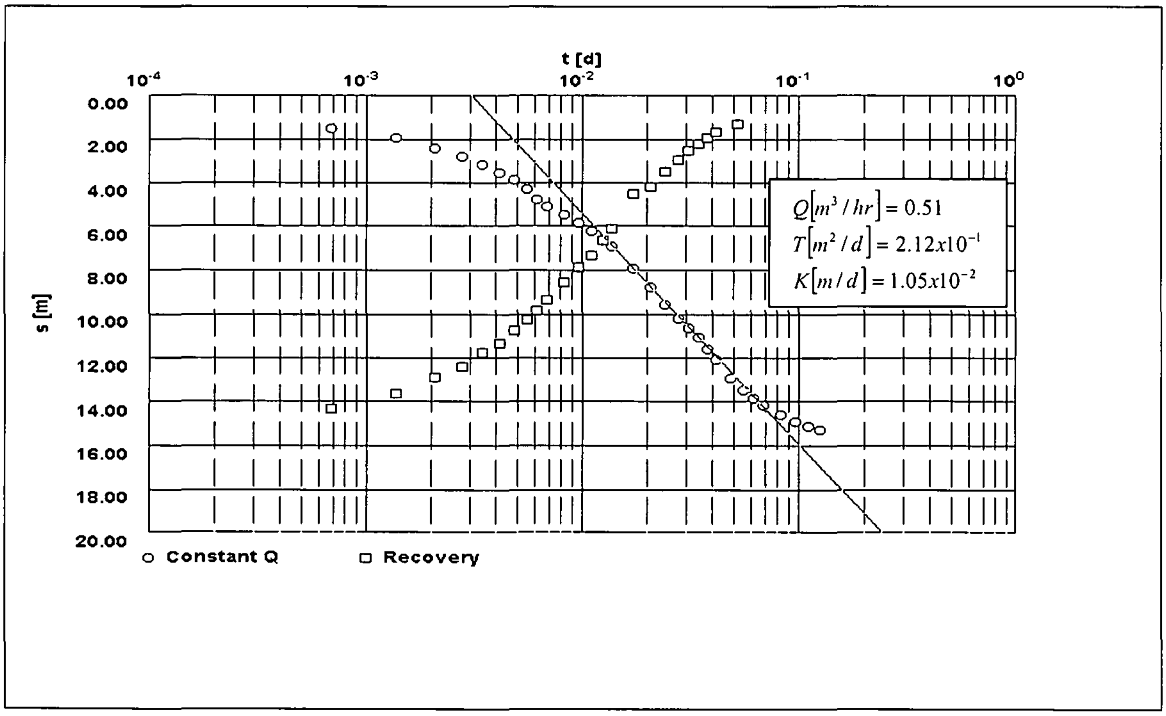


Figure 49. **Analysis of pumping test data for borehole DCL1077/DWD14553 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

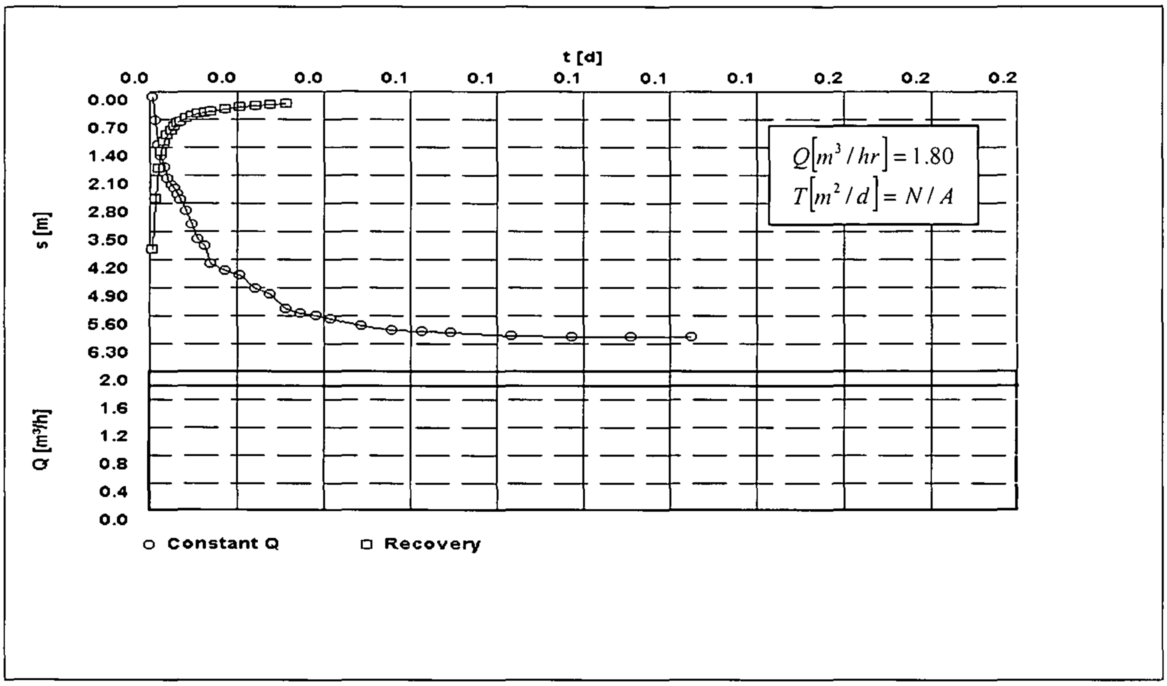


Figure 50. **Analysis of pumping test data for borehole DCL1078/DWD14554 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

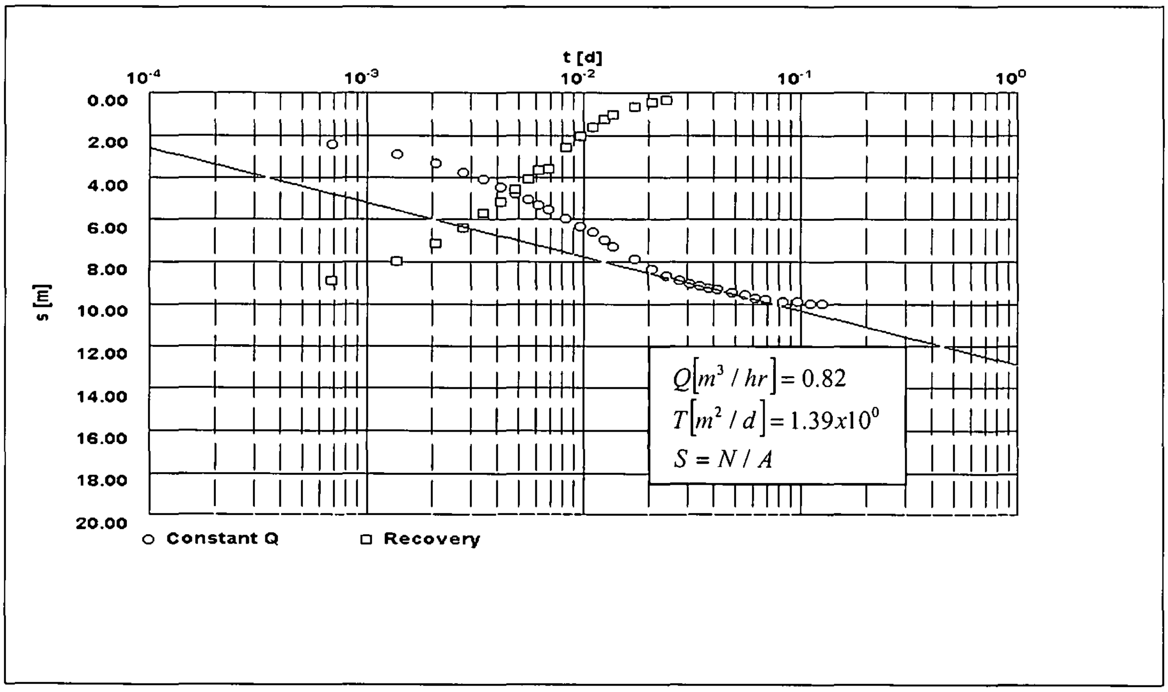


Figure 51. **Analysis of pumping test data for borehole DCL1079/DWD14555 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

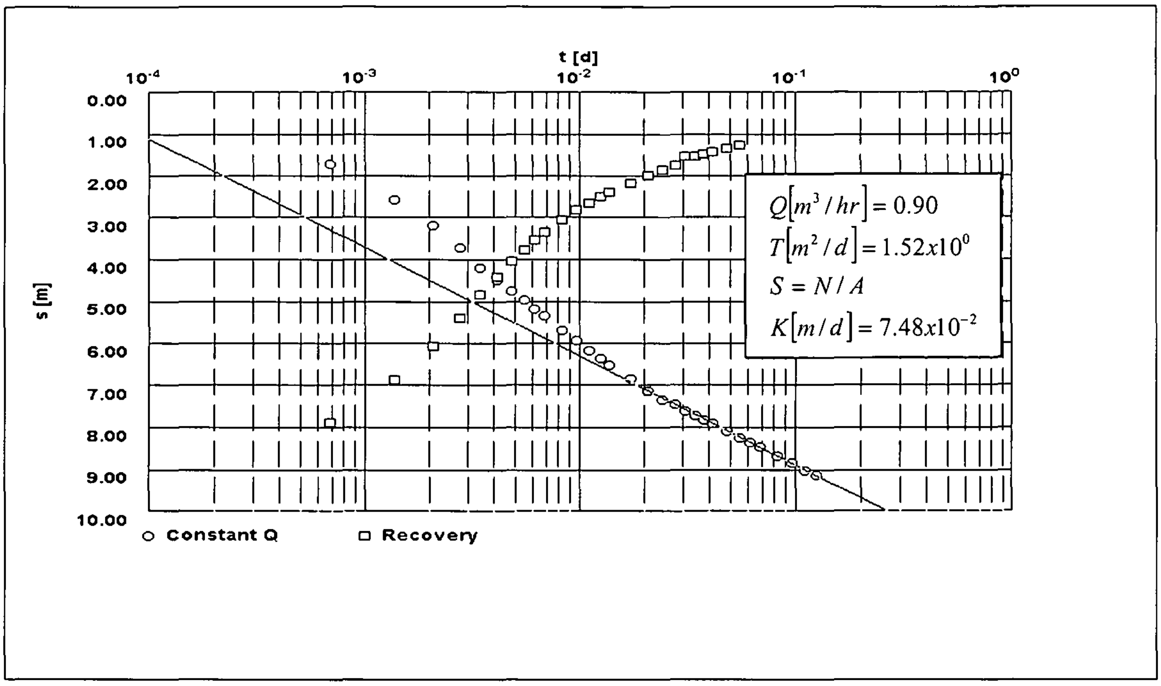


Figure 52. **Analysis of pumping test data for borehole DCL1622/DWD14903 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

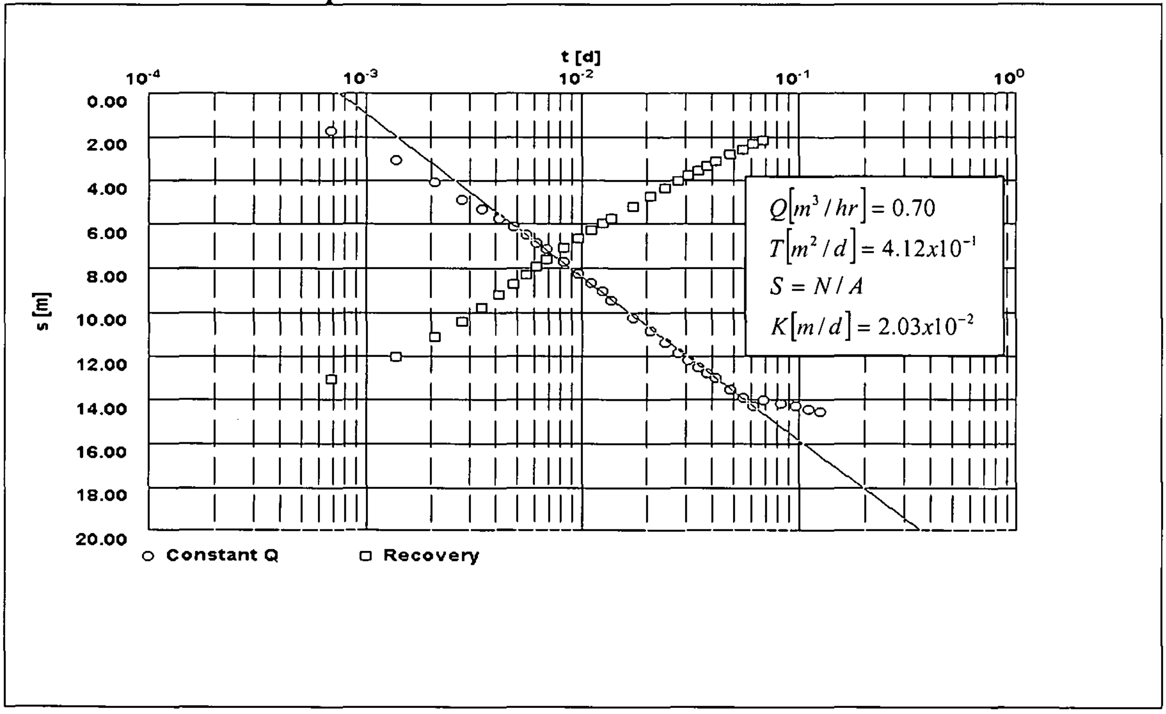


Figure 53. **Analysis of pumping test data for borehole DCL1623/DWD14904 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

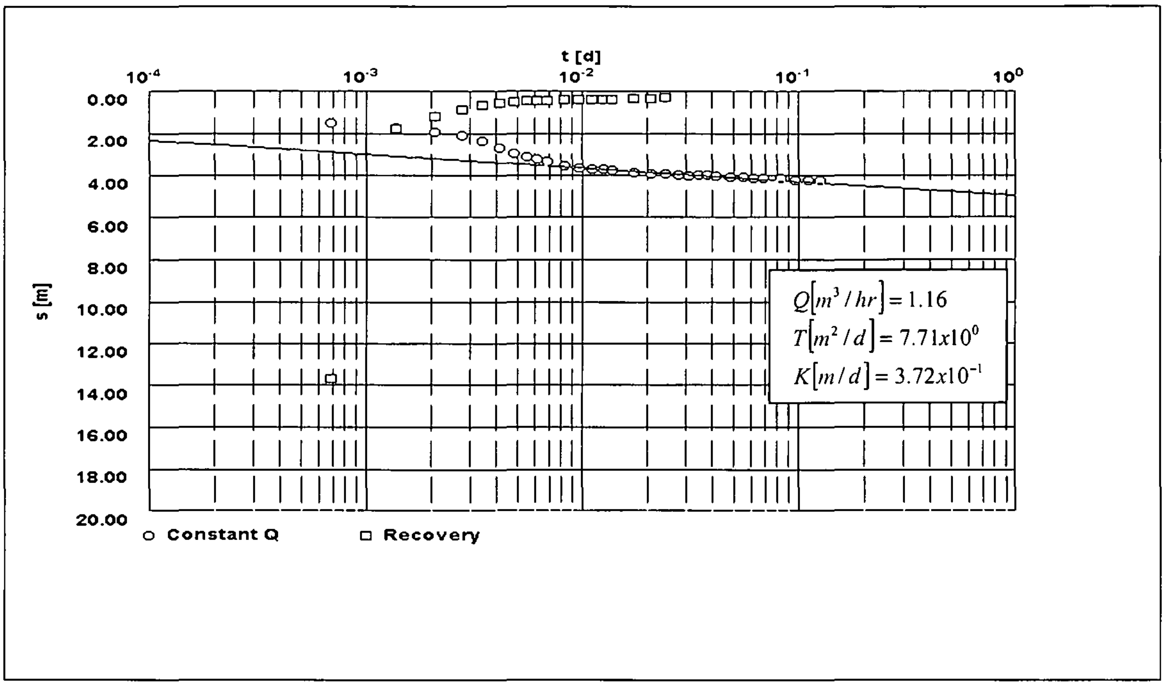


Figure 54. Analysis of pumping test data for borehole DCL1624/DWD14905 using a Time-drawdown method after Cooper-Jacob in Pallisa district.

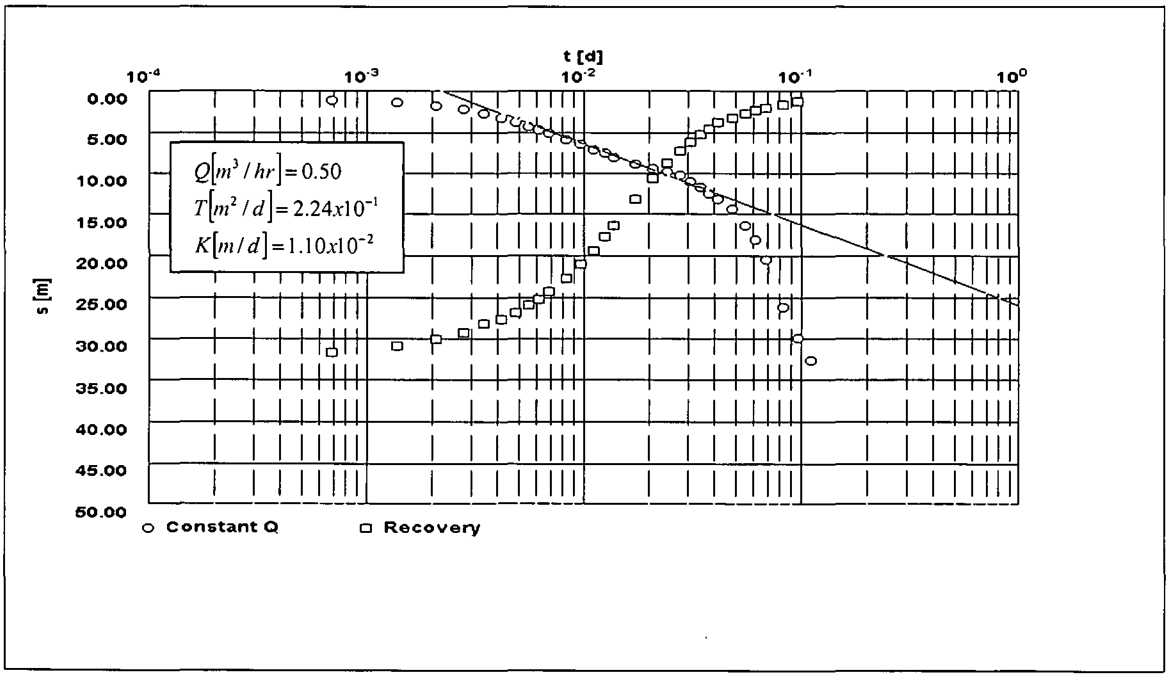


Figure 55. Analysis of pumping test data for borehole DCL1625/DWD14906 using a Time-drawdown method after Cooper-Jacob in Pallisa district.

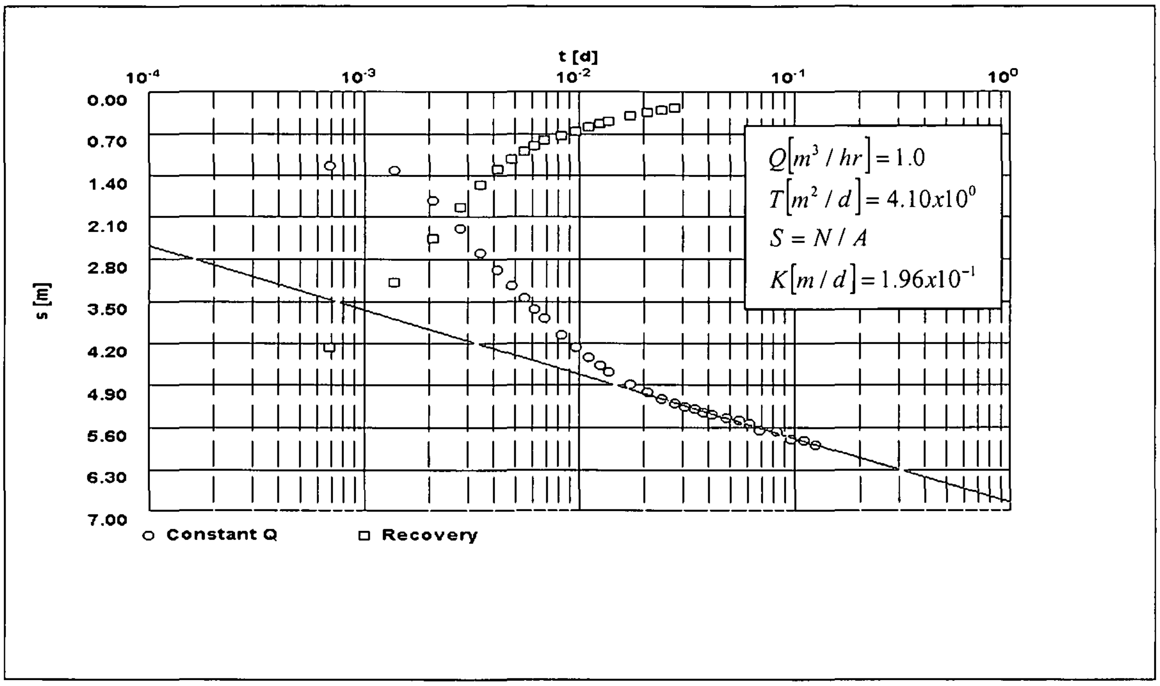


Figure 56. **Analysis of pumping test data for borehole DCL1626/DWD14907 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

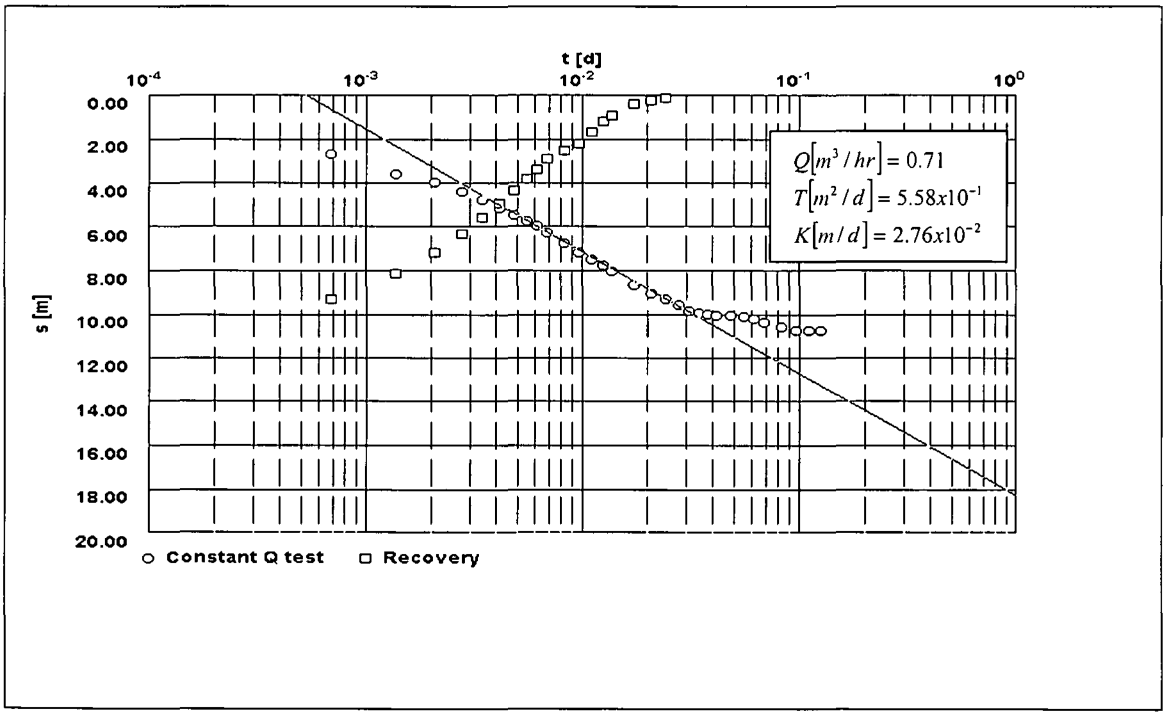


Figure 57. **Analysis of pumping test data for borehole DCL1627/DWD14908 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

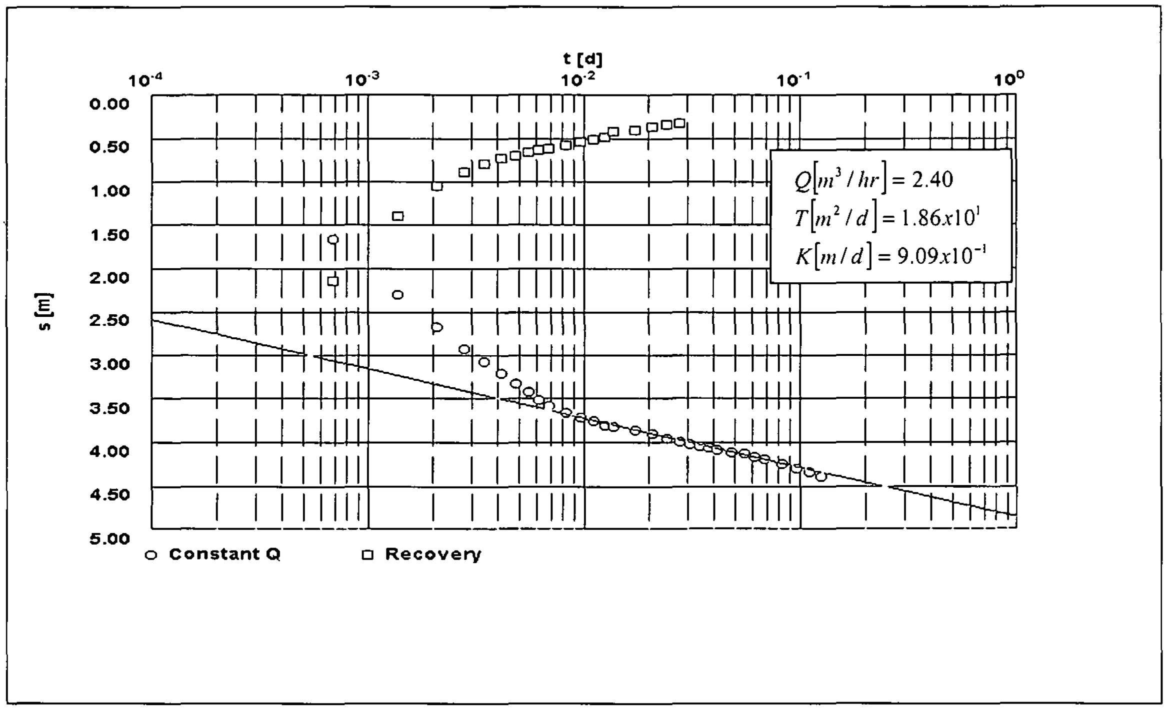


Figure 58. **Analysis of pumping test data for borehole DCL1628/DWD14909 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

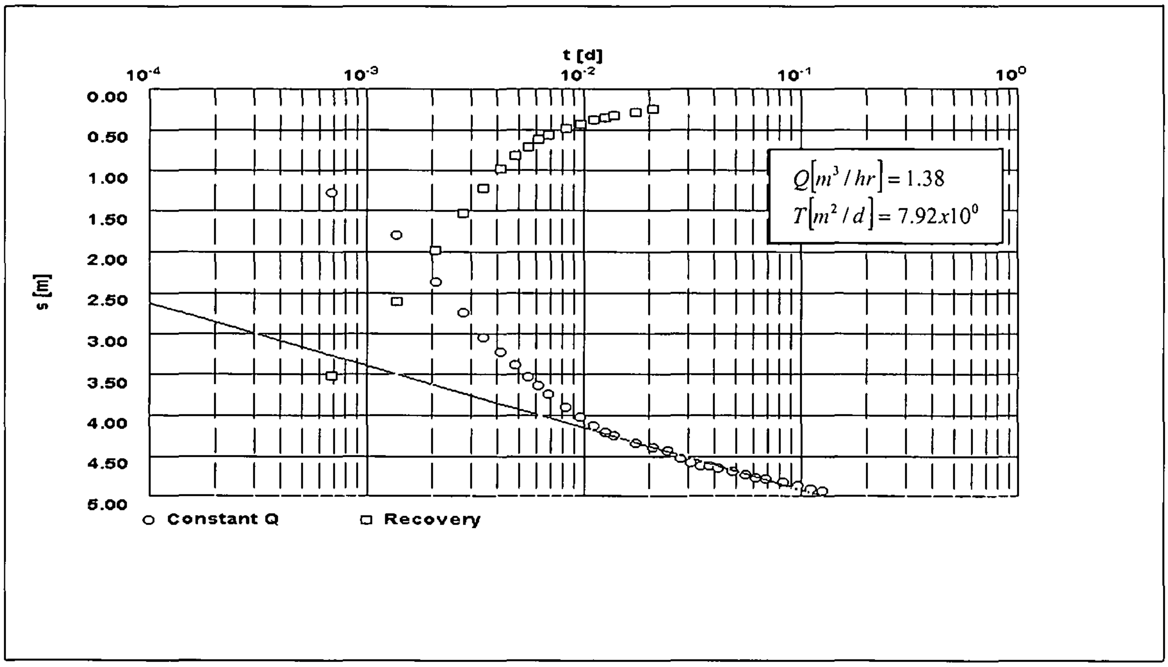


Figure 59. **Analysis of pumping test data for borehole DCL1635/DWD14916 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

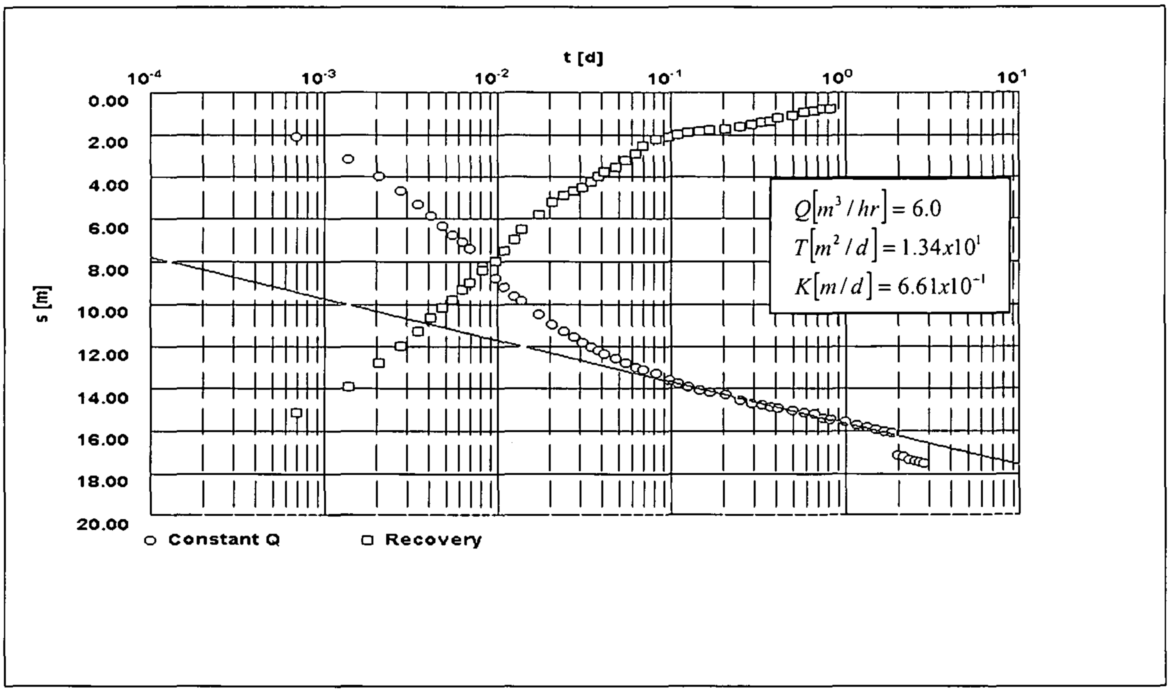


Figure 60. **Analysis of pumping test data for borehole DCL580/DWD13066 using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

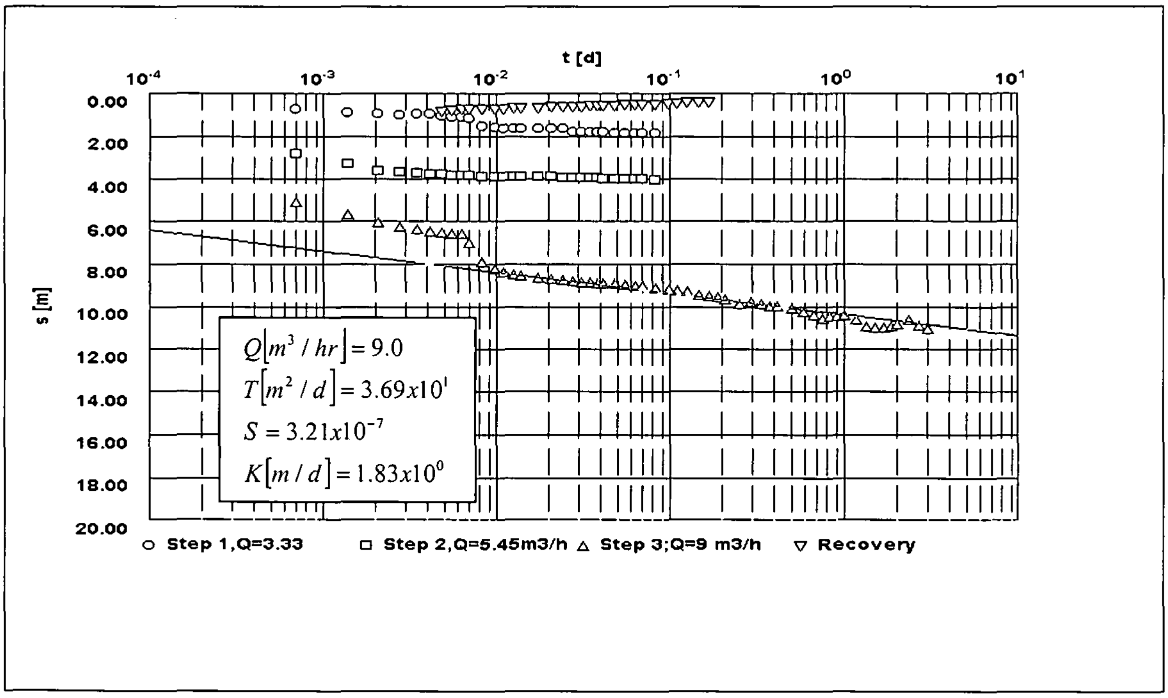


Figure 61. **Analysis of pumping test data for borehole DCL681/DWD using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

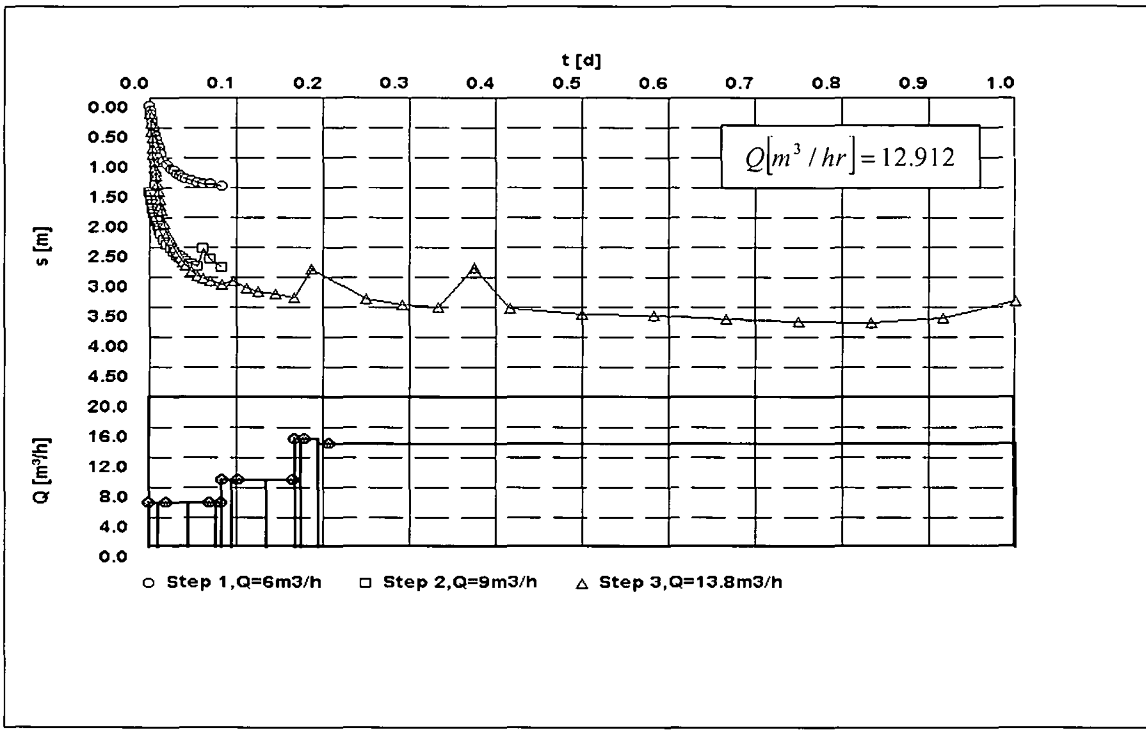


Figure 62. **Analysis of pumping test data for borehole DCL682S1/DWD using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

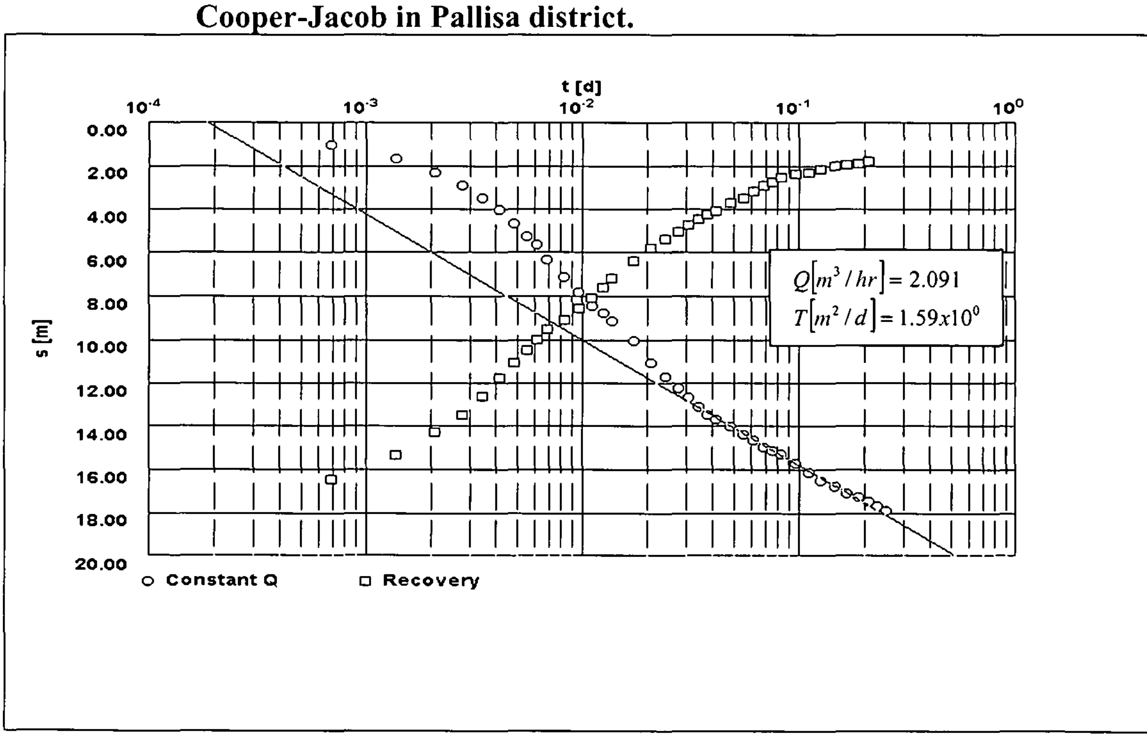


Figure 63. **Analysis of pumping test data for borehole DCL684C/DWD using a Time-drawdown method after Cooper-Jacob in Pallisa district.**

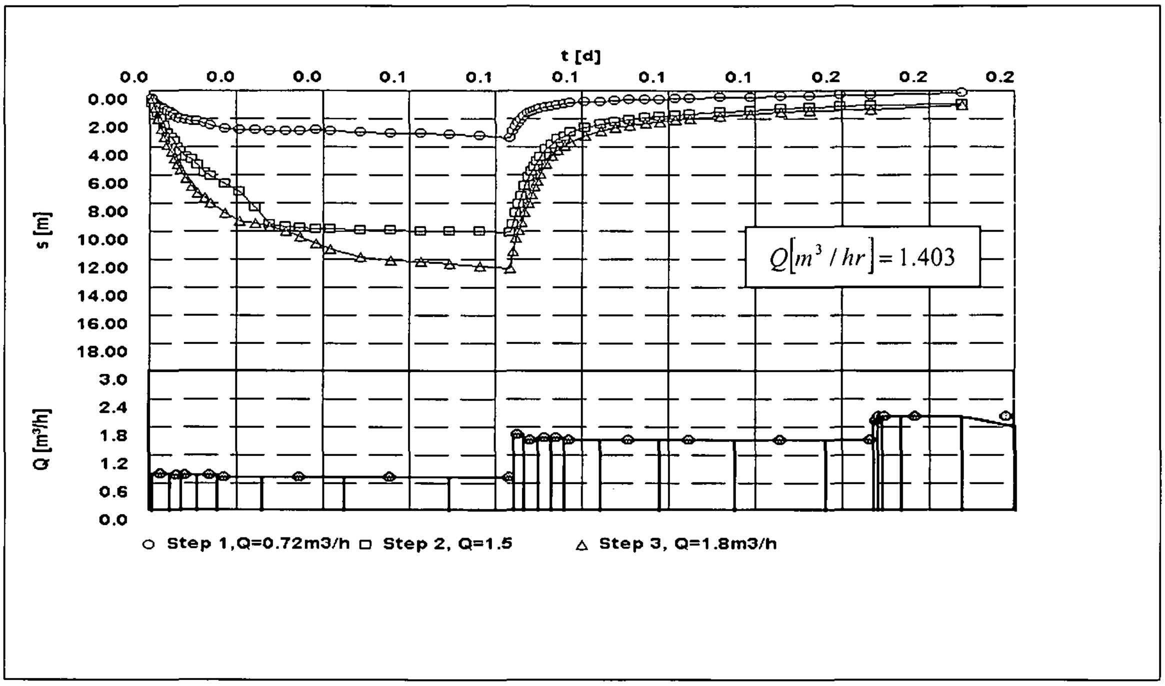


Figure 64. Analysis of pumping test data for borehole DCL684C1/DWD using a Time-drawdown method after Cooper-Jacob in Pallisa district.

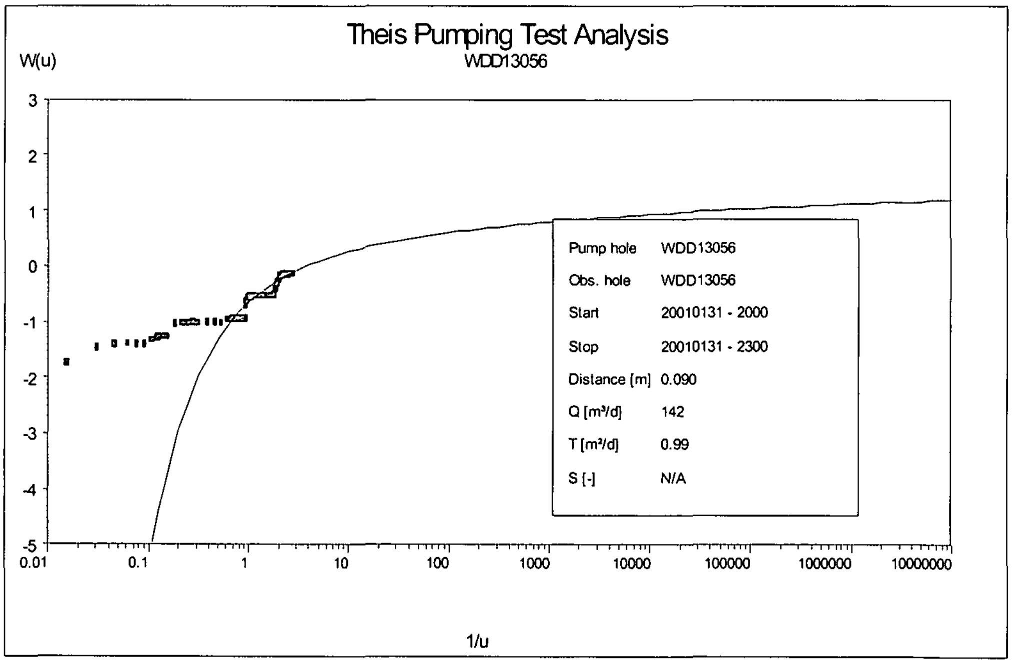


Figure 65. Analysis of data from pumping test of borehole WDD13056 by Theis Method.

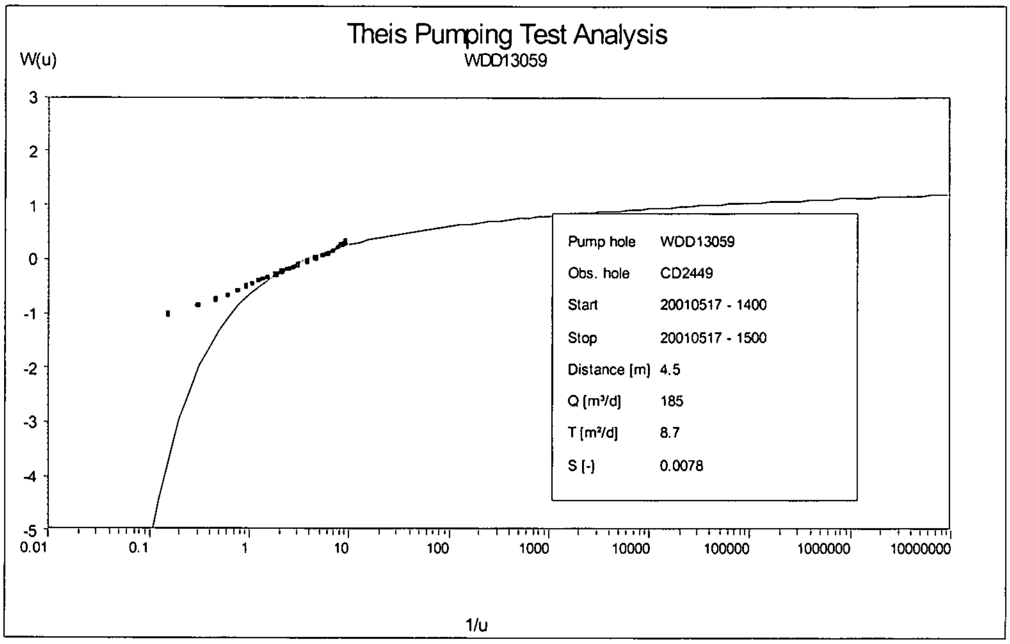


Figure 66. **Analysis of data from pumping test of borehole WDD13059 by Theis Method.**

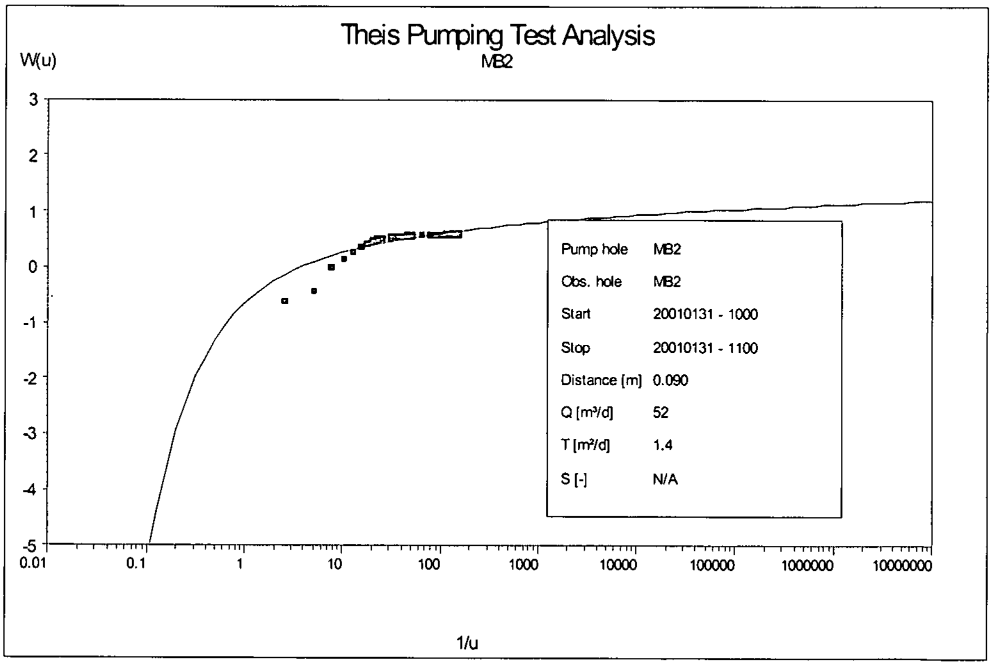


Figure 67. **Analysis of data from pumping test of borehole MB2 by Theis Method.**

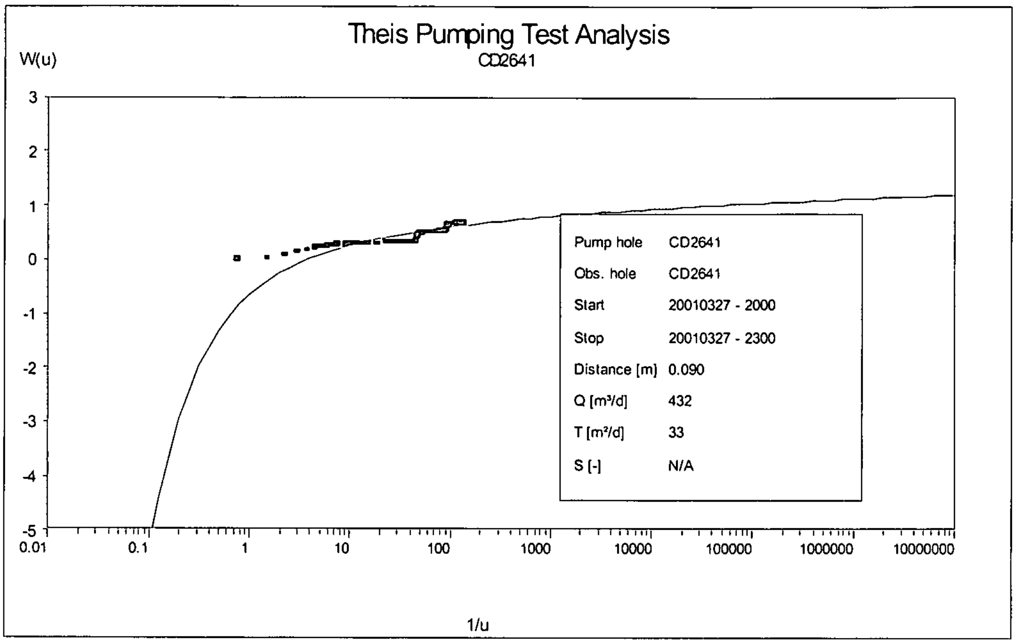


Figure 68. Analysis of data from pumping test of borehole CD2641 by Theis Method.

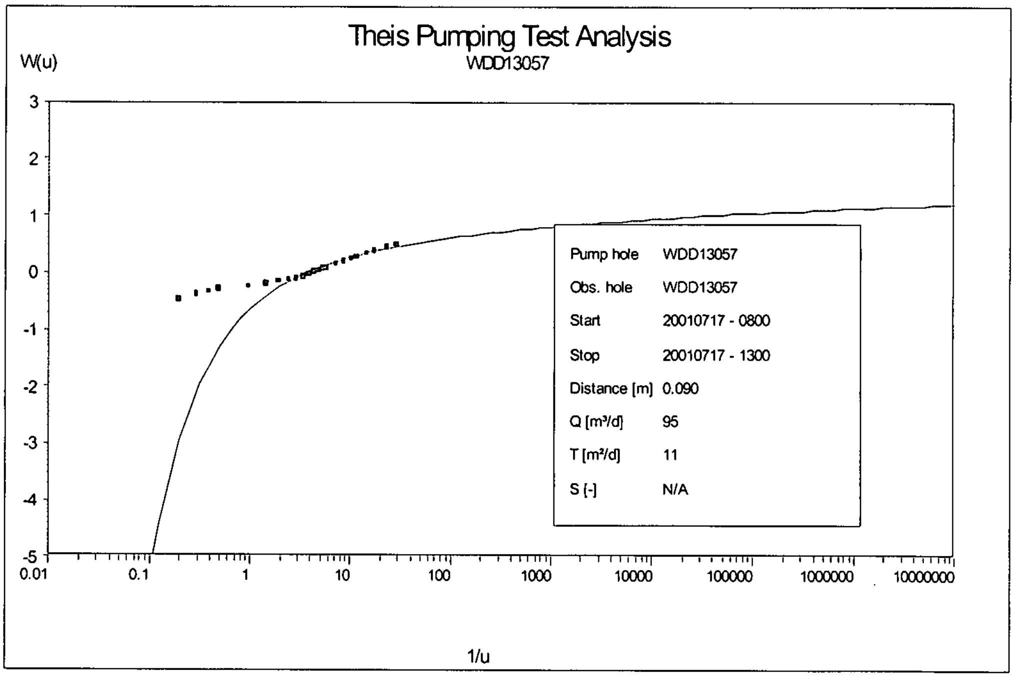


Figure 69. Analysis of data from pumping test of borehole WDD13057 by Theis Method.

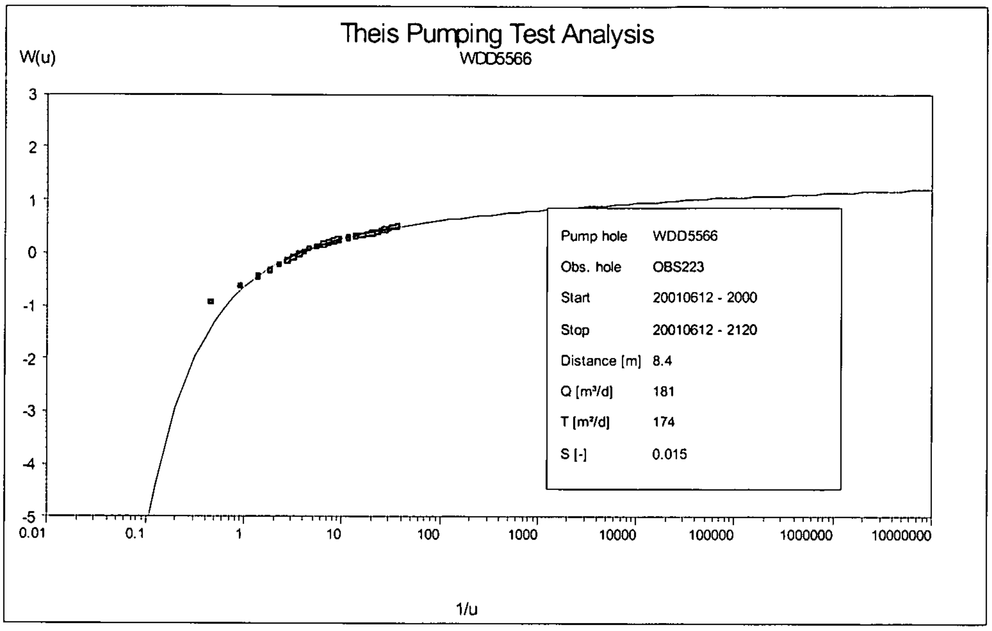


Figure 70. **Analysis of data from pumping test of borehole WDD5566 by Theis Method.**

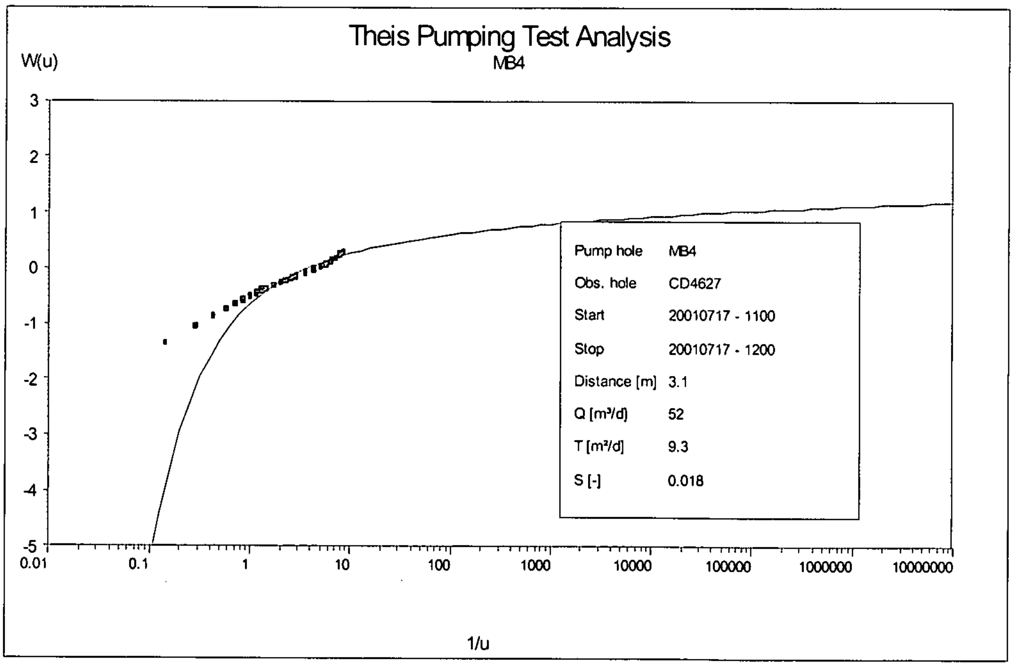


Figure 71. **Analysis of data from pumping test of borehole MB4 by Theis Method.**

Table 7. Pumping test results of the production boreholes.

Borehole	Pumping Test Results				Specific Capacity at 1 hour.	Transmissivity
	Duration Hours	Yield m^3/h	Draw-down 1 hour	Draw-down Full time.	$m^3/h/m$	m^2/s
WDD 13056	72	9.0	8.9	11.04	1.01	3.60×10^{-3}
WDD 13057	72	20.0	6.27	8.47	3.19	4.10×10^{-3}
WDD 13059	72	2.0	13.72	17.91	0.15	3.10×10^{-3}

Table 8. Well efficiency results of boreholes.

Boreholes	**WDD 13056**	**WDD 13057**	**WDD 13059**
Well Efficiency (%)	80	84	100

The well efficiency describes the percentage of pressure loss occurring in the aquifer. A low well efficiency indicates a non-optimal borehole construction.

The transmissivity have been calculated by the use of Theis and Cooper-Jacob (Appendix D); however, the Theis estimates do not include the hydrologic boundaries or non-isotropic aquifers, which are likely to be the case in fractured media. However, the transmissivities have been calculated to provide some parameters for comparison of the wells.

For the two potential production boreholes WDD13056 and WDD13057, the drawdown after one year of continuous pumping has been calculated to evaluate the potential of the resource. This is by using the Theis formula of incorporating the well efficiency.

The drawdown calculated can only be considered as a rough indication; the real drawdown can be either larger or smaller.

Table 9. Drawdown in potential boreholes.

Borehole	Static water level, m	Estimated yield m^3/h	Drawdown 1 year	Water level 1 year
WDD13056	9.81	5.0	13.2	23.0
WDD13057	9.22	15.0	4.5	13.7

For WDD 13056 an estimated yield of 5.0 m^3/h causes a drawdown beyond the top of the screen, however, regarding the pumping test curves there is a significant difference between the curves for the yield of 5.45 m^3/h and for 9.0 m^3/h. It seems as if using 9.0 m^3/h is over pumping of the well. Pumping with 5.0 m^3/h the propagation of the curve shows no problems in relation with the screen.

For WDD13057, an estimated yield of 15.0 m^3/h causes a drawdown at only 4.5 m. However, from the long duration-pumping test it is clear that full leakage is obtained. This occurs after 18 hours of pumping, hereafter the drawdown is stable for the remaining 54 hours.

Table 10. Results of pumping test analysis for some boreholes in Pallisa.

PUMPING TEST RESULTS AFTER COOPER-JACOB USING THE AQUITEST PROGRAMME

Well	Discharge		Transmissivity	Storativity
	(m^3/h)	(L/s)	(m^2/d)	
DCL1066/DWD14543	0.780	0.22	3.43×10^{-1}	-
DCL1068/DWD14545	0.840	0.23	9.73×10^{-1}	-
DCL1069/DWD14546	1.440	0.40	1.08×10^{1}	3.52×10^{-6}
DCL1071/DWD14548	0.800	0.22	9.94×10^{-1}	-
DCL1074/DWD14550	1.500	0.42	2.13×10^{0}	-
DCL1077/DWD14553	0.510	0.14	2.12×10^{-1}	-
DCL1078/DWD14554	1.800	0.50	-	-
DCL1079/DWD14555	0.820	0.23	1.39×10^{0}	-
DCL1622/DWD14903	0.900	0.25	1.52×10^{0}	-
DCL1623/DWD14904	0.700	0.19	4.12×10^{-1}	-
DCL1624/DWD14905	1.160	0.32	7.71×10^{0}	-
DCL1625/DWD14906	0.500	0.14	2.24×10^{-1}	-
DCL1626/DWD14907	1.000	0.28	4.10×10^{0}	-
DCL1627/DWD14908	0.710	0.20	5.58×10^{-1}	-
DCL1628/DWD14909	2.400	0.67	1.86×10^{1}	-
DCL1629/DWD14910	0.500	0.14	1.50×10^{-1}	-
DCL1631/DWD14912	0.680	0.19	4.92×10^{-1}	-
DCL1634/DWD14915	2.770	0.77	1.86×10^{1}	-
DCL1635/DWD14913	1.380	0.38	7.92×10^{0}	-
DCL1636/DWD14917	10.290	2.86	2.29×10^{1}	-
DCL1637/DWD14918	10.000	2.78	2.54×10^{1}	-
DCL1638/DWD14919	0.620	0.17	1.95×10^{-1}	-
DCL1639/DWD14920	1.330	0.37	1.87×10^{0}	-
DCL1640/DWD14921	1.330	0.37	1.38×10^{0}	9.32×10^{-1}
DCL579/DWD13065	0.750	0.21	9.08×10^{-2}	-
DCL580/DWD13066	6.000	1.67	1.34×10^{1}	-
DCL681	8.365	2.32	3.69×10^{1}	3.21×10^{-7}
DCL682 C	19.990	5.55	3.72×10^{-2}	6.08×10^{-2}
DCL682 C_1	13.865	3.85	1.18×10^{2}	-
DCL682 S_1	12.912	3.59	-	-
DCL684C	2.091	0.58	1.59×10^{0}	-
DCL684C_1	1.403	0.39	-	-

PUMPING TEST RESULTS AFTER COOPER-JACOB USING THE WISH PROGRAMME

Well	Q(m^3/d)	Q(m^3/h)	(L/s)	Transmissivity (m^2/d)	Storativity
WDD13056	142	5.921	1.669	9.90×10^{-1}	-
WDD13059	185	7.708	2.174	3.8×10^{0}	7.2×10^{-3}
MB2	52	2.167	0.611	8.5×10^{0}	-
CD2641	432	18.014	5.076	3.3×10^{0}	-
WDD13057	95	3.958	1.116	8.8×10^{0}	-
WDD5566	181	7.530	2.127	1.31×10^{2}	2.2×10^{-2}
MB4	52	2.167	0.611	4.3×10^{0}	1.6×10^{-2}

5.5.3 DISCUSSION ON AQUIFER PROPERTIES

The results analysed from the pumping test data not only allowed to obtain transmissivity (T), hydraulic conductivities (K) and storativity (S) values (Table 10), but to also make more general conclusions on the properties of the Kyoga catchment where Pallisa district falls.

a. Generally, the transmissivity of water-conducting crystalline rocks in Pallisa district varies widely from 0.15 m^2/d to more than 131 m^2/d. Nevertheless approximately 75% of rocks (73-82%) are characterised by $T<10$ m^2/d, and 30% (23-37%) of rocks have a transmissivity less than $T<131$ m^2/d. Hence, half of the tested aquifers may be characterised by transmissivity of limited values between 10 m^2/d and 131 m^2/d.
b. Higher transmissivity values in the crystalline rock aquifer are related to the western and north – western of Pallisa district, $T_{50\%} = 13.5$ m^2/d, due to the presence of open waters of Lake Kyoga, Mpologoma and Dodoi rivers. Such transmissivity values typically correspond to drawdowns in order of a few meters at pumping yields of about 1 m^3/h.
c. Generally, about 20% (7 out of 40) of all the boreholes tested indicated a small storage capacity of the aquifer with values ranging from 3.0×10^{-7} to 6.1×10^{-2}, which is characteristic of fractured rock aquifers. The remaining 80% did not indicate the capacity to store groundwater meaning that the aquifer is comparatively low yielding with a limited areal extent and poor hydraulic characteristics.
d. There is a significant relationship between transmissivity and the depth of occurrence of groundwater in Pallisa district. The permeability of water-conducting strata demonstrates a consistent increase with depth (see pumping test data sheets - Appendix F), which is particularly significant within the first 30 m and the next 40 m. This in general reflects the depth of most crystalline rock weathering.
e. However, on analysis, it is found out that the average abstraction rate computed for each of these tested boreholes would be 3.43 m^3/h. This is

quite a representative figure and conforms to the suggested average yield in the range of 1-4 m^3/h for eastern parts of Uganda (Uganda Water Action Plan-Doc.007, 1995).

f. Looking at the recovery data on the different graph results above, there is an indication that groundwater in the study area move through the interstices very fast when pumping is stopped.

The data from all these wells were selected, analysed and evaluated to determine the properties of the aquifer, but there were no observation wells when the wells were being test pumped. It was therefore assumed that there were observation wells located at an infinitesimal distance of 0.001 m from the pumping well. In some instances it could not give a clue to the responses of the neighbouring wells to be pumped.

5.5.4 IMPLICATIONS OF THE RESULTS

An approach to aquifer transmissivity assessment described in this study may be considered as a tool for regional aquifer characterisation on the basis of the available hydrogeological data, and transmissivity and storage values could provide additional information toward existing Ugandan aquifer classification.

These data may be used for different regional groundwater programmes and planning operations which require rock permeability assessment and approximate hydrogeological estimation, for instance: (i) planning a programme of groundwater tests, (ii) approach to environmental impact assessment and, (iii) design of ground water monitoring programmes.

In addition, T and S data may be inserted into an aquifer protection scheme, when in addition to the existing scheme the distribution of pollutants within an aquifer might be considered on a regional scale.

5.6 WATER QUALITY OF BOREHOLES

5.6.1 INTRODUCTION

The quality of groundwater source is not the only factor contributing to disease prevention. The magnitude and reliability of the groundwater supply must also be considered since failure of a safe groundwater source to meet the daily water requirements of the users throughout the year would force them to seek other sources. As a result, the health benefits gained from the periodic use of safe water supply would be either reduced or eliminated. The monitoring of water quality and pollution of groundwater has been put in place (Figure 89).

Recent developmental efforts in Uganda by the Water Resources Management, Entebbe in conjunction with agencies as DANIDA, Water Aid and UNICEF have focused on the regolith in preference to the bedrock that has traditionally been harnessed

5.6.2 ANALYSIS AND EVALUATION OF WATER SAMPLES

Hydro-chemical evaluation of groundwater from the regolith and basement aquifers were undertaken in Pallisa district, and the groundwater samples analysed for minor and major elements. This was to enable the quality of groundwater presently being pumped from the fractured bedrock aquifer to be compared to the quality of water that could be expected from the development of the regolith aquifer.
Water samples were collected at the end of the test pumping and analysed at the water quality and pollution control laboratory at Entebbe. However, water quality defined in terms of aesthetic and health-related guidelines furnished by the World Health Organisation (WHO, 1984) were compared to the values obtained from the boreholes drilled in eastern Ugandan.
The results of the analyses are given in the Table 11.

Table 11. Average values for water quality parameters from dug wells, protected springs and boreholes in Pallisa district. Source: RUWASA in eastern Uganda.

PARAMETR	AVERAGE DUG WELLS (Nos. = 24)	AVERAGE PROTECTED SPRINGS (Nos. =28)	AVERAGE BOREHOLES (Nos. = 38)	WHO 1984 GUIDELINES
PH	6.8	5.8	6.7	6.5-8.5
Conductivity, µS/cm	390	113	737	-
Total iron, mg/l $Fe^{2+} + Fe^{3+}$	**0.5**	0.3	**0.8**	0.3
Manganese, mg/l Mn^{2+}	0.10	0.05	0.07	0.1
Alkalinity, mg/l $CaCo_3$	119.5	38.8	186.1	-
T-Hardness, mg/l $CaCo_3$	124.6	48.4	229.8	500
Calcium, mg/l Ca^{2+}	41.0	20.7	94.1	-
Magnesiun, mg/l Mg^{2+}	9.1	5.2	22.1	-
Bicarbonate, mg/l HCO_3	140.5	51.1	216.3	-
Carbon dioxide, mg/l CO_3	97.5	126.5	165.6	-
Sodium, mg/l Na^+	25.3	6.4	60.6	200
Potassium, mg/l K^+	5.6	1.6	5.1	-
Chloride, mg/l Cl-	22.1	9.3	73.4	250
Sulphate, mg/l SO_4^{2-}	27.8	12.8	57.5	400
Phosphate, mg/l PO_4^{2-}	1.3	0.4	0.8	-
Nitrate, mg/l NO_3^-	2.2	2.6	3.7	10
Fluoride, mg/l F^-	0.7	0.14	0.8	1.5
TAlk, mg/l	186	173	211	-
% Water points with E.Coli count > 0	34	13	5	0
Aluminum, mg/l	**0.46**	**0.35**	**0.5**	0.2
Turbidity, NTU	0.8	0.15	0.39	5
TDS, mg/l	460	350	375	1000

The figures in bold indicate the value not in accordance with WHO guidelines. From Table 11, some of the parameters were not analyzed despite being required. This is mainly due to the lack of capacity of the laboratory to analyse all parameters.

The average parameter values for different categories of water points (dug wells, protected springs and boreholes) have been compiled in Table 11. Significant differences clearly emerge reflecting the variations in both construction mode and geological environment. From Table 11, it appears that the boreholes show the lowest frequency of bacteriological (E.Coli) contamination and dug wells the highest. This is clearly caused by the difficulties in construction and maintenance of proper sealing on large diameter dug wells, whereby seepage of surface water into the wells may occur. Boreholes on the other hand are sealed with cement or bentonite and further more backfilled.

In terms of organic chemistry, it is interesting to note that conductivity values (and thus degree of mineralisation) are significantly lower for springs than for dug wells which in turn are clearly lower than boreholes. This is explained by the fact that spring water trajectories have been intensively leached through many years of flow whereby the water in these aquifers shows relatively manor enrichment in organic substances. Spring water clearly show the lowest PH values, which again demonstrates that water, in spite of the low PH, has caused limited decomposition of aquifer minerals.

Boreholes on the other hand, clearly show the highest degree of mineralisation with relative enrichment of nearly all tested elements. This is due to the ability of aggressive groundwater to decompose the relatively fresh minerals in the bedrock fractures. Water from dug wells show an immediate enrichment in organic constituents, in accordance with the aquifers' geological setting.

The general picture described above does not apply to nitrates. This shows that other than geological factors influence the nitrate concentrations. The nitrate values are determined by the contents of infiltration of water, which reflects the nitrate concentrations in rainwater and the nitrate load produced by humans and livestock.

The Figures 72, 73, 74, 75, 76 and 77 show the chemistry composition of some of the drilled boreholes in Pallisa district. The water quality in almost all the boreholes in Pallisa district is safe for drinking purposes.

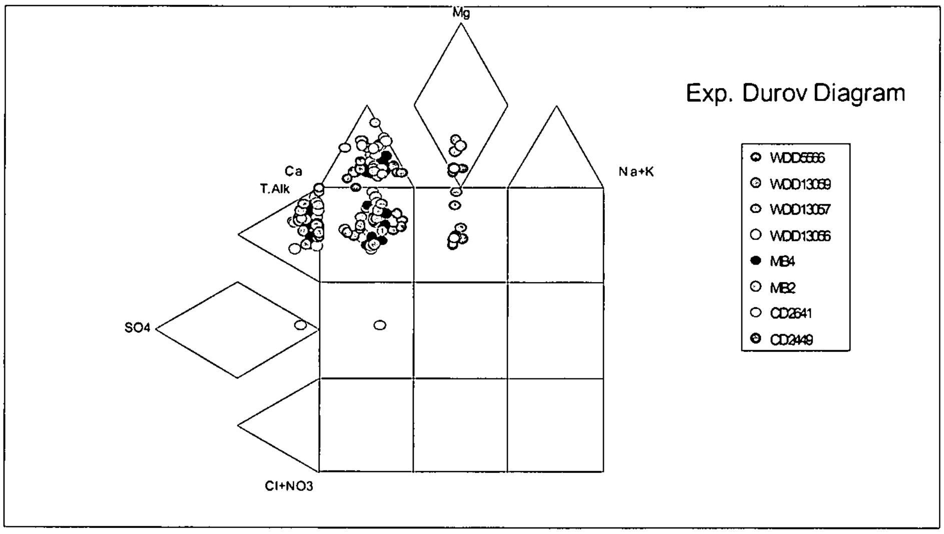


Figure 72. Concentrations of different ions in the expanded durov of all the boreholes drilled in Pallisa.

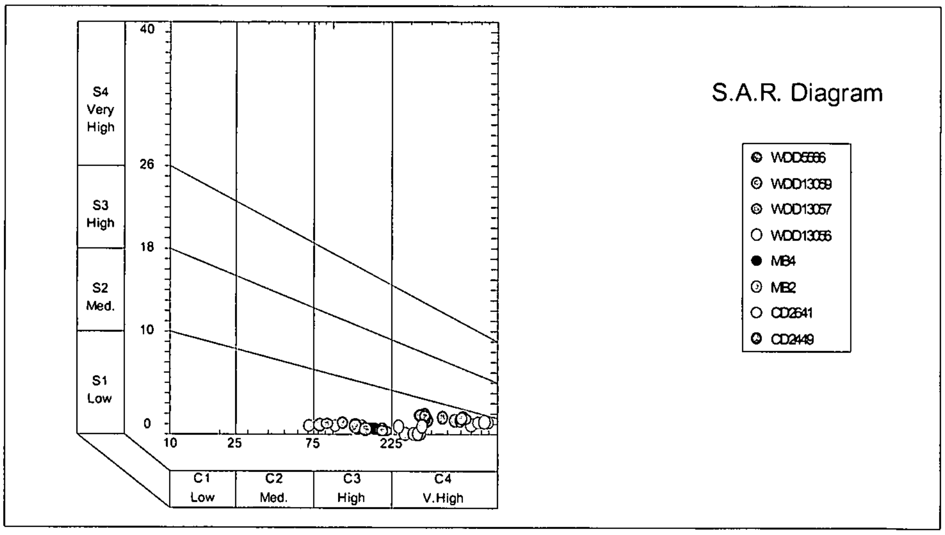


Figure 73. Hydrograph of sodium adsorption ratio to conductivity in µS/cm.

Figure 73 shows the salinisation of the boreholes shown is generally very low, but the sampling points on the right of the diagram has a very high electrical conductivity as one moves away from River Mpologoma (See the position of borehole CD2641). The decrease in salinity may be due to dilution along or near the Mpologoma River.

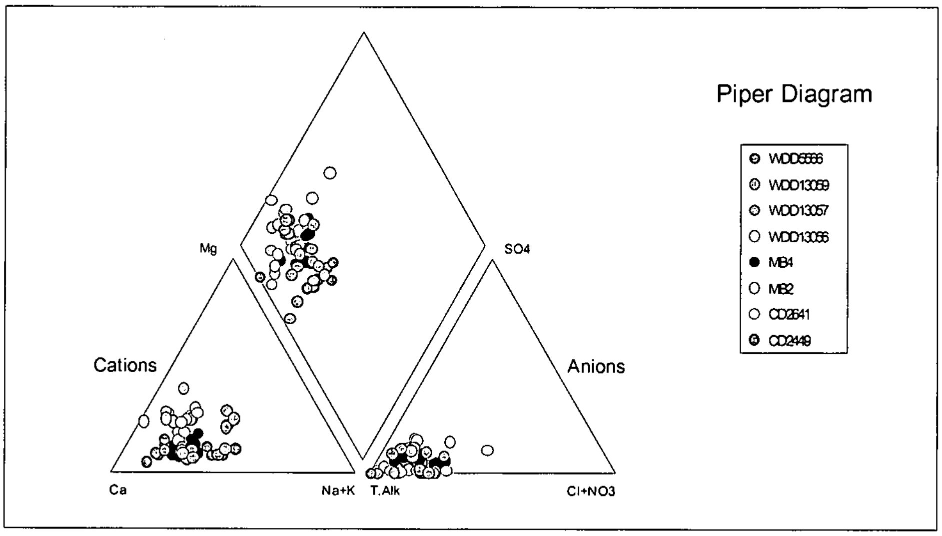


Figure 74. **Piper diagram of groundwater from the boreholes in Pallisa, lying in both the regolith and the basement complex (bedrock).**

5.6.3 DISCUSSION

Figures 72, 73 and 74 show Piper, Hydrograph and Durov plots of boreholes situated in both the regolith and the basement complex (bed rock) of Pallisa district. Looking at the Figures 72 and 74, it can be observed that the boreholes situated in these aquifers of Pallisa represent a regime where there is calcium enrichment, which is typical of lime dosing to neutralize acid waters. In the Piper diagram, plot of water contains approximately 70% Ca, 70% Mg, 80% TAlk, 10% Cl and 10% SO_4. This is typical of calcium/magnesium bicarbonate waters. So both the regolith and bedrock groundwaters are dominated by the carbonate ions. All in all the groundwaters in Pallisa district are unpolluted and therefore generally suitable for drinking except for few areas with high concentration of iron. Although water rock interactions in both aquifer units may lead to parallel geochemical evolution of groundwater, the data at least do not deny a hydraulic connection. It is known with the exception to correlation is aluminum. Higher concentrations of aluminum are observed in the regolith while low levels in the bedrock. The significantly lower level of aluminum in the bedrock aquifer appears to provide further support for the notion of relatively limited hydraulic interaction between the two units.

For example, given that the higher levels of aluminum are the product of highly active weathering in the regolith, it would seem that the bedrock aquifers receives recharge primarily in areas where the aquifer units are sufficiently linked to allow the water to move through the regolith and into the bedrock with minimal geo-chemical interaction. Where hydraulic interaction is poorly developed, the groundwater will tend to remain in the regolith and the geo-chemical weathering is able to proceed without inhibition.

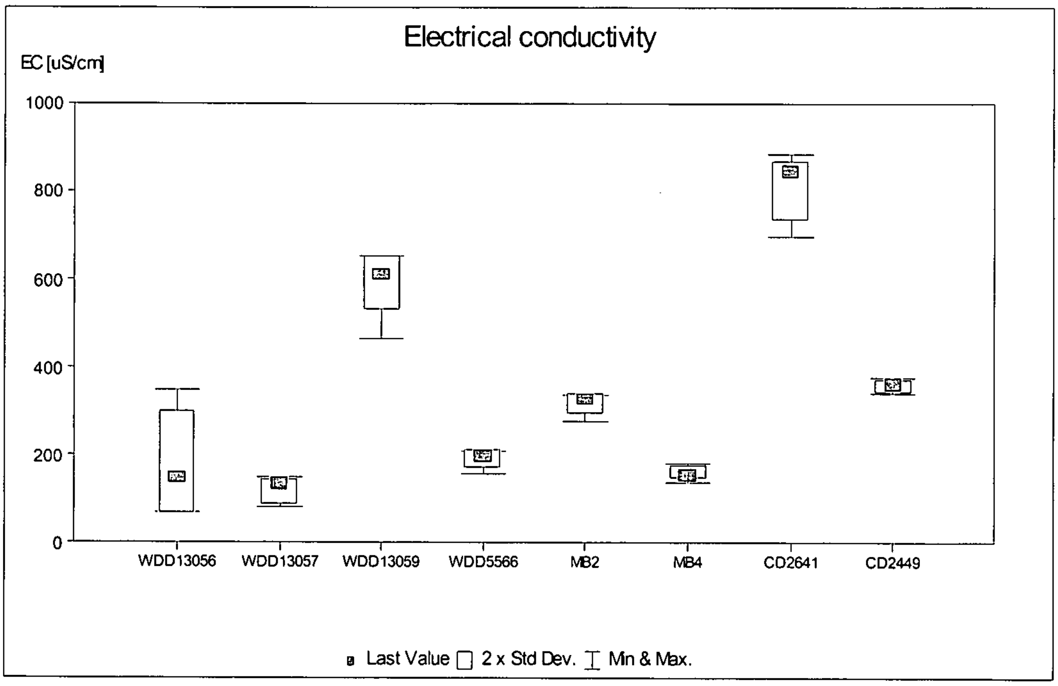


Figure 75. **Box and whisker plot of electrical conductivity of the boreholes drilled to less than 800 μS/cm. within the basement complex.**

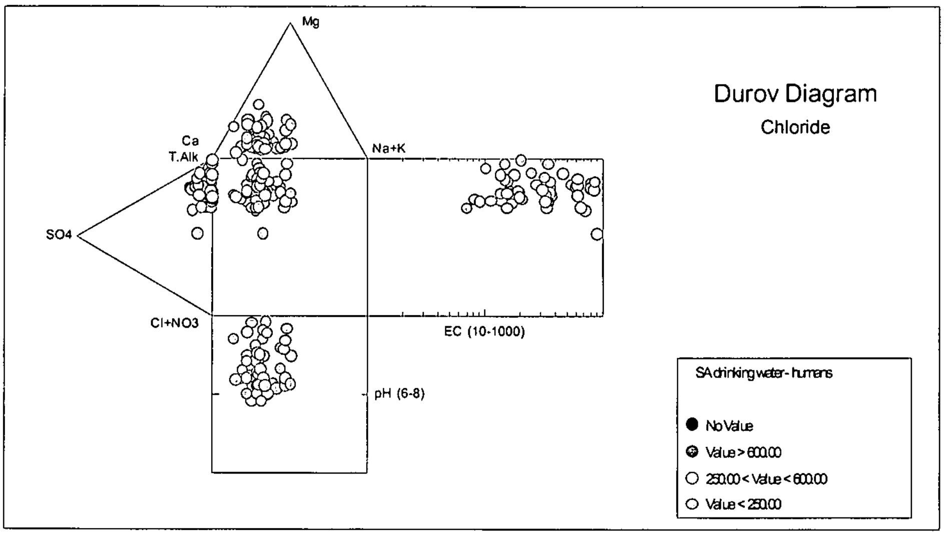


Figure 76. **Concentrations of chloride of all the boreholes tested in Pallisa.**

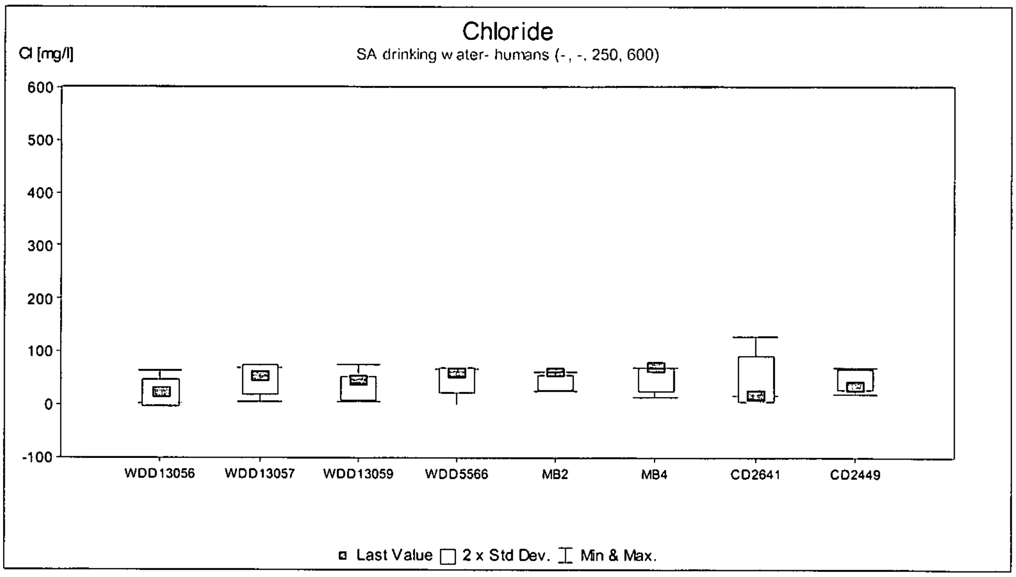


Figure 77. **Box and whisker plot of chloride concentration (mg/l) of boreholes drilled in Pallisa basement complex.**

An experiment to study the corrosiveness of water was conducted, but using the background information, it was observed that severe problems with corrosive water had been detected and even stainless steel had been corroded. Recommendations were made to identify corrosive water by the index given in DIN 50930:

$$\frac{\text{Chloride} + 2.\text{Sulphate (mmol/l)}}{\text{Alkalinity (mmol/l)}}$$

If the index is less than 1, then the water should be classified as "not corrosive". However, experience still calls for the use of stainless steel, and although quality SS304 can be used, SS316 is preferable. Between 1 and 2, SS316 can still be used, preferably in combination with non-corrosive material. Above 2, non-corrosive materials should be used only. Since stainless steel is not cost effective, the use of PVC pipes screens has now come into play.

For the proposed production boreholes in Pallisa, the corrosion index were calculated as in Table 12 below:

Table 12. Corrosion index of production boreholes.

BOREHOLE	CORROSION INDEX
WDD13056	0.86
MB2	0.37
MB4	0.16

The bacteriological quality of the groundwater in the area has been assessed in the four districts of Iganga, Jinja, Kamuli and Mukono. Approximately, 1879 water quality analyses were conducted. Of these 274 included bacteriological analyses, E.coli and Tot-coli. The E.coli can only occur as a result of pollution, while the Tot-coli can have geological origin. The table below shows the overview of the detection of E.coli.

Table 13. Detection of E.coli in boreholes.

	Sources analysed	Sources E.coli detected CFU/100ml	Max. Value E.coli CFU/100ml	Mean value E.coli CFU/100ml
Shallow boreholes	131	81	180	28
Deep boreholes	143	9	7	2.6
Total	274	90		

From Table 13, it seems that the risk of bacteriological pollution mainly occur in the shallow wells, which is of course fully correspond with the surface related pollution and the presence of pit latrines nearby.
For the deep boreholes, it cannot be ignored that the cause for the occurrence of the E.coli can be related to the use of the boreholes.

The likelihood that the new boreholes would be polluted is minimal.

For the new borehole WDD13057, the water quality was found beyond the WHO recommendations for the parameters, (recommendations in brackets): TDS (1000 mg/l), Sodium (200 mg/l), Fluoride (1.5 mg/l), Sulphate (250 mg/l).

5.7 WATER BALANCE

5.7.1 GENERAL

Along with the development of groundwater resources, several types of water balance studies have been developed to evaluate the groundwater resource potential and to obtain a reasonable limit of its utilisation.

Generally, water balance must exist between the quantity of water supplied to the basin and the amount leaving the basin. Inadequate data, however, made an assessment of water balance for the study area more or less questionable, especially lack of data for change in groundwater storage.

A more simplified, but fundamental water balance equation that applies the climatological and hydrological water balance, was considered.

The following relation depicts the respective components of the hydrological cycle:

$$\Delta S = P - R - E - I$$

where

ΔS	=	Change in storage within the system
P	=	Precipitation
R	=	Run-off
E	=	Evapotranspiration
I	=	Infiltration

Groundwater level records are one of the important parameter to calculate the change of groundwater storage. However, groundwater observation networks have not yet been set in the study area, except very limited measured data of groundwater table has been observed through the monitoring well at Mrs. Asiire's home in the whole of Pallisa district.

This monitoring well is located at grid 33.71236^{0}E, 01.18260^{0}N and at an altitude of UTM 0579080E and 0131067N. The hydrological and hydrometrerological data indicate that the area is located at the slope of the hill with a swampy valley below the outskirts of Pallisa town.

The vegetation covered is forest/savannah mosaic and the elevation range is from 3850 - 3600 m with temperatures ranging between 25 – 30^{0}C.

The geology of the area indicates some sediments, alluvium, black soils and moraines in the swampy valleys, undifferentiated gneisses including elements of partly granitized and metamorphosed formations. Figures 70, 71 and 72 show the location sketch map of the monitoring well, the groundwater level and rainfall data and the groundwater hydrograph respectively.

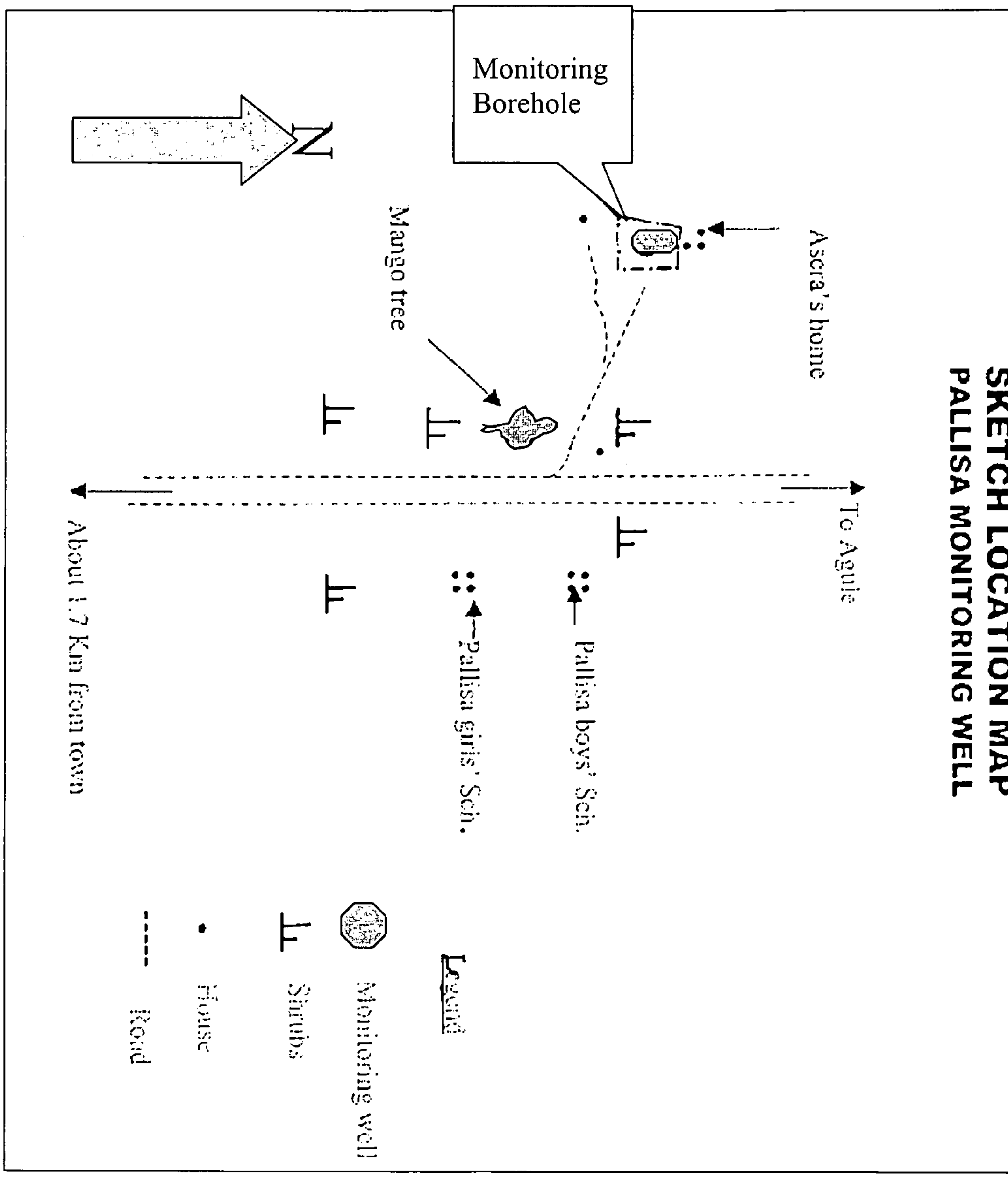


Figure 78. **Location map of Pallisa monitoring well.**

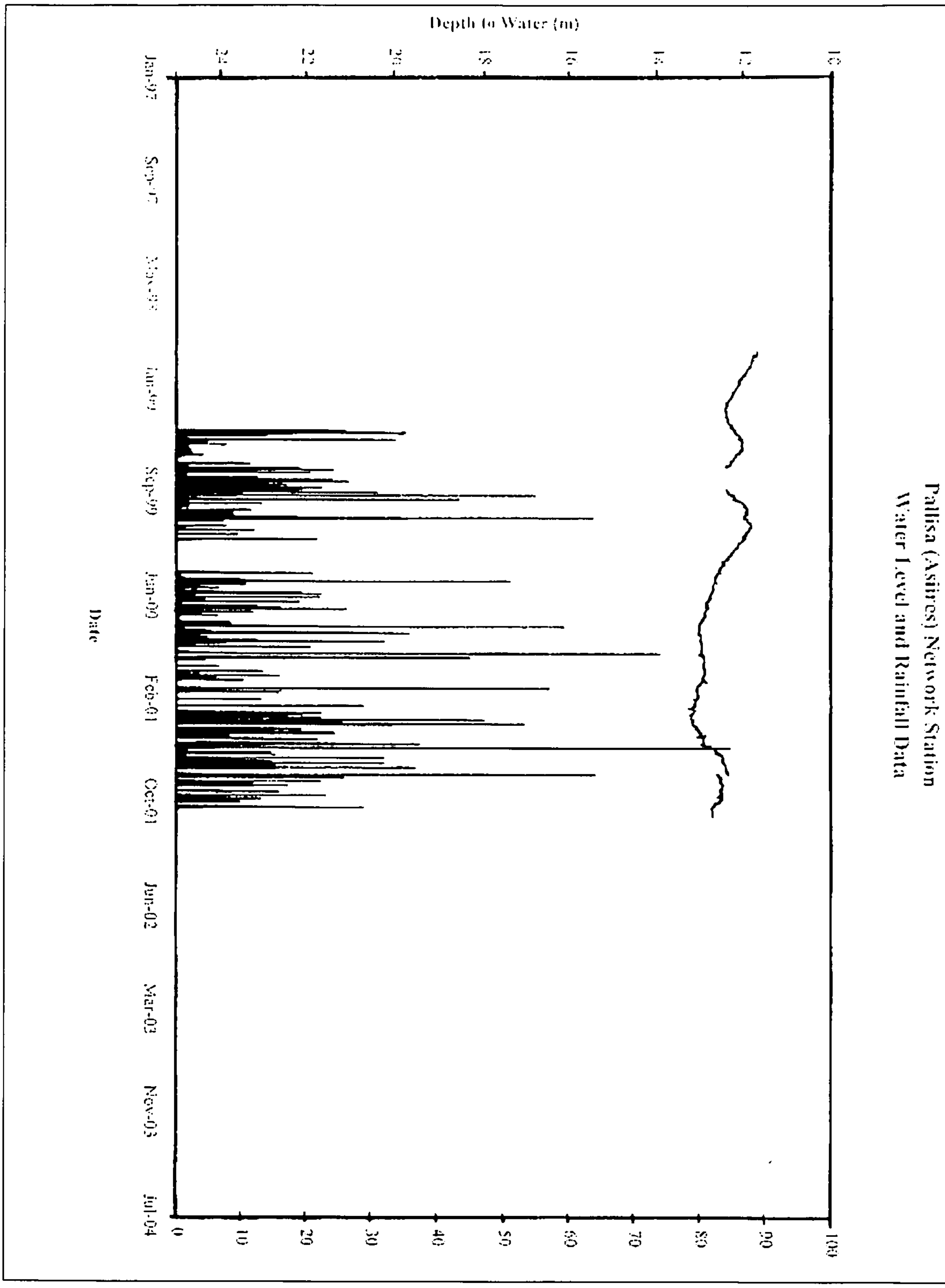


Figure 79. **Graph of water level and rainfall data at Pallisa network station. Source: WRMD, Entebbe.**

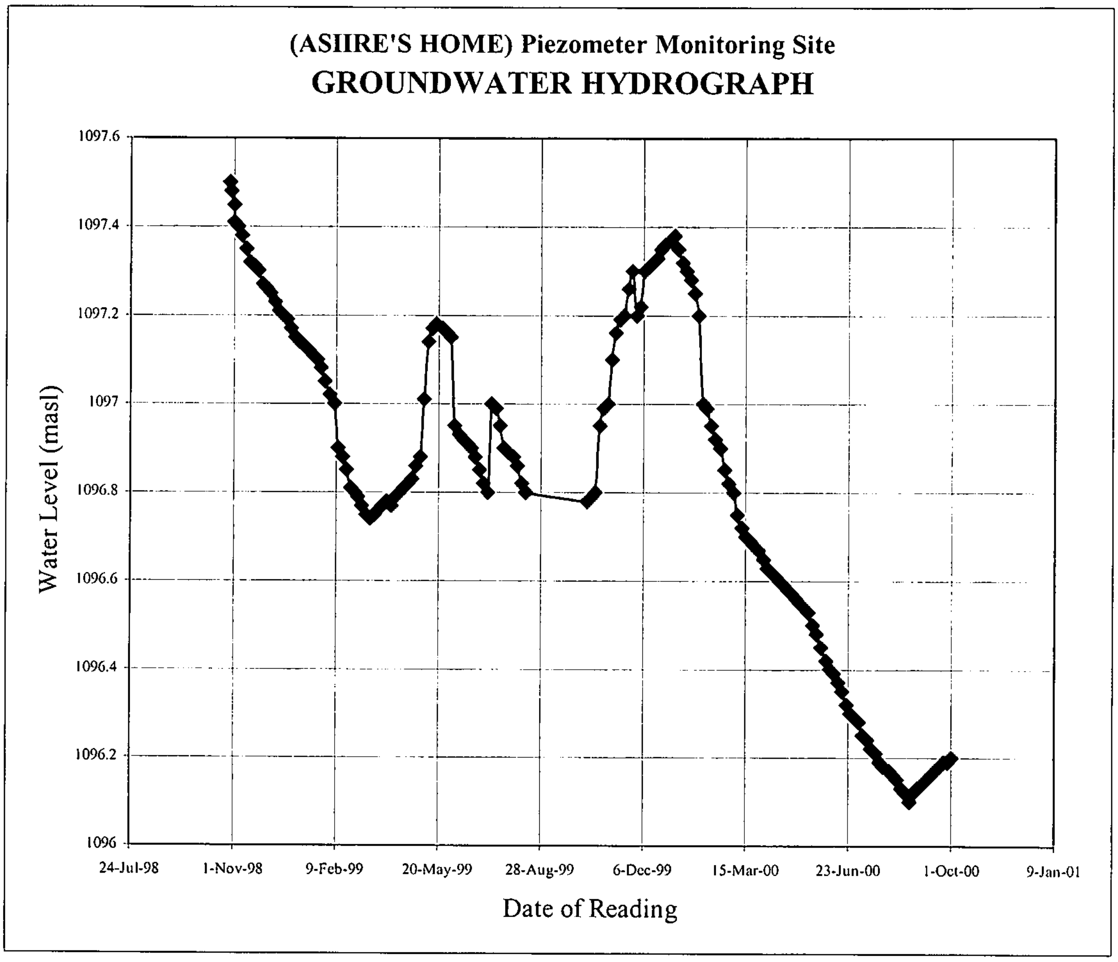


Figure 80. **Piezometric groundwater hydrograph at Asiire's home, Pallisa.**

Nevertheless, components, such as evapotranspiration, runoff, will be discussed, albeit briefly.

5.7.2 EVAPOTRANSPIRATION

The combined effects of evaporation and transpiration in returning water to the atmosphere are frequently grouped together as evapotranspiration.

The daily potential evaporation (mm) in the country was calculated by D.A. Rijks *et al.*, (1970) and the evaporation in Entebbe is shown in Table 14;

Table 14. Daily evaporation potential in Entebbe.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Entebbe	5.1	4.8	5.1	4.9	4.9	4.7	4.4	4.6	5.0	4.9	4.8	4.8

The averaged evaporation is applied for the estimation of the total amount of potential. Distribution of daily rainfall is an important parameter to estimate potential evaporation.

5.7.3 TRANSPIRATION

Transpiration is the process that green plants use to release water to the atmosphere. Only a small fraction of the water that plants absorb is retained in the plants. Transpiration depends on the following:

- ii) The soil type
- iii) Type of vegetation.
- iv) Availability of moisture.
- v) Density of the vegetation.
- vi) Density of the roots.

5.7.4 EVAPORATION

Evaporation is the process through which water is transferred from the land and the water masses back to the atmosphere. Evaporation is a function of the following:

i) Solar radiation

ii) Temperature

iii) Velocity of the wind

iv) Atmospheric pressure

v) Difference in vapour pressure between the water surface and the layer of air.

In Pallisa district, no available information was obtained concerning the stations, which measure evaporation, but values were considered depending on the surrounding districts. Evaporation was measured directly with pans. The following tables show the temperature and evaporation for the three stations in the districts of Soroti, Jinja and Tororo in eastern Uganda.

Table 15. Monthly temperature of the three districts stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov`	Dec	Aver Year
Soroti:													
Aver. Max.	31.6	31.4	30.8	29.3	28.9	28.6	27.8	28.0	29.0	29.4	29.2	30.1	29.5
Aver. Min.	17.8	18.6	18.8	18.7	18.3	18.0	17.8	17.7	17.6	17.8	17.9	17.8	18.1
Jinja:													
Aver. Max.	29.3	29.7	29.6	28.2	27.3	27.3	27.1	27.9	28.5	28.9	28.5	28.8	28.4
Aver. Min.	15.3	16.1	16.9	17.2	16.7	15.7	15.1	15.0	15.4	16.1	15.9	15.3	15.9
Tororo:													
Aver. Max.	30.5	30.7	30.2	28.9	28.1	27.8	27.4	27.9	28.9	29.0	29.3	29.4	29.0
Aver. Min.	15.8	16.5	16.7	17.1	16.7	15.9	15.7	15.6	15.4	15.9	16.0	15.6	16.1

It is seen from the Table 15 that the temperature differences between the stations are small, although Soroti has the warmest and Jinja the coolest climate. Also, the temperature differences over the year are small. Since Pallisa district has an average temperature ranging from 20 – 30^{0}C, and Soroti is a neighbouring districts with almost the same temperature differences, then for purposes of this study the temperatures of Soroti were recommended.

Table 16. Long-term average pan evaporation of the three districts stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Soroti:	245	226	195	174	143	150	142	169	155	206	225	240	2,270
Jinja:	147	143	163	141	135	114	117	126	137	143	150	153	1,669
Tororo:	194	186	191	166	158	147	138	147	169	173	165	175	2,009

It can be observed that the evaporation differs between stations; Soroti has around 30% higher evaporation than Jinja. The slightly lower temperature in Jinja, combined with higher relative humidity causes the difference. The difference between the evaporation figures for Soroti and Tororo are small from March to October, but in November to February, the evaporation in Tororo is considerably lower than in Soroti.

Looking at the above figures in Table 16, and that since Pallisa district has the same evaporation as Soroti district, then I do have the reason to believe in reference to the above that the evaporation of Pallisa is high from January to February and from October to December with the highest evaporation rate in December to January amount to about 20% of the annual rainfall.

5.7.5 RIVER RUNOFF

Stream flow data have been obtained from Directorate of Water Development (DWD), Entebbe for 5 flow-gauging stations (Figure 13 and Table 17).

The characteristic values shown in the following table have been extracted from the various stream/river gauging data.

Table 17. Characteristic values of gauging stations along key rivers in the study area.

Gauging station No.	River	Catchment area (km^2)	Mean runoff (mm/a)	Median minimum flow (mm/a)
82225	Sezibwa	175	451	112
82240	Sironko	265	490	*
82212	Manafwa	473	528	63
82218	Malaba	1,603	265	34***
82217	Mpologoma	3,319	213	**

Notes;

- * Using the raw data, the median minimum flow for the station is 0. However, doubts have been raised about the validity of some of the flow data and therefore, the minimum flow for the station is considered in this context.
- ** For this station, the water level is so close to the downstream lake Kyoga, which the flow velocity at low flow is too low to be determined accurately with the standard equipment used. Therefore, the minimum flow for the station is not considered in this context.
- *** For this station, the median minimum flow will be strongly influenced by the considerable swamp areas found up-stream of the station. The figure is therefore not directly comparable with those for other stations.

It can be seen from the table, that the mean runoff for the three smallest catchments corresponds to 450 – 530 mm/a. Assuming that the direct surface runoff is very high in these catchments due to the steep slopes, say 20% of the total rainfall, the remaining part of the runoff will be in the range around 200 mm/a. This runoff will originate from groundwater, and it thus represents an estimate of groundwater recharge.

For the two bigger catchments, the direct surface runoff will be smaller and tentatively, 5% of the total rainfall is assumed. By similar calculation, the groundwater recharge should then be at the range 140 mm to 190 mm/a.

From the median of flows for Manafwa and Sezibwa, it is seen that the amount of groundwater draining to the streams at the peak of dry season is in the order of 60 mm to 150 mm/a. The average annual rainfall over the study area exceeds, 1200 mm/a. This is justified by statistical analyses of the minimum rainfall.

The groundwater recharge is estimated on the basis of comparative analysis of other more detailed studies from areas with similar conditions and with average flow data from gauging stations in the area. Based on this, an average recharge of 110 mm/a is proposed for Pallisa district.

5.8 GROUNDWATER RESOURCE EVALUATION

5.8.1 GROUNDWATER RECHARGE

Quantitative assessment of groundwater recharge is an important issue in groundwater development. Estimation of groundwater recharge requires proper understanding of the recharge and discharge process and their interrelationship with geological, geomorphological, soil, landuse and climatic factors. There are various methods in use for the quantitative evaluation of groundwater recharge e.g.:

(a) Groundwater level fluctuation and specific yield method;

(b) Rainfall infiltration method and;

(c) Soil moisture balance method (Thornthwaite and Mather, 1957).

In the present study, the Soil moisture balance method is used for the quantitative estimate of groundwater recharge in Pallisa district watersheds.

The conventional approach for groundwater recharge assessment has some limitations in spite of its simplicity and wide applicability in varied hydrogeological setup.

Groundwater movement is in most cases controlled by natural boundaries like valleys and ridges. Hence, watershed is the most appropriate unit for groundwater recharge estimation. In case of conventional methods like rainfall infiltration method or water level fluctuation method average values of rainfall or water level fluctuation is taken for a part of the land. The spatial variability in the components of recharge is not considered. Seasonal information is required for estimation of recharge.

The purpose of this analysis was to form a basis for assessing the safe yield of groundwater reservoirs. For this purpose climatic data was collected and analysed with the focus of obtaining useful estimates of the available groundwater resource, by identifying major differences within the study area.

Evaluation of groundwater recharge in Pallisa and across Uganda is typically constrained by a paucity of regional meteorological and hydrological records. In particular, lack of sustained hydrological measurements commonly prevents any detailed comprehension of dynamics of the sub-surface environment.

The common source of recharge of groundwater stems from the direct and rapid infiltration of rainfall at the soil surface. Two studies employing stable isotope tracers within the monsoon belt of which Uganda falls (Geirnaert *et al.*, 1984; Adanu, 1991) demonstrated that the enrichment in the heavy isotopes of water through evaporation exhibited by surface water, could not be detected in the groundwater system. Recharge was, therefore, considered neither to have been derived from surface water bodies nor to have undergone significant evaporation to prior to infiltration.

The timing of recharge has been found to correspond with the heaviest rainfalls of the monsoons when the rates of incoming precipitation temporarily exceed the intense evapotranspirative flux found over much equatorial Uganda (Howard & Karundu, 1992).

Table 18. Findings regarding groundwater recharge in Uganda.

Recharge Characteristics	Aspect	Location
Source	By direct infiltration of rainfall with no evaporation occurring.	Uganda
Timing	At the height of rainy season (March-June) and (August – November) when rainfall exceeds evapotranspiration.	Uganda
Magnitude	110 mm/a[1] (8% of an average rainfall of 1400 mm/a).	Eastern Uganda

Where [1] is estimated from the soil moisture balance techniques.

Using the information around and near the study area for which a Soil Moisture Balance was conducted, the model provided two parameters with which to validate its predictions. This gave the best option and reliable information on the recharge estimate for Pallisa district (Table 18).

Apart from estimating groundwater recharge to be in the order of 110 mm/a, the study also concluded, from Darcy through flow calculations that most of the recharge in this environment were being transmitted by both the regolith and the fracture system within the underlying bedrock which is the traditional target of groundwater exploitation schemes in most of the eastern Uganda areas.

The timing and magnitude of recharge, was confirmed through the isotope studies. Stable isotopes (^{2}H and ^{18}O) were applied in the recharge investigation in order to verify the timing of the recharge events while a groundwater flow used to check the magnitude of the recharge estimate.

5.8.2 RESULTS AND DISCUSSION

Figure 81 shows the bi-modal nature of monsoonal rainfall for the periods of 1954 to 1964 within the catchment. The plot represents the average daily rainfall over these periods. Although the annual volume of precipitation show a slight increase from the 1950s to the present, this rise is not considered significant in terms of climatic variation due to limited time scale on which the data was based.

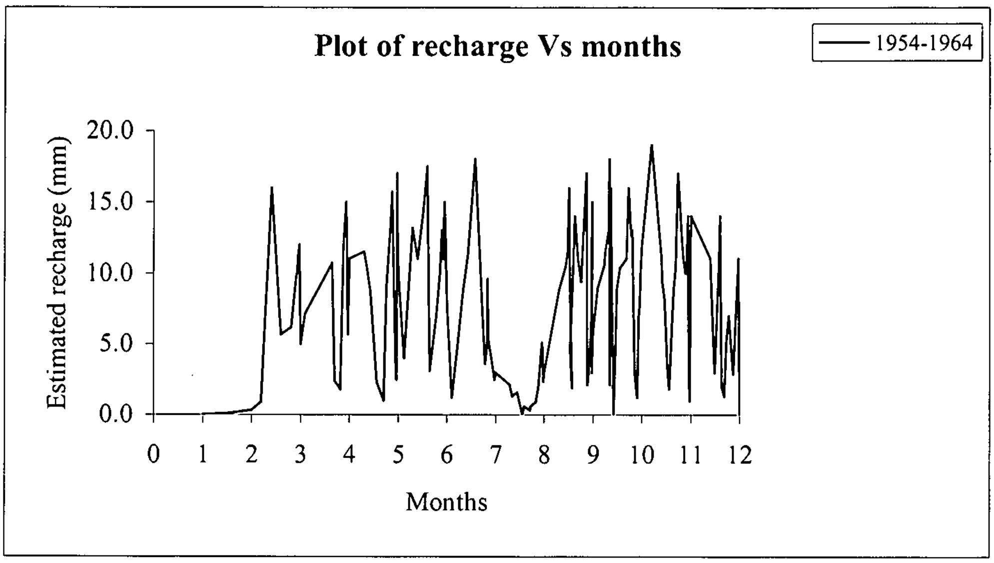


Figure 81. Annual distribution of estimated recharge (daily averages from 1954-1964).

The annual distribution of the daily average recharge, predicted by the soil moisture balance model over the periods of 1954 to 1964 results from the periods indicate that the recharge occurs exclusively during the wet season from April to September and reflects the bi-modal nature of incoming precipitation.

It is apparently known that the recharge is restricted to intensive rainfalls during the monsoons when soils are saturated and precipitation can exceed evapotranspiration. The plot also suggest that the annual recharge has doubled over the last 30 years from 100 mm/a to 220 mm/a. despite the slight rise in the annual rainfall observed between the periods, also in Pallisa district, it has been observed that there was a lot of rainfall that increased the recharge rate (Figure 82). The increase in recharge is considered to result primarily from the reduced evapotranspirative ability, over 25% of the catchment surface, of the crop cover.

There is a relationship observed between annual estimated recharge and annual precipitation as seen in Figure 82 and this supports this assertion that if extreme cases in rainfall volumes are considered, the annual estimate of recharge does show an increase with rise in its source, annual rainfall.

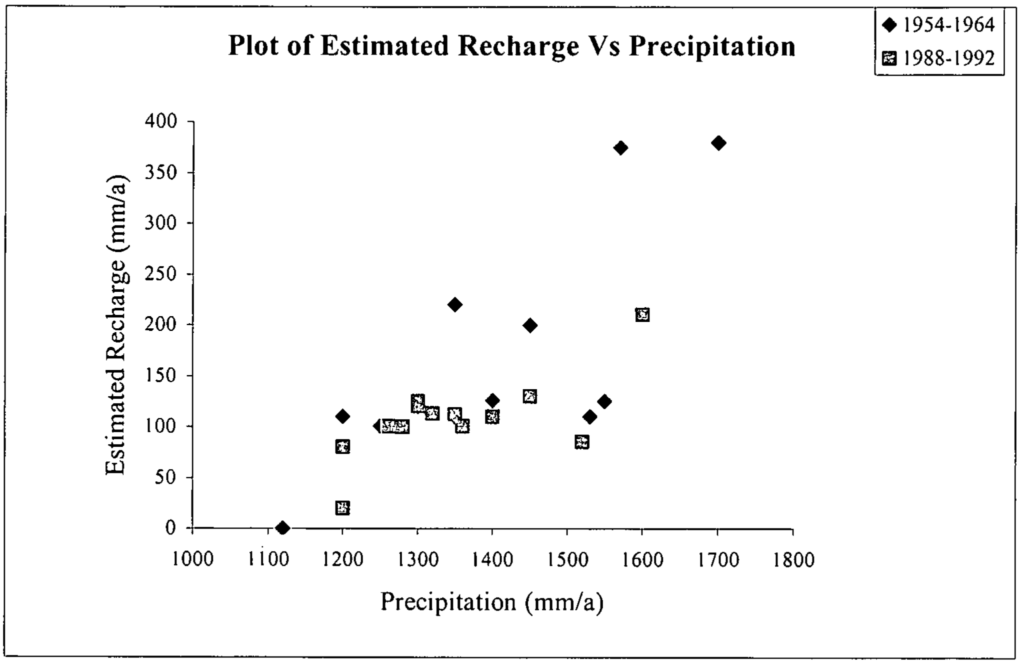


Figure 82. Estimated recharge versus precipitation for 1954-1964 and 1988-1992 in Pallisa district.

A plot of estimated recharge, Re, versus the number of heavy rain events, H_r (> 10 mm/d) each year (Figure 83) yields an improved correlation between recharge and precipitation and supports the notion that rainfall intensity is a more important factor than rainfall volume in determining the quantity of recharge entering the groundwater system.

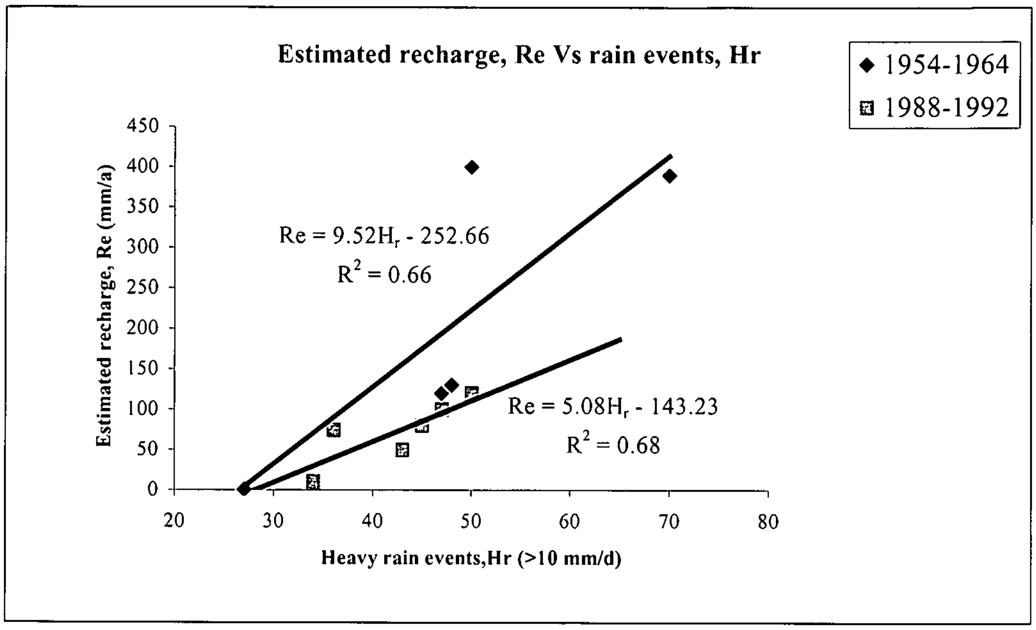


Figure 83. **Estimated recharge versus the number of heavy (> 10 mm/d) rain events.**

The graph also implies that roughly 27 days of heavy rain are required each year for any significant recharge to occur.

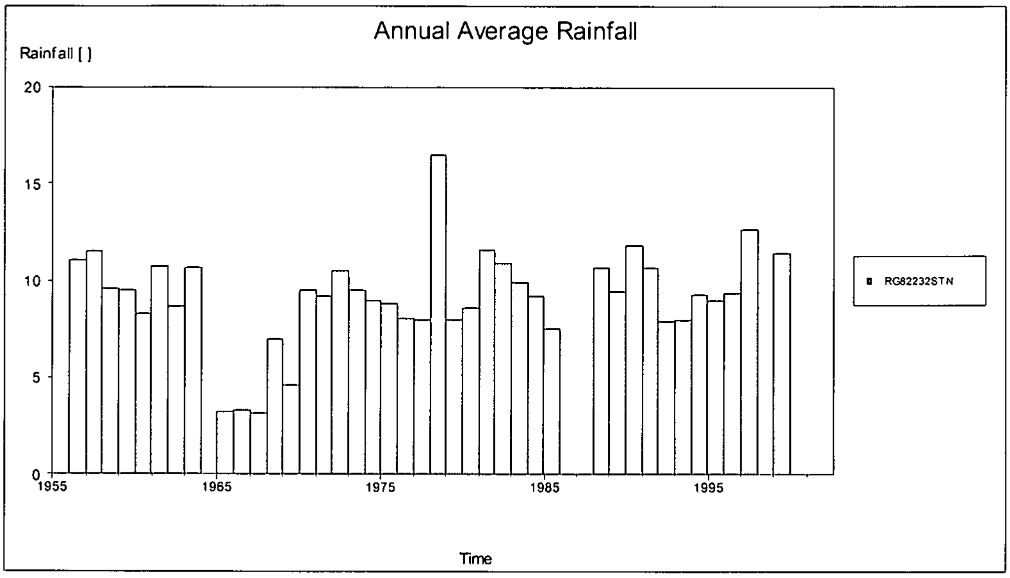


Figure 84. **Annual average rainfall (mm) measured at station RG82232STN in Pallisa district.**

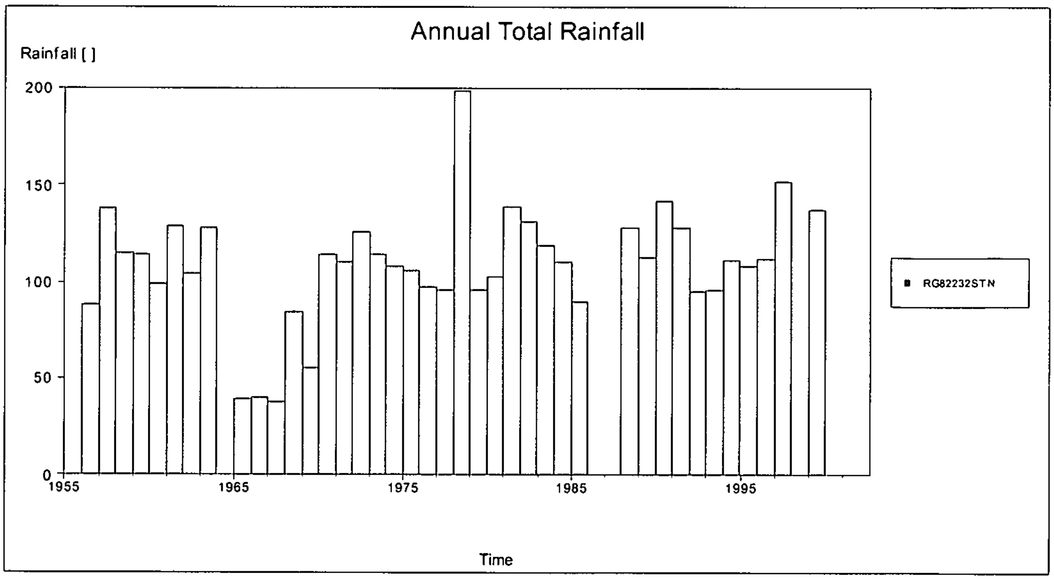


Figure 85. **Annual total rainfall (mm) measured at station RG82232STN in Pallisa district.**

This study shows that the recharge depends not only on the total rainfall, but also on the distribution over the year, how much the rain falls in concentrated rainfall events (for instance exceeding 10 mm) (Figures 84 and 85), on topography and on vegetation cover and land-use.

There was little information on geological, hydrological and meteorological data available for several years for which the recharge could be evaluated at wide intervals.

In order to evaluate the quantity of renewable groundwater resources per year, some of the approaches were possible. Considering that the purpose was to obtain a reasonably good estimate of the mean groundwater recharge as a basis for further estimates, some of these approaches were found adequate.

The main approaches were:

- Comparison with other much more detailed studies in comparable areas.
- Comparison with spring flow measurements in the area, if representative data are available (covering an adequate number of springs and adequate period)
- Comparison with average and low flow data from gauging stations in the area.

Figure 86 shows the relationship between average annual rainfall and the estimated average groundwater recharge.

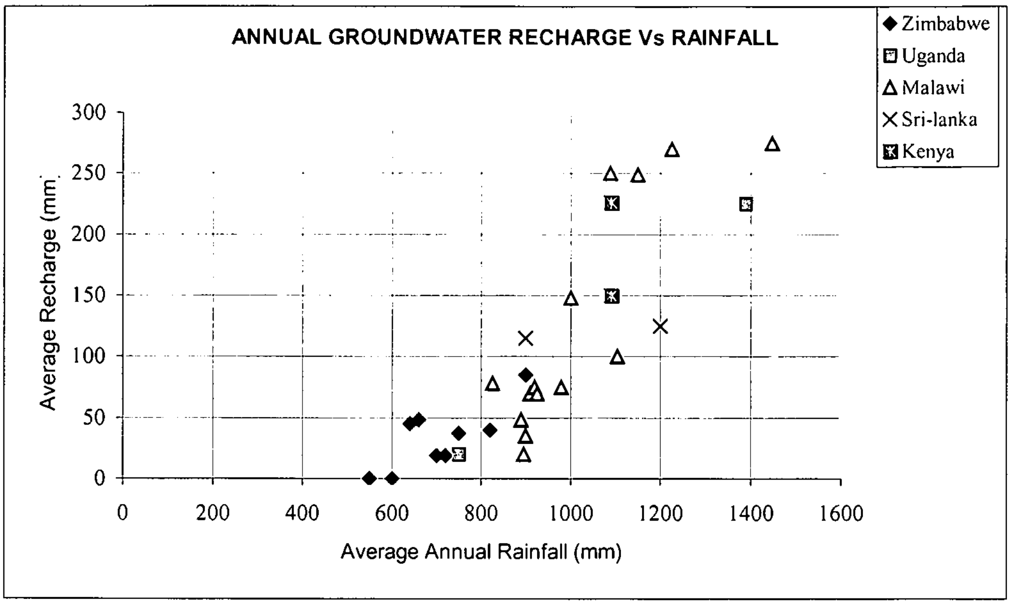


Figure 86. **Annual groundwater recharge vs. rainfall in different African and Asian Countries. (Source: Water resources status report, Pallisa – 1999).**

The figure above, includes results from studies of two Ugandan catchments, the Aroca catchment in Apac district in northern Uganda, receiving an annual rainfall of 1400 mm with a recharge estimate of over 200 mm/a or over 15% of the total annual rainfall and Nyabisheki catchment in Mbarara district in western Uganda receiving a minimum annual rainfall lower than 750 mm with a recharge estimate of about 25 mm/a or below 3%.

The relationship between rainfall and groundwater baseflow (average recharge) in the figure above is more or less linear and strongly dependent on the total rainfall as well as on rainfall intensity. Considering such variations in rainfall intensity at different locations on the graph, it is possible to establish a rough correlation between the annual rainfall and annual groundwater recharge.

The combined baseflow data for the selected countries above shoe linearity in the fact that minimum recharge approaches zero at annual rainfall of about 700 mm.

Typically, from Figure 78, since Pallisa district has an average annual rainfall ranging between 1200 – 1400 mm, then a recharge estimate of around 110 mm/a is more realistic.

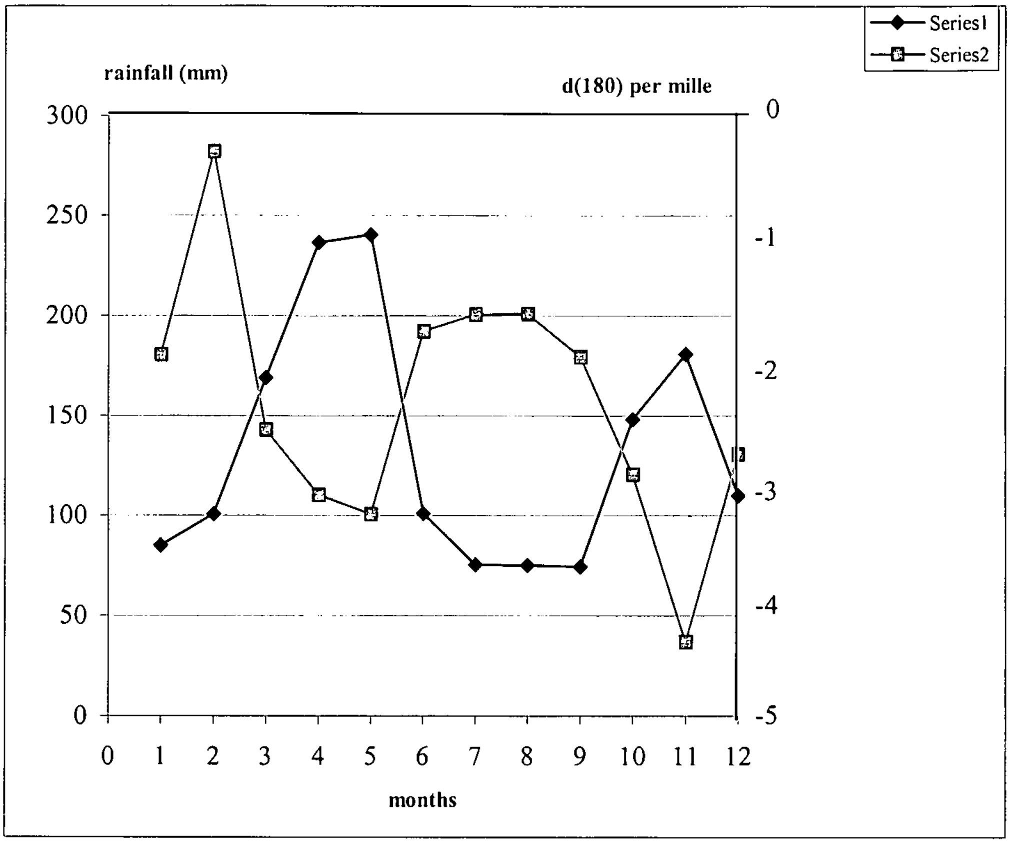
Table 19. Summary of groundwater infiltration rates for selected catchments at annual rainfall in the range of 700 – 1500 mm. Source: Rapid water assessment –WAP.Doc.007.

Areas / Method of calculation	Meru district, Kenya	Selected Catchments, Malawi	Selected Catchments, Zimbabwe	A'pura District, Sri-lanka	Selected Catchments, Uganda
Groundwater level measurements %	6-24	---	---	10	---
Baseflow/water balance %	>20	14-30	2-7	10	2
Soil moisture balance %	---	---	---	---	16
Annual precipitation (mm)	1100	900-1500	700-900	1200	750-1400

Table 19 gives a complete summary of groundwater recharge rates and it is readily concluded from the results that the variation is considerable. This equally reflects the margins of error involved in this type of calculation as actual differences from one area to another. It is however, possible to establish that the order of magnitude of variation ranges between 10 -15% or 100 – 150 mm.

5.8.3 ISOTOPIC VARIATION IN PRECIPITATION

With no extensive record of stable isotope measurements in rainfall from the study area i.e. Pallisa district, seasonal patterns in the deuterium and ^{18}O content of rainfall were inferred from historical observations at Entebbe, approximately 180 km to the south. Monthly measurements, though sporadic, extend from 1961 to 1974 (International Atomic Energy Agency (IAEA) 1969, 1970, 1971, 1973, 1975, 1979). A plot of the average monthly rainfall and δ_{18} at Entebbe (Figure 87) clearly demonstrates a relationship between the amount of rainfall and depletion in ^{18}O.



Series 1 and 2 represent the annual rainfall (mm) and ^{18}O (per mille) content respectively.

Figure 87. Annual distribution of rainfall and its ^{18}O content at Entebbe (monthly averages from 1961 – 1974).

Dansgaard (1964), proposed three mechanisms to account for the enrichment of ^{18}O when observed in lighter rainfall:

1. Enrichment may stem from rain clouds condensing to a proportionately lesser extent during lighter rain events. This assertion draws from the principle of Rayleigh distillation where the process of condensation leads to an exponential decline in the ^{18}O content of the condensate as a function of the remaining fraction of vapour. As a result, heavier rain events, consuming a greater proportion of the available vapour, should exhibit a depleted ^{18}O composition.
2. Lighter rainfall might alternatively be enriched through isotopic exchange with vapour below rain clouds which, having not been exposed to the same cooling process as the rains and their associated storm clouds would,

however, effectively determine the isotopic composition of underlying vapours so preclude the process of isotopic exchange.

3. Finally, light rains may also be enriched in their heavy isotope content through the re-evaporation of falling drops, enhanced by the reduced humidity, which exists during the periods of lighter rainfall.

The role of each of these general processes in controlling the "amount effect" observed at Entebbe is considered below. The influence of temperature on isotopic composition, which is dominant as polar climates, is not regarded since average monthly temperatures deviate less than 1°C from the annual mean of 21.5°C throughout the year.

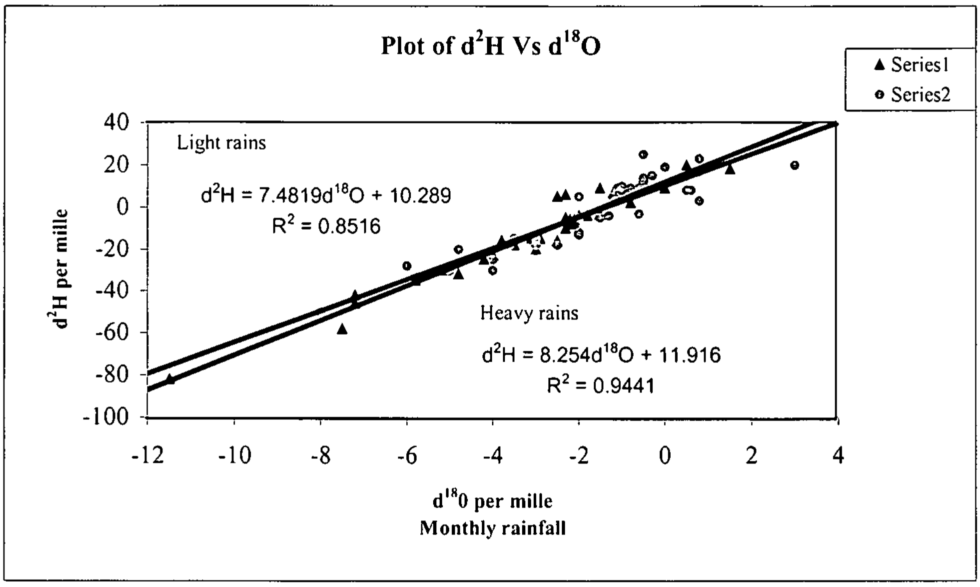
Considering the above observations, the following conclusions could be drawn:

a) That the enrichment in the heavy isotope composition of lighter rains through Rayleigh distillation involves two key assumptions. 1. Rainfall throughout the year is divided from the same source. 2. Heavy rains consume a larger fraction of the available vapour than light rains. However, at Entebbe, rainfall arises from two sources, monsoonal and convectional. Although depletion of the heavy isotope through condensation may arguably overshadow the impact of the cloud vapour and thus, condensate, being generated from different sources, the requirement that heavy rains utilize a greater proportion of the available vapour is not plausible as, regionally, there are no orographic features that would compel heavy (typically monsoonal) rains to behave in this manner.

b) That the mechanism of enrichment through isotopic exchange between falling condensate and underlying local vapour appears technically feasible at Entebbe where poorly distributed precipitation yields distinct periods of light (72 mm/month) and heavy (243 mm/month) rainfall (Figure 87). However, the ^{18}O content of the local vapour with which isotopic exchange processes are proposed to occur, is expected to be in the vicinity of –5‰. Therefore it does not seem possible that isotopic exchange with local vapour (equilibration) could enrich light rains to δ_{18} values of around –1.8‰ that have been observed at Entebbe (Figure 87). It is worth noting that based on the 12 samples collected from 1961 to 1962 at Entebbe, Dansgaard (1964) attributed a δ_D/δ_{18} slope of >8 (10 ± 1) to the enhanced isotopic exchange of light rains with the local vapour. However, examination of the 102 samples collected from 1961 to 1974 reveals a δ_D/δ_{18} slope of < 8 (7.5 ± 0.3) and questions of influence of this process on isotopic enrichment.

c) At Entebbe, the relative humidity drops by an average of 10% during the periods of lighter rainfall (Leroux, 1983). During this time, a heightened evaporation of condensate would be expected and is reflected in a plot of δ_D versus δ_{18} for Entebbe rainfall (Figure 88). Based on the monthly patterns of rainfall displayed in Figure 88, "light rains" may be represented by those months when less than 150 mm falls while "heavy rains" are those months when precipitation is greater than 150 mm. In Figure 48, "heavy rains" feature a range of isotopic compositions but rests along the slope for the Global Meteoric Waterline for precipitation (r^2 = 0.94) with an average δ_{18} of –3.4‰. "Light rains" are more scattered (r^2 = 0.85) and exhibit a slope of less than 8 (7.5 ± 0.4) which is indicative of enrichment (average δ_{18} = -1.8‰) through evaporation (Craig, 1961).

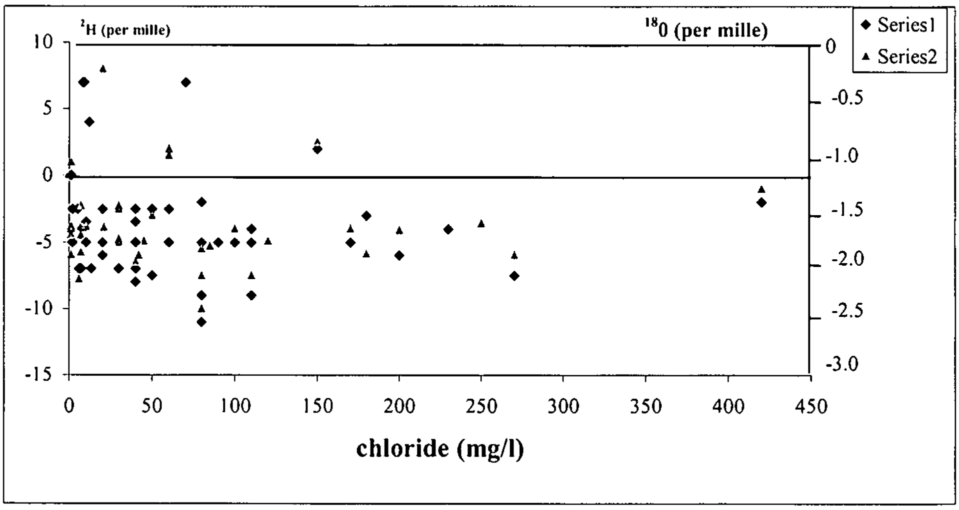
Among the three mechanism offered by Dansgaard (1964), evaporation of falling condensate during periods of lighter rain appear to be the most reasonable, regional process to account for the "amount effect" witnessed at Entebbe.
Despite this sampling limitation, strong correlations exist between the monthly means for the amount of rainfall and its ^{18}O content.



Series 1 = P > 150 mm/month; Series 2 = P < 150 mm/month

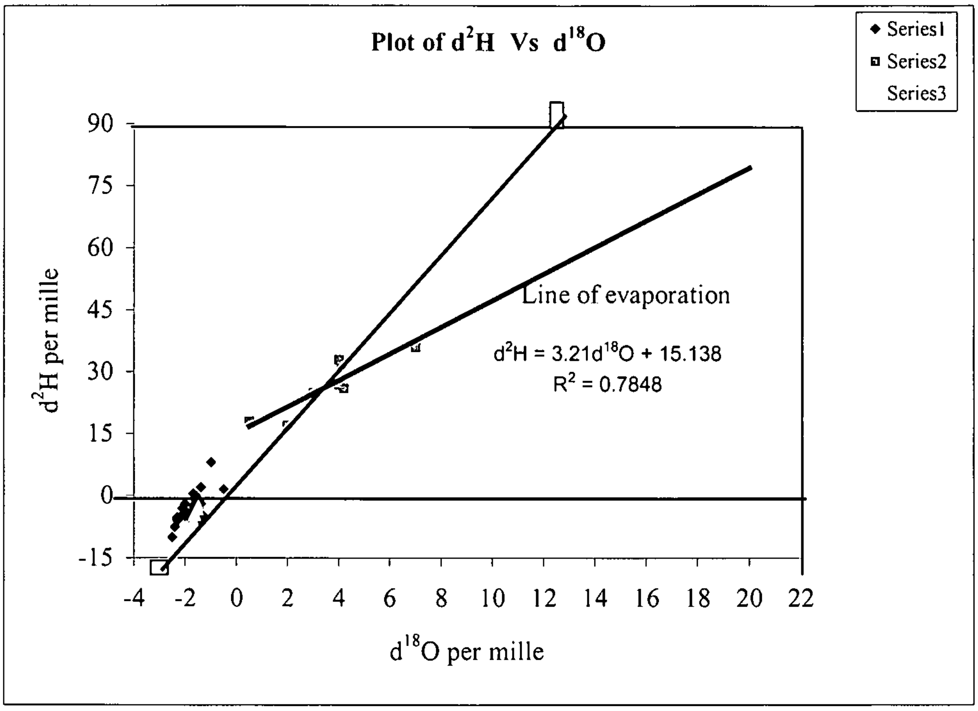
Figure 88. Plot of δ^2H Vs $\delta^{18}O$ for Entebbe rainfall (monthly data from 1961-1974.

Among the three mechanism offered by Dansgaard (1964), evaporation of falling condensate during the periods of lighter rain appears to be more reasonable, regional process to account for the "amount effect" witnessed at Entebbe.



Series 1 = ^{18}O (per mille) and Series 2 = ^{2}H (per mille)

Figure 89. Deuterium and oxygen –18 versus chloride for groundwater in Pallisa.



Series 1 = Basement groundwaters; Series 2 = Regolith groundwaters;

Series 3 = Surface waters and □ indicate Entebbe heavy rain.

Figure 90. **Plot of δ_D vs. δ_{18} for the catchment groundwaters and regional surface waters relative to the meteoric waterline for non-evaporated rainfall at Entebbe.**

5.8.4 ISOTOPIC RELATIONSHIP BETWEEN PRECIPITATION AND GROUNDWATERS

If a recharge were to be evaporated prior to infiltration, the increase in chloride concentrations of the water, due to reduced volume but constant mass of chloride, would produce a corresponding enrichment in the heavy isotope of water deuterium. A plot of the deuterium versus chloride is in groundwaters is shown in Figure 89, which yield no correlation ($r^2 = 0.00$) between the two parameters. As a result, the recharge was not considered to have undergone any significant evaporation prior to infiltration.

It should be realised that the second condition causing the isotopic composition of groundwater to match its recharging precipitation required that the rainfall to be the only source of recharge. In the study area, the potential exists for the two other forms i.e. from surface water bodies in the form of vertical leakages from swamps or horizontal leakages from River Mpologoma and Lake Kyoga. The stable isotope content of groundwaters and surface waters are plotted relative to the meteoric water line for non-evaporated, "heavy rains" at Entebbe in Figure 90. These waters deviate considerably from the meteoric water line and follow an evaporative slope of 3.21.

5.9 EVALUATION OF WATER RESOURCES POTENTIAL

5.9.1 INTRODUCTION

The amount of groundwater, as measured by groundwater levels in bores, indicates the water balance of a region. It also reflects the amount of groundwater resource available for human use, and the potential for problems such as water logging and dry land salinity to develop. These impacts upon the sustainability of land use within a region.

Changes to groundwater levels not only impact upon land use, but also reflect changes in land use, such as conversion of forest to agriculture, changing the proportion of perennial vegetation in a groundwater catchment, or changing the amount of water used for irrigation or urban consumption.

Increases in groundwater levels can be a result of reduced extraction (i.e. taking less groundwater out of the system), or improved land management in dryland areas. Declining groundwater levels could indicate that the amount of water being extracted exceeds the recharge rate.

5.9.2 THE RESOURCE – QUANTITY

In Pallisa district the evaluation of groundwater resource was based on existing data and information obtained from test drilling.
Based on both data, but more importantly on the practical data, the following parameters were of interest:

- i) Overburden thickness;
- ii) Average yield of boreholes and
- iii) Main water strike.

In Pallisa district, the average overburden is of considerable thickness of about 19 meters on average, indicating a good possibility for groundwater storage. The average yield is as high as 2.6 m^3/h. The main strike of water is very deep, 67 meters, indicating that when drilling new boreholes, the drilling should continue to a considerable depth of not less than 80 meters.

It was however, noted that the test drilling results indicated that the groundwater potential in Pallisa is fairly high with a possibility of meeting the needs of the population.

The map of the catchment areas and sources, show that some of the existing high yields boreholes lay on the watershed. There is however, no report as to whether they have sustained the initially recorded high yield. The existing motorized boreholes; MB1 and MB3 are obviously located close if not on watershed.

The two drilled new potential production boreholes WDD13056 and WDD13057 are located within the same catchment area. WDD13056 is fairly located much upstream in the catchment area, and since much of the water is abstracted from the overburden, emphasis should be made when using a production borehole not to over pump the borehole.

The high yielding WDD13057 is likely to be in connection with Lake Lemwa and a significant part of the water might be infiltrated from the lake.

Table 20. Impact of groundwater abstraction from the drilled potential production boreholes.

Borehole	Catchment area km^2	Yield m^3/h	Yield m^3/a	Abstraction mm/a
MB2	8 or 2	4.0	35040	4 or 16
MB4	8	4.0	35040	4
WDD 13056		5.0	43800	
WDD13057	11	15.0	131400	13

From Table 20 above, it is seen that all abstractions are significantly below the estimated groundwater recharge of 110 mm/a. There should therefore be adequate resources for an abstraction from the 4 proposed boreholes to supply the town of Pallisa.

Based on the information about the area, population and water demands, some general estimates have been made of the abstraction and lowering of groundwater. See Table 20.

The purpose of the abstraction was to determine if sufficient water resources exist within the town to fulfill the population demands. In considering the sustainability of the resource, the water demands for the year 2010 was used.

Since the production boreholes were not limited in this area, it was necessary to evaluate. For the evaluation purposes, it was assumed that the water intake was evenly distributed within Pallisa. The storage capacity was set to 2%.

Table 21. Impact of groundwater abstraction for the year 2010 water demands.

	Core	Fringe	Total
Area, km^2	302	2201	2503
Population	22188	23413	45601
Water demand, m^3/d	951	468	1419
Abstraction, mm/a	115	8	21
Lowering of groundwater table, m.	5.75	0.39	1.03.

If the total water demand is taken within the sampled studied area, there will be a groundwater abstraction of 21 mm/a and for the hand pumps placed in the fringe areas; there will be an abstraction of 8 mm/a, which is insignificant in addition to the naturally occurring fluctuations. From the source point of view, there are no objections to an even distribution of all production boreholes placed within the town and all areas within Pallisa district as a whole.

The lowering of the groundwater table represents one dry year without any recharge. However, close to the production borehole, the impact will be higher.

5.9.3 SUSTAINABLE YIELDS OF BOREHOLES

Based on the pump tests of the boreholes, a sustainable long-term yield were determined for the boreholes. For these discharges, the drawdown after one year of pumping with 16 h/d has been calculated to evaluate the potential of the resource. The drawdown estimates were obtained by using the formula of Theis incorporating the well efficiency, and the results are shown in the Table 21.

The drawdown estimates could only be considered as a rough indication, and the real drawdown could also be either smaller or larger due to the effects of hydrologic boundaries and recharge rainfall, which are both disregarded in the estimate.

Table 22. Drawdown in the drilled production boreholes.

Borehole	Static water level. m	Estimated yield m^3/h	Drawdown 1 year m	Water level, 1 year m
WDD 13056	9.81	6.5	7.28	17.09
MB2	2.0	7.2	14.16	16.16
MB4	20.53	4	11.27	31.80

WDD 13056 and MB4 are the boreholes whose data was known after a drilling and pump test; where the water level did not fall below the uppermost water bearing zones. The impacts of seasonal water level variations are not clarified at present. For MB4, the water level was still fairly high and it was therefore assumed that the drawdown could be acceptable.

For evaluation of the consequences of future groundwater abstraction, it is the aim that the impact of the aquifers and the catchment areas are more or less the same for all production boreholes.

In the study area, the required pumping yield was 110 m^3/h. Based on the pumping of 16 hr/d from both boreholes, average yields were proposed in Table 24.

Table 23. Proposed average discharge from the production boreholes.

Borehole	Average Discharge, m^3/h
WDD 13056	6.5
MB2	3.0
MB4	2.5
Additional Boreholes	27, for 4 boreholes equals 6.75 per BH

However, it is evident that when dealing with a fractured media, this can only be approximation, and there is quite some uncertainty related to this. All the four sites are located within the same catchment of 12 km^2, this has been evaluated as a whole.

Table 24. Impact of groundwater abstraction from the drilled production boreholes.

Aquifer Characteristics

Storage Coefficient	0.02
Recharge, mm/a	110

Borehole Characteristics

	WDD13056	MB2	MB4	4 New BH
Catchment area (Estimated), km^2	5	8	2	12
Top soil thickness at BH, m	19	-	9	-
GW level at BH, m	10	2	20	-
Saturated thickness, m	9	-	-11	-

Pumping Rates

Time, days:	365
Per day, hours:	16

	WDD13056	MB2	MB4	4 New BH
Hourly Pumping, m^3/h	6.5	3.0	2.5	27
Daily Pumping, m^3/d	104	48	40	432

Impact of pumping per Catchment

	WDD13056	MB2	MB4	4 New BH
Average induced drawdown, m*	0.38	0.11	0.37	0.66
Annual recharge, m^3/a	550000	880000	220000	1320000
Annual pumping, m^3/a	37960	17520	14600	157680
Proportion abstracted, %age	7%	2%	7%	12%

Note *: After one year of pumping without recharge

-: Indicate no value

From Table 21 above, it is seen that the abstractions are below the estimated groundwater recharge of 110 mm/a. There are therefore adequate water resources for the abstraction from the production boreholes as proposed.

5.9.4 IMPACT OF WATER EXTRACTION ON OTHER WATER SOURCES WITHIN THE STUDY AREA

The impacts of groundwater abstraction on water sources nearby the production boreholes were estimated. The use of RUWASA database and also the field surveys conducted to identify the water sources that were not included in the RUWASA database located the water sources.

Some approximations were made. The aquifer is considered as homogeneous and isotropic. The transmissivity values found in the production boreholes were applied for the whole aquifer when evaluating the influence of the pumping from each borehole.

The two worst scenarios that were investigated due to high uncertainty related to the estimate of storage capacity are:

i) A pumping period of one year without any recharge but draining from the overburden. The storage capacity was therefore set to 0.02 in accordance with the assumption made.

ii) A pumping period of three months using the storage capacity of 10^{-4} describing the situation where no draining from the overburden takes place. A storage capacity of 10^{-4} corresponds to what is commonly used for fractured media and confined aquifers.

Scenario I, describe the impact on all water sources of a full dry year and continued pumping from the production boreholes.

Scenario II, describes the impact on boreholes drawing water from a fractured media in connection with the production borehole. This means that the scenario does not evaluate the impact on springs and shallow wells.

For scenario I, no significant impact on other sources was found. At a distance of around 200 m from any of the production boreholes the drawdown caused by a single production borehole could be noticed.

For scenario II, the impact of the production borehole was increased. This scenario described mainly the impact on boreholes in fractured media. This scenario did not evaluate the impacts on spring and dug wells realistically. Maximum impact was found in DWD128 located about 300 m from MB4, where the drawdown of 2.2 meters was estimated. It was noted that at a distance of about 700 m from any production boreholes the drawdown caused by a single production borehole was less than 1 m. Conclusively, the impact on nearby sources was minimal and would not cause any problem. It was observed that there were no wetlands located close to any of the established boreholes.

5.9.5 ABSTRACTIONS FROM LAKE LEMWA

5.9.5.1 Overview

The water level variations in Lake Lemwa were evaluated. For this purpose data from the nearest water level gauging station, No. 82232, located on the Mpologoma River at Kasodo, about 13 km from Pallisa town, and around 3 km downstream from the outlet of lake Lemwa.

As lake Lemwa forms a branch of the Mpologoma swamp, the gauging station was estimated to be representative for low and average water levels, which was experienced in lake Lemwa. For the extreme maximum levels in Lake Lemwa, it was expected that they could slightly exceed those of Mpologoma, due to the delayed runoff through the swamp to Mpologoma.

For this gauging station, the monthly minimum, maximum and mean water levels were retrieved. The data records covers the period from 1965 to 1999.

From the data obtained, shows that the water level usually reaches a minimum in the period of January to March while the maximum can occur between May and November. For evaluating the minimum water levels, a water year from August to July was therefore used and with the maximum levels, a water year from March to February was used.

5.9.5.2 Recorded Data

The recorded water levels varied between 1.00 - 4.13 m, with a median minimum of 1.29 m and median maximum of 2.68 m.

To assess the water level variations, the annual extremes were evaluated by use of the probability plots as shown in Figure 88.

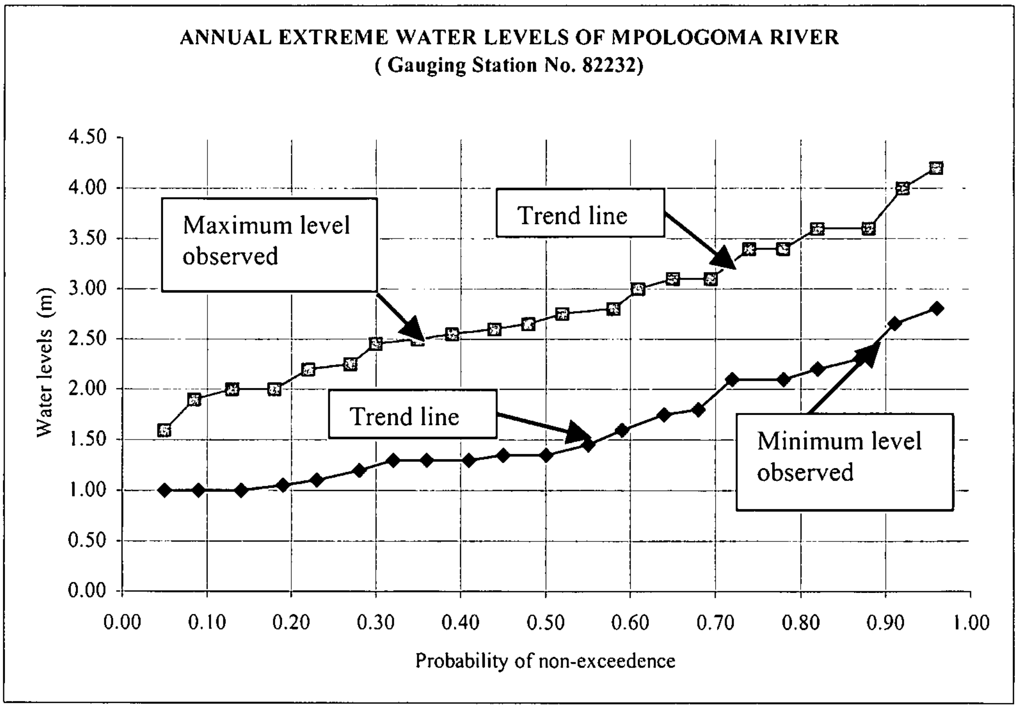


Figure 91. **Graph of annual extreme water levels of River Mpologoma (GS No. 82232). Source: Water status report-Pallisa.**

The plots were obtained quite traditionally by determining the extreme water levels recorded in water year, ranking them against the plotting probabilities found as: rank/(number of records +1). The plot was used to determine the extreme values within a period of 20 yrs.

From the data and plots, the characteristic values were found as shown in Table 25.

Table 25. Characteristic values of lake Lemwa.

	Extreme on record (m)	20 years extreme (m)	Median (m)
Annual minimum level	1.00	1.00	1.30
Annual mean level	1.26 – 3.06	-	1.93
Annual maximum level	4.13	3.85	2.80

It is seen that the water level variations recorded for Mpologoma falls within a range of 3.13 meters. Also, there seems to be a practical minimum water level, probably defined by down stream flow conditions. It can therefore be assumed that Lake Lemwa would not experience a very low water level that could put a lake intake out of service.

5.9.6 QUANTIFICATION OF GROUNDWATER IN PALLISA

Generally, considering the needs of water in Pallisa district, the following information was necessary for proper management and sustainability of the groundwater resource.

General evaluation of the groundwater resource quantity was therefore based on:

a. The consumption rate the present rural population per year and annual recharge estimate;
b. The population livestock data and forecasts according to World Bank 1993;
c. Water demand for irrigation purposes and;
d. Water demand for urban areas within Pallisa district.

Table 26. Population data and forecasts of water demands in Pallisa district.

PALLISA DISTRICT	Population (1991) * 1000	% Rural	Density Persons/km^2	Growth % per annum 1991-2010	Population 2010 * (1000)
	356.0	99	229	2.9	612.8

Table 27. Livestock data and forecasts in Pallisa district.

PALLISA DISTRICT	Livestock Nos. 1989 (* 1000)			Growth % per year	Livestock Nos. 2010 (* 1000)		
	CATTLE	PIGS	GOATS /SHEEP		CATTLE	PIGS	GOATS /SHEEP
	98.7	11.9	99.5	5.1	254.8	33.7	282.9

N.B. * is a multiplication sign.

Table 28. Present and potential irrigation water use in Pallisa district.

PALLISA DISTRICT	SOURCE	MAIN CROP	PRESENT IRRIGATED AREA (Hectares)	CURRENT WATER USE PER YEAR IN MILLION (m^3).
	Mpologoma River	Rice	5,000	30.0

Table 29. Rural and urban water demands in Pallisa district.

PALLISA DISTRICT	POPULATION (* 1000)			WATER DEMAND (* 1000) m^3/a			
	1991	%RURAL 1991	2010	RURAL 1991	URBAN 1991	RURAL 2010	URBAN 2010
	356	99	613	3216	97	5536	168

5.9.6.1 DISCUSSION

From Table 26 above, the rural population of Pallisa district accounts to 99% and most if not all this population depends on groundwater as their source of supply. In any case, the population density of Pallisa stands at 388 persons/km^2. Meaning that with 1956 km^2 that Pallisa district covers, the real population is 758928. Therefore, 99% of 758928 provide a population of 751339 persons that lives in rural areas of Pallisa district.

But an average person consumes 20 liters of water everyday. So the population of Pallisa demands approximately 15.1 million cubic meters a day. This will mean within 365 days that make up a year, the water demand will be 15.1*365 m^3/a, giving a product of 5484773 m^3/a or approximately 5.5 million m^3/a.

In calculating the livestock water demands, the following were considered:

a) One livestock unit consumes 50 litres/head/day;

b) Cattle = 0.7 livestock equivalents;

c) Pigs = 0.4 livestock equivalents and;

d) Goats/sheep = 0.15 livestock equivalents.

Therefore, taking the figures for 2010 forecast in Table 27, the consumption for cattle in a year amounted to 3255070 litres, that of pigs is 246010 litres, and that of goats/sheep is 774439 litres. The total of all these figures amounted to 4276 m^3/a.

Drawing water from Mpologoma River for mainly rice growing does irrigation in Pallisa district. This amounts to 30 million m^3/a (Table 28).

From Table 29, the water demand for urban population in Pallisa town is 168000 m^3/a. The total amount of water demand for rural areas in Pallisa district is 35.5-million m^3/a. We also know that the recharge estimate for Pallisa district is 110 mm/a, which is equivalent to 0.11 m/a. Pallisa district covers an area of 1956 km^2 that is equivalent to $1.956 * 10^9$ m^2. If the recharge rate is taken as uniform throughout Pallisa district, then the total amount of groundwater recharged is $1.956*10^9*0.11$ m^3/a = 215.2 million m^3/a. So the amount of water demanded by both the rural and urban is 35.7-million m^3/a, which is 17% of the groundwater. The rest 83% of groundwater is unutilised.

5.9.7 DARCY'S LAW IN QUANTIFICATION OF GROUNDWATER FLUX IN AQUIFERS.

The contribution of groundwater to the flow system is quantified based on Darcy's law defined by the following equation:

$$Q = \frac{-KA(h_A - h_B)}{L} \tag{5.6}$$

where Q is the discharge into aquifer measured in m^3/d, K is the hydraulic conductivity in m/d, A is the product thickness and width of the aquifer as the cross-sectional area of saturated aquifer in the direction of flow in square meters. h_A

and h_B are heads of two points that define the line of flow of groundwater and h_A-h_B is the head difference between the two points and L is the length or distance of travel or the flow length in meters.

Generally, the Darcy's law from equation 5.6 is often expressed as;

$$Q = -KA\left(\frac{dh}{dl}\right) \qquad (5.7)$$

where $\frac{dh}{dl}$ is the hydraulic gradient. However, the above-mentioned formula when used for aquifers in Pallisa district would be based on the assumption that there is slow moving groundwater which is the upper limit of Darcy's law and that the aquifer is confined. More detailed information by use of Darcy's law would be necessary in future research work.

5.10 MANAGEMENT

Proper management is dependent on accurate and consistent monitoring and for the system to work efficiently; both the resources and the consumption must be well managed. Of concern is the increasing population and the boreholes and wells that are utilised over where there is no proper system of management or monitoring control.

5.10.1 WATER RESOURCE MANAGEMENT IN UGANDA

5.10.1.1 WATER STATUTE, 1995

The Water Statute, enacted in 1995, is the fundamental code for the use, protection and management of water resources and water supply; for the constitution of water and sewerage authorities; and to the devolution of water supply and sewerage undertakings. The main objectives of the Statute are:

a. To promote the rational management and use of the waters of Uganda;
b. To promote the provision of clean, safe and sufficient supply of water for domestic purposes for all persons;
c. To allow for orderly development and use of water resources for purposes other than domestic use, such as the watering of stock, irrigation, agriculture,

industrial, commercial and mining purposes, energy, navigation, fishing, preservation of flora and fauna and recreation in ways which minimizes harmful effects to the environment and;

d. To control pollution and promote safe disposal of wastewater.

The Statute provides the basic declarations of Government and individual rights to water. It is the fundamental code for the investigation, planning and management of water resources. It also confers powers, which previously did not exist, on any person or public authority including local councils or other central, regional or local government body, which may be given responsibility over either water supply or sewerage.

Currently, the overall goal of Government of Uganda with respect to water resources management under the Water Resources Management Department (WRMD) is to promote and ensure the rational and sustainable utilisation and development, and the effective management and safeguard of water resources of Uganda for social and economic welfare and development.

5.10.1.2 THE FUNCTIONS OF WRMD

The functions of WRMD are:

a. Monitoring the quantity and quality of surface and ground water resources nationally;
b. Providing reference water quality analytical services;
c. Storing, processing and disseminating water resources data and information to all users;
d. Conducting water resources assessment studies and providing guidance to water development programmes and to government based on study findings;
e. Formulating and reviewing national water resources development and management plans and frameworks;
f. Providing advice to the National Environment Management Authority (NEMA) through the review of Environmental Impact Studies on water resources related projects;

g. Reviewing and providing advice to NEMA on standards for water quality effluent discharge;
h. Processing, monitoring and enforcing permits for water abstraction, wastewater discharge, borehole drilling and construction of hydraulic works and;
i. Providing advice to the Water Policy Committee (WPC) on transboundary water policies and agreements to ensure their equitable use and adequate protection.

For people to have sustainable improvement in their standards of living, they must have among others, access to safe water and adequate sanitation.

Under the constitution of the Republic of Uganda (1995) and the National Water Policy, (1999), the state has a duty to: a) protect the natural resources such as water on behalf of the people of Uganda; b) promote clean and safe water and its management at all levels; c) promote sustainable development and public awareness in utilising natural resources such as water, of the need to manage it in a balanced and sustainable manner for the present and future generations.

This forms the core of the two Government of Uganda's water sector institutions, namely; the Directorate of Water Development (DWD) and the National Water and Sewerage Corporation (NWSC) - all under the Ministry of Water, Lands and Environment. Therefore, the Government of Uganda is responsible for and has the authority over, water resource management, the necessary allocation and usage of water and the transfer of water between catchments and international water matters through the Ministry of Water Lands and Environment.

The Ministry of Water Lands and Environment, has the authority over the water resources, the government of Uganda ensures that the development, apportionment, management and use of those resources is carried out by using the method to suit the public, on sustainability, equality and to be used efficiently in a situation that public would trust with the necessary obligations and the value of water to different communities in Uganda and Pallisa in particular, given that the basic domestic needs, the requirements of the environment and international interests are met.

Water resources should be developed and managed in such a manner as to enable all those that use, to gain equitable access to the desired quantity, quality and reliability of water. Conservation and other measures to manage demand should be actively promoted as a preferred option to achieve these objectives. Water quality and quantity are interdependent and should be managed in an integrated manner, which has to be consistent with broader environmental management approaches.

Water quality management options include the use of economic incentives and penalties to reduce pollution; and the possibility of irretrievable environmental degradation as a result of pollution has been done, Water Statute (1995) and the Water (Waste Discharge) Regulations, (19998). Water resource development and supply activities are managed in a manner that is consistent with the broader government's approach to environmental management.

Since many land uses in Uganda have a significant impact upon the water cycle, the regulation of land use where appropriate, is used as an instrument to manage water resources within the broader integrated framework of land use management. Any authorisation to use water is not given in a timely fashion and in a manner that is clear, secure and predictable in respect of the assurance of availability, extent and duration of use due to the fact that the Land Law in Uganda that provides that land belongs to the people.

The development and management of water resources is carried out in a manner that is regulated through the administrations of permits for water abstractions that specify the types of uses that need to be regulated as well as abstraction fees to be charged, waste water discharge because of the need to ensure adherence to international and national standards, through enforcement of standards regulations and by-laws, by mediation that is the use of elders and LC systems as appropriate including local council (s), (LCs), courts and capacity building with a view of analysing water quality.

5.10.1.3 INSTITUTIONAL FRAMEWORK

The institutional framework was established and in particular the following were put in place.

a. ***A Water Policy Committee (WPC),*** established under the Water Statue, 1995 has been operationalised. For the first time there is now a statutory body overall responsible for setting national policies and standards, coordinating the plans of the various water related sectors and mediating in any disputes between agencies. The 12 Members comprise relevant government ministries and departments, representatives from district administrations and two persons having special qualifications and experience.

b. The dual roles of the ***Directorate of Water Resources*** have been rationalized. Before WAP, DWD was responsible for both water resources management and for development of small urban and rural water supplies and sewerage works. This was against the general view that responsibility for water resources management should be separated from the responsibility for development of the resources - to allow for impartial allocation between different users. The separation of responsibilities is even more critical between wastewater disposal and issuing permits for effluent discharges. In the recent civil service reform, the functions, powers, responsibilities of DWD has been rationalised. The development, operation and maintenance of water supplies and sewerage services have been transferred from DWD to the districts and lower local governments. DWD's remaining role, with respect to water supply and sanitation, is that of central planning, monitoring, and supervision of services provided by others. This new role now compliments, rather than conflicts, with DWD's strengthened role as manager of the nation's water resources.

c. A ***Water Permit Unit*** has been established within DWD, as a result of the recent civil service reform, to strengthen DWD's new statuary role in regulation of water use and wastewater discharge. The Unit is responsible for coordinating processing of applications for water permits.

d. A ***Sector Planning and Co-ordination Unit*** has also been established under the DWD to monitor the implementation of the WAP. Besides following-up of implementation of WAP, the Unit is responsible for internalising the plan to DWD staff and serves as a lighthouse for capacity building. Also, it is responsible for defining how and when the Water Action Plan should be updated and acts as a Secretariat for the Water Policy Committee.

e. The establishment of ***The National Environment Management Authority (NEMA)*** *in 1996* has strengthened the overall linkage between water and the general environmental management. In particular the supervision and co-ordination of environmental impact assessment, a requirement before a water permit is issued for new developments

f. The ***District and Local council levels*** with the overall strategy that is in line with Government of Uganda policy of "SOME FOR ALL - RATHER THAN MORE FOR SOME" that is to say:

- User ownership
- Gender participation
- Community financing
- Private sector participation
- Decentralization

All the implementation is carried out by the district officers down to the communities through the emphasized use of participatory methods. DWD only gives guidance and support.

Likewise the private sector to carries out all construction activities like drilling, spring construction, training etc. and DWD offers back-up support. In line with the decentralization policy, DWD's major task is capacity building right from the district to the village level. Capacity building is in terms of management skills including planning, coordination, implementation, monitoring, budgeting, community mobilization, material and infrastructure support.

The demand driven approach is used in order to create a sense of responsibility of the facilities and practices attained.

The Water Action Plan lays down the process and actions, which ensure sustainable management of water resources. It prioritized functions for immediate and later consideration and placed some of these at the national level while others were to be decentralized to the district level.

The National Water Policy among others provides the village water users groups which are mandated to manage, operate and maintain point water sources through village level operation and management and to protect such sources to ensure safe and clean water (Directorate of Water Development, 1995).

5.11 GROUNDWATER MONITORING

In principle a groundwater project designer should always be in a position to predict the long-term behaviour of the aquifer in relation to the planned programme of water abstraction and to the possible climatic fluctuations, which may affect the recharge of the aquifer. Many of these monitoring wells have been constructed (Figure 92).

Water wells should be designed in such a way that in no case the water level would drop down out of the reach of the designed water lifting devices. This means for example that dug wells should be deep enough to always contain sufficient water for the users to draw it.

5.11.1 GROUNDWATER QUALITY MONITORING

Groundwater quality monitoring could be understood as a continuous, methodically and technically standardized programme of observations, measurements and analysis of selected physical, chemical and biological variables of groundwater.

The objectives were:

i) To collect, process and analyse data on groundwater quality as a baseline for assessing the current state, anticipating changes and forecasting trends in groundwater quality due to natural processes and human impact in time and space and;

ii) To provide information for improvements in planning, policy, strategy and management of groundwater protection and quality conservation.

Figure 92 shows the distribution of monitoring water points/sites in Uganda. Pallisa district has been included.

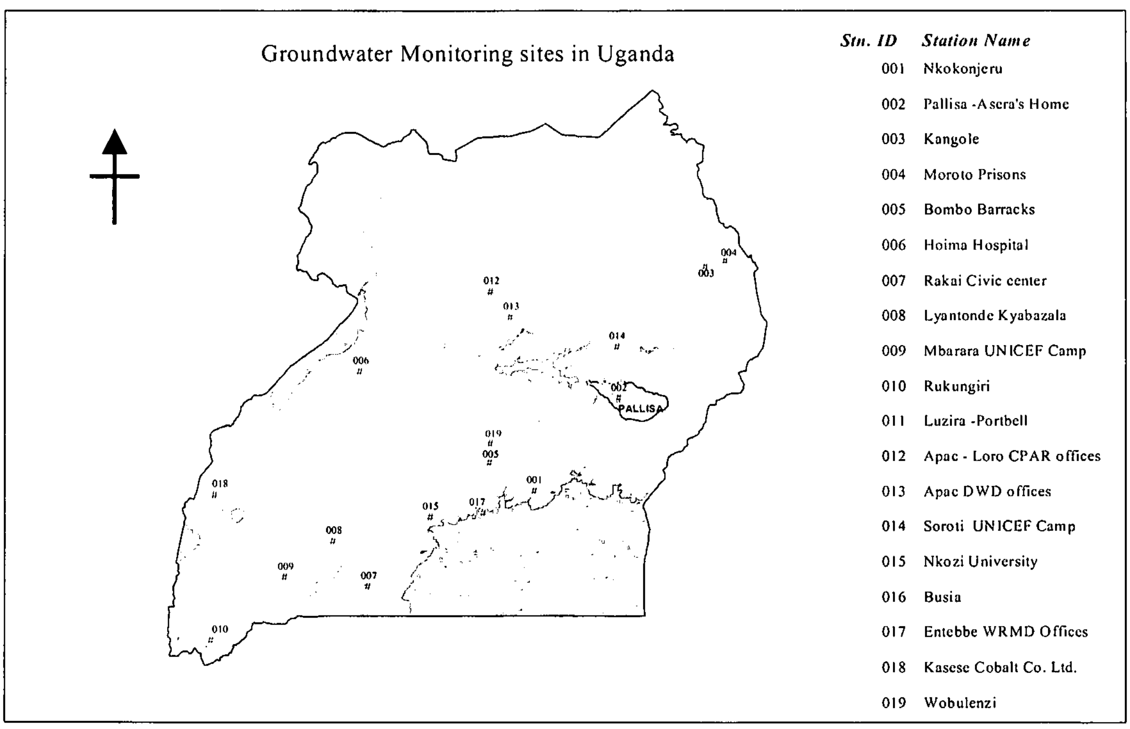


Figure 92. Groundwater monitoring sites in Uganda. Inclusive is Pallisa district. Scale 1:5 000 000. Source: GIS department, Entebbe.

This means also, in the case of the drilled wells, usually much deeper than the water level, to design the pumping equipment in such a way that no risk would occur for the pumps to run dry and either to be damaged or to let thousands of animals without water.

The water authority in this case the Directorate of Water Development (DWD) should be responsible for the following: -

- Monitoring of the production aquifers with respect to water level and quality variations;
- Monitoring of consumption at all water outlets;
- Management of reticulation system including arranging for repairs and maintenance to be undertaken and providing metered outlets;
- Management of the resource to prevent over utilization and to take the required steps should the resource reach a critical level. It should be noted that a critical level would occur when the water level along the aquifer drops by 50% of the saturated zone;
- Management of the water quality in order to take the required steps should pollution of the aquifer occur;
- Strict control over the waste disposal activities.

A proposed monitoring and management programme could be summarised as follows: -

- Monitor water levels within a sufficiently representative number of boreholes penetrating the aquifer;
- Maintain all the automatic water level recorders as these provide an excellent reflection of the status of the aquifer;
- The number of specific boreholes to be monitored for each village and;
- Have this data analysed by geohydrologists on quarterly basis.

For an efficient monitoring system, Table 30 proposes the different monitoring frequencies in the assessment of groundwater quality intended for domestic use in Pallisa district.

Table 30. Proposed monitoring frequency in the assessment of groundwater quality intended for domestic use in Pallisa.

SUBSTANCE	MONITORING FREQUENCY
Electrical conductivity (EC)	Quarterly. May depend on available financial resources.
pH	Quarterly. May depend on available financial resources.
Turbidity	Quarterly. May depend on available financial resources.
Faecal coliforms	Quarterly, depending on the microbial quality of the water.
Commonly present in groundwater	
Nitrate/Nitrite as N	Quarterly
Fluoride	Quarterly
Sulphate	Quarterly
Chloride	Quarterly
Arsenic	Quarterly
Total coliforms	Quarterly, depending on the microbial quality of the water.
Occurs less frequently of real concern to health.	
Cadmium	Quarterly
Copper	Quarterly
Commonly present at concentrations of aesthetic or economic concern	
Manganese	Quarterly
Zinc	Quarterly
Iron	Quarterly
Potassium	Quarterly
Sodium	Quarterly
Magnesium	Quarterly
Calcium	Quarterly
Total Hardness	Quarterly

Please note: The substances, which should be included in a groundwater monitoring and any health assessment, depend on the characteristics of the pollutant or pollutants, the source of pollution, area of assessment for example at the water source or at the point of use and various other factors.

Monitoring of groundwater quality forms an integral part of groundwater protection and is essential whenever the water forms an important resource or where human activities may generate substances that may pollute groundwater.

Where groundwater is being used for human consumption and domestic purposes the water quality can be monitored to ensure that the water quality is acceptable and remains as desired.

The frequency of monitoring differs from constituent to constituent and depends on the characteristics and concentration of a constituent or pollutant, seriousness of the pollution problem or potential pollution problem. With the monitoring frequencies proposed, the next Chapter 6 deals the conclusions drawn from the findings and recommendations for further research in the study area.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSION

The following conclusions are drawn from this study:

a. The hydrogeology of Pallisa district can be summarised in the groundwater domains, defined by the porous aquifers (water contained in the soil covers) and the fractured aquifers (water contained in the basement complex);

b. The importance of groundwater is strongly increasing in urban areas where surface water was dominating the supply of potable water. Many of the small towns of Budaka, Kamuge, Kibuku and Kamonkoli are now supplied with groundwater. The demand of water in the more remote areas where a growing population is today can cheaply be managed with groundwater supply;

c. The study reveals that there is enough groundwater in Pallisa district. Groundwater will remain important for rural areas in Pallisa and Uganda as a whole and not much overexploitation is anticipated. In periods more especially from March to June and September to November, where 50% of the annual rainfall precipitate, rainwater harvesting should be promoted.

d. This study further confirmed that groundwater flow in the bedrock aquifer is entirely due to the secondary permeability in the form of rare, discrete, and seemingly random fractures;

e. Quantitative assessment of the hydrogeological properties of the bedrock aquifer confirms that the aquifer is extremely weak, with little transmissive capacity. The weakly transmissive character of the bedrock is demonstrated by the constant yield tests conducted at the various sites in Chapter 5. Taken as a whole, over 28% of the wells show transmissivity values of less than 1 m^2/d; just 23% show transmissivity values greater than 5 m^2/d. This means that most of the yields from these boreholes lie between 1 –5 m^2/d;

f. Significantly, none of the higher transmissivity values occur in the areas where unusual physiographic or natural features might have indicated that higher transmissivities could be encountered. Neither is there evidence that the higher values of transmissivity are due to any contribution from the regolith;

g. From this research, it is evident that the crystalline basement rocks are extensively concealed by a regolith, which is a result of intense chemical weathering. The saturated thickness of this unit is variable and the aquifer can be dry in areas of low rainfall and/or steeply sloping topography;

h. Quantitative hydrogeological studies of the regolith reveals that the unit is considerably more permeable than the underlying bedrock and, where a substantial thickness exist, is likely to provide a significant better aquifer;

i. In this study area, the rainfall predicts the timing and magnitude of the groundwater recharge. The magnitude of the recharge estimates appear to be controlled by the number of heavy rain events (> 10 mm/d): estimates vary, but are in the order of 100mm/a to 200mm/a. Land-use clearly has a very important effect on recharge rates, with both forest and wetland playing major factors in the catchment water balance;

j. From a human health point of view, most of the groundwaters are generally acceptable in terms of their inorganic water quality. Aesthetically, however, many groundwaters show excessive levels of aluminum, chloride, iron, manganese, zinc and hardness in a limited number of wells, thus substantiating concerns raised by the consumers nearby some of these wells;

k. Where health standards are exceeded, nitrate and chromium are the usual problems. Evidence of groundwater quality deterioration is associated with the corrosion of the borehole casings and the raising mains, or the seepage of the wastewater into shallow wells from domestic wastes due to insufficient sanitary practices by humans and livestock. Wastewaters are generally responsible for elevated concentrations of chlorides and nitrates, while corroded pipe work increases the contents of iron, zinc and manganese. However, elevated aluminum, iron, manganese and to some extent chromium, are also associated with natural weathering of the aquifer matrix;

l. The study further reveals that groundwater recharge in Pallisa is 110 mm/a produces an equivalent of 215.2-million m^3/a and with the total amount of water demanded for rural and urban being 35.7-million m^3/a, almost 83% of groundwater is left unutilised. This means that rainfall plays an important role in the recharge process in Pallisa district with almost 11% of annual rainfall recharge

m. Geophysical survey data analysed indicate the availability of groundwater within 30 – 70 m deep.

6.2. RECOMMENDATIONS

- The report has shown that there is sub-surface outflow and inflow from River Mpologoma and River Dodoi and from Lake Kyoga and Lake Lemwa, could be tapped for a better groundwater development. Recommendations for further research would be undertaken in assessing the groundwater potential in the study area by modelling of the sub-surface inflow.

- The current monitoring station in Pallisa district is around Pallisa town, which only monitors a small distance that is not representative of the whole of Pallisa district. It is further recommended that more monitoring stations be put in place within Pallisa district county by county to cater for seasonal fluctuations of the groundwater and to detect pollution.

- The present state of chemical composition of groundwater in Pallisa district was not finalized and it is recommended the sodium absorption ratio (SAR) of the soil should be re-evaluated in the subsequent studies.

- Efforts should be made to carry out standard aquifer test pumping with observation wells in the north-east of Pallisa district to really come out with a more realistic aquifer properties that control the groundwater flow system and hydraulic links between shallow and deep groundwater in the study area.

- A further recommendation on complete isotopic analysis should be done for the wells in the study area. Plot of δ_D against $\delta^{18}O$ values should clearly indicate whether water lies on the direct recharge mixing line or not.

- Given the enormous variations in conductivity over short distances, there is need to study the hydrogeology of the area at a high resolution. This will enable the study and understanding of the spatial variation of hydrogeology and its causes.

- Further studies should be conducted in the quantification of groundwater based on Darcy's law.

- More boreholes to the north-east of Pallisa district should be sampled for further isotopic studies to identify the real source of recharge to these boreholes.

REFERENCES

Acworth, R. I. (1987): The development of crystalline basement aquifers in tropical environment. *Quarterly Journal of Engineering Geology (London), Vol. 20, pp 265-272.*

Aller, L., T. Bennet, L.H. Lehr, R.J.E. Petty & G. Hackett. (1987): DRASTIC, a standardized system for evaluating groundwater pollution potential using hydrogeologic settings. *U.S. Environmental Protection Agency, Ada, OK. EPA Report 600/2-87-035:1-445.*

Almond, D.C. (1962): Explanation of the Geology of Sheet No. 15 (Kitgum) *Report No.8 Geology Surv., Uganda.*

Anon. (1970): Groundwater Pollution, *Water well Jour., Vol. 24 No. 7, pp. 31-36.*

Arora and Bhattachariya. (1994): Water Resources Engineering *pp. 47-66.*

Bailey, K.D. (1996): Methods of Social Research. *4th ed. New York: Free Press; Maxwell.*

Banks, H. O. (1952): Utilization of Groundwater storage reservoirs., *Trans. Amer. Sci. Civil Engrs Vol. 118., pp. 220-234*

Beeson Sarah and Jones C. R. C. (1988): The combined EMT/ves Geophysical methods for siting Boreholes. *Groundwater, Vol. 26 No. 1, January-February*

Benson, R.C. and Pasley Jr, D.C. (1984): Groundwater Monitoring: A Practical Approach for Major Utilities. *Fourth National Symposium and Exposition on aquifer Restoration and Groundwater Monitoring, May 23-25, 1984. The Fawcett Center, Columbus, Ohio. Pp270-278.*

Bishop, W. W., (1969): "Pleistocene stratigraphy in Uganda", *Geology Surv. Uganda. Memor x*

Botha, J.F. and Muller, J.L. (1984): A preliminary investigation of modelling the Atlantis aquifer. *Published M.Sc thesis, UOFS, Bloemfontein, pp 10.*

Bredenkamp, D.B (1999): Groundwater monitoring, A critical evaluation of groundwater resource evaluation and management. *Final technical report to the Water Research Commission- Project WRC K5/838. pp.1-17.*

Briggs, D., P. Smithson and T. Ball. (1989): Fundamentals of Physical Geography (Can. Ed.), *Copp Clerk, Ontario, Canada, pp594.*

Busha, C.H & Harter, S.P. (1980). Research Methods: *Techniques and interpretation. London: Academic Press*

Carter, R.C. (1999): The Impact and Sustainability of community water supply and sanitation programmes in developing countries. *J. Instn. Wat. And Envir. Mangt. 13, pp. 292-296.*

Chilton, P. J. and Smith-Carington, A.K. (1984): Characteristics of weathered basement aquifer in Malawi in relation to rural water supplies. Challenges in African Hydrology and water resources (Preceeding of Harare Symposium, July 1984), *International Association of Hydrogeologists' series Publication No. 144, pp 15-23.*

Chiew, F. H. S. and McMahon, T. A., (1990): Estimating groundwater recharge using a surface watershed modelling approach. *Journal of Hydrology, 114(3-4): pp.285-304.*

Clark, L. (1985): Groundwater abstraction from Basement Complex Areas of Africa. *Q. J. Eng. Gell. 18 pp 25-34.*

Cooley, R.L. and C.M. Case. (1973): Effect of a water table aquitard on drawdown in an underlying pumped aquifer. *Water Resources Res., Vol. 9, pp.434-447.*

Covers, C. S. (1961): Groundwater resources Development and Management. *US. Geological Survey Circ., 442, pp. 7*

Cowi, Consult. (1981): Rehabilitation of rural water reservoirs - Feasibility study report – Republic of Uganda - *UNCDF Project UGA/79/003, pp.70*

Cowi,. ECWSP. (1999): Water Resources Investigation Consultancy, Phase 1, *Siting Report, Pallisa, (February 1999).*

Cowi,. ECWSP. (1999): Water Resources Investigation Consultancy, Phase 1, *Water Resources Status Report, Pallisa.*

Dansgaard, W., (1964): Stable isotopes in precipitation. *Tellus, 16(4), pp. 436-468.*

Darling, W.G., Edmunds, W.M., Kinniburgh, D.G. and Kotoub, S., (1987): Sources of recharge to the basal Nubian sandstone aquifer, Butana Region, Sudan.

In: *Isotope Techniques in Water Resources Development, IAEA-SM-299/177, Vienna, pp. 205-225.*

David Keith Todd. (1984): Groundwater Hydrology., *pp. 353-376.*

Department of water Affairs and Forestry. (1994): Water Supply and Sanitation Policy. White Paper, Cape Town.

De Ridder, N. A. (1961): The hydraulic characteristics of the Tielerwaard calculated from pumping test data, *Inst. Land and Water Manag. Res., Wageningen, report no. 83 pp.15.*

Directorate of Water Development, (1995): Rapid Water Resources Assessment. Document 007. Uganda Water Action Plan. Ministry of Natural Resources. Kampala. Uganda.

Dobrin, M.B. and Savit, C.H. (1988): Introduction to Geophysical Prospecting. McGraw Hill Book Co. New York (2nd Ed.).

Driscoll, F.G. (1999): Groundwater and Wells, Second Edition.

Duggal, K.N. and J.P. Soni. (1999): Elements of Water Resources Engineering, *Groundwater, pp. 263-297.*

Enon, J.C., (1998): Educational Research: Statistics and Measurements. *2nd ed. Kampala: Department of Distance Education, Makerere University, pp.14-16.*

Environmental Protection Agency. (1976): Manual of water well construction practices - Office of water supply - EPA 57019-75-001 - Washington D.C., USA.

Everett, L. G. et al. (1984): Monitoring Groundwater quality. *Methods and costs, Rept. EPA- 600/4-76-023, US Environmental Protection Agency.*

Farooq Khan, .A. (1998): Water Resources Management, Trust and Challenges. *Water Resources Development under Dry Environment, pp.87-96.*

Farr, J. L. (1982): Groundwater Supply and Exploration in semi-arid regions. *Wat. Supply and Management 6:4, pp. 343-352.*

Fetter, C.W. (1994): Applied Hydrogeology (3rd edition), Prentice-Hall, New Jersey.

Flathe, H. (1970): Interpretation of geo-electrical resistivity measurements for solving hydrogeological problems. *Min. Groundwater Geophys/1967. Ottawa, Econ. Geol. Rpt., 26: pp. 580-597.*

Gat, J.R., (1987): Variability (in time) of the isotopic composition of precipitation: consequences regarding the isotopic of hydrologic systems. *In: Isotope Techniques in Water Resources Development, IAEA-SM-299/177, IAEA, Vienna, pp.551-563.*

Geirnaert, W., Groen, M., Van Der Sommen, J. and Leusink, A. (1984): Isotope studies as a final stage in groundwater investigation of African shield. Proceedings of the Harare Symposium*: Challenges in African Hydrology and Water Resources, IAHS Publ. No 144, pp. 141-153.*

Gringarten, A.C. (1982): Flow test evaluation of fractured reserviours. In: **Narasimhan, T.N**. Recent trends in hydrogeology. *Geological Soc. Am. Special Paper 189, pp 237-263.*

Groundwater Manual. (1981): A water resources technical publication. U.S. Department of the Interior; Water and Power services, *pp 480.*

Guidelines for drinking water quality. (1984): WHO Report, Geneva. *pp 80-85.*

Gupta, A. S. and Onta, P. R. (1982): Sustainable groundwater resource development. *Hydrological Sciences Journal 42, pp. 565-582.*

Gurcharan Singh (1999): Water Supply and Sanitary Engineering, (5^{th} Ed.) *Quantity of Water, pp.13-40.*

Hartman, L. M. (1965): Economics and groundwater development. *Groundwater Vol.3 no. 2, pp. 4-8.*

Hazell, J. R.T., C.R. Cratchley and C.R.C. Jones. (1992): The Hydrogeology of crystalline aquifers in Northern Nigeria and geophysical techniques used in their exploration. In: Wright, E.P and Burgess W.G (eds), Hydrogeology of crystalline Basement Aquifers in Africa Geological Society, London, *Special Publication No.66, pp155-182.*

Hodgson, F.D.I. (1991): Report on the installation of water quality monitoring systems at the Tutuka Power Station. *Confidential Report to Eskom, pp 76.*

Houston, J., (1990): Rainfall – Runoff – Recharge Relationships in the Basement Rocks of Zimbabwe. In: *Groundwater Recharge; a guide to understanding and estimating natural recharge. IAH 8: Chapter 21.*

Howard, KWF and Lloyd, J.W., (1979): The sensitivity of parameters in the Penman evaporation equations and direct recharge balance. *Journal of Hydrology, 41, pp. 329-344.*

Howard, K.W.F., M Hughes, D.L. Charlesworth and Ngobi, G. (1992): Hygrogeologic evaluation of fracture permeability in crystalline basement aquifers of Uganda. *Journal of Applied Hydrogeology, Vol. 1, pp 55-65.*

Howard, K.W.F. and Karundu, J. (1992): Constraints on the exploitation of basement aquifers in East Africa – Water balance implications and the role of the regolith. *Journal of Hydrology, Vol. 139, pp 183-196.*

Jacob, C.E. (1944): Notes on determining permeability by pumping tests under water table conditions. U.S. Geol. Surv. Open. File.

Jones, M.J. (1985): The weathered zone aquifers of basement complex areas of Africa. *Quarterly Journal of Engineering Geology (London), Vol. 18, pp 35-46.*

Kerlinger, F.N, (1979): Behavioral research: A Conceptual approach. *New York: Holt Reinhart & Wilson, pp. 701.*

Key, R.M. (1992): An introduction to crystalline basement of Africa. In: Wright, E.P and Burgess W.G (eds), Hydrogeology of crystalline Basement Aquifers in Africa Geological Society, London, *Special Publication No.66, pp29-57.*

Kothari, C.R, (1990): Research Methodology: Methods and Techniques. *2nd ed. New Delhi: Wishwa Prakashan, pp. 39.*

Kruseman, G. P. and De Ridder N. A. (1994): Analysis and Evaluation of Pumping Test Data. *IILRI Publication 47, The Netherlands. pp 55-71.*

Lee, J and Lee, K. (1999): Analysis of the Quality of Parameter Estimates from Repeated Pumping and Slug Tests in Fractured Porous Aquifer System in Wonju, Korea, *Groundwater 37 No. 5.*

Leroux, M., (1983): The Climate of Tropical Africa, *Paris, pp. 274.*

Mbaaga, F.M.K., (1990): Introduction to Social Research. *Kampala: Makerere University, pp 94*

McFarlane M.J.(1992): Groundwater Movement and water chemistry associated with weathering profiles of African Surface in parts of Malawi. In: Wright, E.P. &

W.G. Burgess (Editors), *Hydrogeology of crystalline basement aquifers in Africa. Geological society (UK) Special publication No. 66, pp 264.*

Morgan, N.E. (1998): Groundwater chemistry and quality assessment of Lake Naivasha area, Kenya. *M.Sc. Thesis, International Institute for Aerospace Survey and Earth Sciences, Enschede (ITC), pp 16.*

Moench, A.F. (1984): Double-porosity for a Fissured Groundwater Reserviour with Fractured skin, *Water Resources Research 20 No.7.*

Morris, D.B. (1964): The application of resistivity methods to groundwater exploration of alluvial basins in semi arid areas. *Journal of the Institution of Water Engineering, Vol. 18, No. 1.*

National Curriculum Development Center, Uganda (2001): Geological, soils and natural vegetation maps of Uganda. *Scale 1:7 000 000. pp. 17.*

Neuman, W.L., (1997): Social Research Methods: qualitative and quantitative approaches. *3rd ed. Boston: Allyn & Bacon, pp. 137-151.*

Nissen, E. and Petersen. (1982): Rain catchment and water supply in rural Africa. A manual - Hodder and Stoughton, Bungay, Suffolk, U.K.

Norconsult, A.S. (1979): Hydrology and Hydrogeology of East and Northern areas of Uganda. *Special reference to Pallisa and Moroto. Pp 19-20.*

Norconsult/Interconsult, RUWASA. (1998): Corrosion Study Report, *Draft Final Report of June, Mbale.*

Odera, F.W., R.W. Van Lisa and H.R.J. Van maanen. (1987):Detecting Fractures by Electromagnetic (EM) and Geo-electric (GE) profiling. World Water.

Omorinbola, E. O. (1984): Groundwater Resources in tropical Africa regolith. Challenges in African Hydrology and water resources (Preceeding of Harare Symposium, July 1984), *International Association of Hydrogeologists' series Publication No. 144, pp 57-72.*

Oppong-Boateng, R. (2001): Assessment of the use of groundwater for irrigation in southern part of Lake Naivasha, Kenya. *M.Sc. Thesis, International Institute for Aerospace Survey and Earth Sciences, Enschede (ITC), pp 36.*

Peacock, R., (1990): "Data Analysis and Interpretation (quantitative)" In Research Methods in Library and Information Studies. *Edited by Margret Slater. London: Library Association, pp.77-106.*

Peters, H.J. (1968): Groundwater Management. *Water resources Bull. Vol. 8., pp 188-197.*

Raghunath, H.M. (1995): Hydrology; Principle Analysis and Design; *Groundwater pp.206-229.*

Rushton, K. R. and Rathod, K. S., (1985): Horizontal and vertical components of flow deduced from groundwater heads. *Journal of Hydrology, 79(1), pp 261-278.*

Ruwasa. (1996): Groundwater Assessment Survey, Pallisa District.

Ruwasa. (1996): Water Point Inventory Survey, Pallisa District, *Final Report of July.*

Santosh Kumar Garg. (1999): Water Supply Engineering. (11^{th} Ed.); *Development of Groundwater, pp.112-230.*

Sambasiva Rao and Sankara P.P. (1991): Water Ecology, Pollution and Management; *Water Resources Management. Vol. 1. pp.67-87.*

Santosh Kumar Garg. (2000): Hydrology and Water Resources Engineering; *Groundwater Hydrology and Sub-surface Sources. Pp.553-675.*

Schoeller, H.J. (1977). - Geochemistry of groundwater - Supplement No. 3 to Groundwater Studies - UNESCO Tech. Papers Hydrol. 7 - UNESCO, Paris.

Serrano, S. E. and Unny, T. E., (1987): Predicting groundwater flow in a phreatic aquifer. *Journal of Hydrology, 95(3-4), pp.241-268.*

Sklash, M.G. and Mwangi, M.P., (1991): An isotopic study of groundwater supplies in the Eastern Province of Kenya. *Journal of Hydrology, 128, pp. 257-275.*

Sondhi, S. K., Rao, N. H., and Sarma, P. B. S., (1989): Assessment of groundwater potential for conjunctive water use in a large irrigation project in India. *Journal of Hydrology, 107(1-4), pp. 283-295.*

Suresh, R. (1997): Watershed Hydrology; *Precipitation Measurement and Analysis pp.26-81.*

Suresh, R. (2000): Soil and Water Conservation Engineering; *Rainfall and Run-off Relationship. Pp.25-96.*

Topographic map. (1998): scale 1:250,000. Series Y732, Sheet 62/1, Pallisa, Edition 3-U.S.D.

Taylor, R.G., K.W.F. Howard, J. Karundu and Callist T. (1993): Distribution and Seasonality of groundwater Recharge to the regolith-basement aquifer system in Uganda. *GSA Abstracts Vol. 25, No.6 (September, 1993).*

Trivedi, P.R. (1997): Water Pollution; *Analysis of Water Quality pp.139-162.*

Uma, K. O. and Kehinde, M. O., (1992): Quantitative assessment of the groundwater potential of small basins in parts of southeastern Nigeria. *Hydrological Sciences Journal, 37(4), pp.359-374.*

United Nation, 1995: Population and Water availability. *Water Jour. for October 1995.*

U.S.E.P.A. (1990): Progress in groundwater Protection and Restoration. *Office of Groundwater Protection, U.S., Environmental Protection Agency.*

Verba, J. (2000): Water quality monitoring and protection.

White C.C., J.F.T. Houston and R.D. Barker, (1988): The Victoria Drought Relief Project, I. Geophysical siting of boreholes. *Groundwater, Vol. 26, No. 3 pp 309-316.*

Williams, M. (1998): Groundwater supply and assessment strategy for Namaqualand, *Water Research Commission, Pretoria.*

Wish, 95/98/NT/2000: Programme for Interpretation of Pumping Data, Time series analysis, contours and sections, Institute for Groundwater Studies, Bloemfontein, S.A.

World Health Organization (1984): Guidelines for Drinking-water Quality, Vol. 1, Recommendations. *World Health Organization, Geneva, pp 130.*

Wright, E.P. (1992): The hydrogeology of crystalline basement aquifers in Africa. In: Wright, E.P and Burgess W.G (eds), Hydrogeology of crystalline Basement Aquifers in Africa Geological Society, London, *Special Publication No.66, pp1-27.*

EXECUTIVE SUMMARY

This study aimed at assessing the groundwater resources potential in Pallisa district, which is found in the eastern part of Uganda.

The aims of the investigation can be listed as follows:

- To determine the reliability and applicability of VES in Pallisa district;
- To evaluate the potential for sustainable harvesting of groundwater resource;
- To determine the hydrogeological properties of the aquifer and make recommendations;
- To suggest improved management strategies of water resource in Pallisa district in order to provide basic water services to the rural population and;
- To propose a monitoring programme in the area that will include boreholes to determine the variation of water quality and quantity with time.

The majority of the population of Pallisa district mainly uses groundwater as a source of supply for potable water. Groundwater is increasingly on demand in Pallisa district due to: (i) Population growth, (ii) Modern agricultural practices (iii) Livestock demands. Though springs and shallow wells are a source of groundwater in Pallisa, many of them have not been developed. There is need to have many of them developed to provide clean water and increase in the number of deep wells also in case of consistent droughts.

The geological environment covered by this study consists of a Gneissic Complex Formation or Gneiss and granitic formations of the Pre-Cambrian origins. The study shows that Gneiss complex forms the principal source of groundwater supplies while fresh metamorphic rocks are impermeable.

From the hydrogeological investigations, it is clear that among the three water bearing zones (the upper, the middle and the lower), the metamorphic formations are widely weathered as you go deeper the earth, meaning that the lower zone of fresh geological granitic material are of a fractured bedrock. The study further revealed that the fracture zones have higher hydraulic conductivity with low storage coefficients and are generally confined.

The hydrogeological investigation shows that groundwater in Pallisa district lies right below 30 – 70 m from the surface topography. This was shown by the hydrogeological profiles constructed through the underlying aquifer of the wells around Pallisa town.

Higher transmissivity values were observed in the crystalline rock aquifer which related to the western and north – western of Pallisa district, with an average of 13.5 m^2/d, due to the presence of open waters of Lake Kyoga, Mpologoma and Dodoi rivers. Such transmissivity values typically corresponded to drawdowns in order of a few meters at pumping yields of about 1 m^3/hr.

The recharge rate of 110 mm/a, taken as uniform throughout Pallisa district, had the total amount of groundwater recharged being $1.956*10^9*0.11$ m^3/a = 215.2 million m^3/a. The amount of water demanded by both the rural and urban is 35.7-million m^3/a, which represents 17% of the groundwater currently used. The rest 83% of groundwater is unutilised.

The hydro-chemical characterisation of waters in the study area show that the groundwater from the bedrock aquifers of Pallisa district represent regimes where there are predominantly calcium enrichment, which is typical of lime dosing to neutralize acid waters and both the regolith and bedrock groundwaters are dominated by the carbonate ions. This diversity of bedrock types is as a result of weathering of the underlying material. However, groundwater from many of the boreholes in Pallisa district is generally acceptable for human and livestock consumption.

Stable isotopes of oxygen and hydrogen has been extensively used to investigate the rainfall and seasonal patterns of deuterium and ^{18}O content of rainfall in the study area i.e. Pallisa district. This was inferred from historical observations at Entebbe, approximately 180 km to the south. The average monthly rainfall and δ_{18} clearly demonstrates a relationship between the amount of rainfall and depletion in ^{18}O.

As. part of the present study, monitoring of the groundwater resource in terms of yield aquifers with respect to drawdowns and water quality, consumption at water using production boreholes and management of these boreholes play important roles that can never be underestimated as per the recommendations made.

APPENDICES

Appendix A –	**Certificates of Water Quality & Pollution Control Analyses.**
Appendix B –	**The Geo-electrical Profiles Horizontal and Vertical Sounding Data**
Appendix C–	**Lineaments and watersheds**
Appendix D–	**Step drawdowns and Cooper-Jacob Graph Analyses**
Appendix E–	**Pumping Test Data for some boreholes and Maps**

Appendix A **Certificates of Water Quality & Pollution Control Analyses.**

APPENDIX A$_1$ Certificate of Surface water Analysis of Lake Lemwa

Form A

WATER QUALITY & POLLUTION CONTROL LABORATORY - ENTEBBE

Certificate of Analysis

NAME OF CLIENT: COWI	SOURCE NAME & TYPE: Lake Leniwa , Surface Water	DATE SAMPLED:	29/06/1999
ADDRESS OF CLIENT KAMPALA	SOURCE LOCATION: Pallisa	DATE RECEIVED:	30/06/1999
LABORATORY NO: E0917	SAMPLED BY: Client	ANALYSIS COMPLETION DATE:	08/07/1999

METHOD CODE	PARAMETER	TEST RESULT	Total S.D of AQC(±)	Deviation from Control(mg/litre)	METHOD CODE	PARAMETER	TEST RESULT	Total S.D. of AQC(±)	Deviation from Control(mg/litre)
1000	Colour (Hazen Units)	20.47	0.303	0.58	2050	Free Carbondioxide(mg/litre)	ND	-	-
2000	Temperature (°C)	ND	-	-	2060	Total Residual Chlorine(mg/litre)	N.R	-	-
1020	pH (pH Units)	8.8	0.015	0.02	2060	Combined Chlorine(mg/litre)	N.R	-	-
1030	Electrical Conductivity (uS/cm)	284	2.22	-9	2060	Free Chlorine(mg/litre)	N.R	-	-
1040	Total Dissolved Solids (mg/litre)	NR	-	-	1130	Fluoride (mg/litre)	0.29	0.084	0.21
1041	Total Dissolved Solids (mg/litre)	225	-	4	1140	Chloride (mg/litre)	45	2.69	5
1050	Suspended Solids at 105°C(mg/litre)	4.1	1.25	-0.3	1150	Sulphates (mg/litre)	7	1.05	0
1051	Suspended Solids at 600°C (mg/litre)	NR	1.44	-	1160	Sulphide (mg/litre) as HS	N.R	-	-
1060	Turbidity (NTU)	22.5	0.052	0.1	1170	Ammonia (mg/litre) as N	N.R	0.023	-
1070	Phenophthalein Alkalinity(mg/litre) as CaCO	NR	-	-	1180	Nitrates (mg/litre) as N	0.08	0.018	0.04
1070	Total Alkalinity (mg/litre) as $CaCO_3$	100	0.949	1.2	1190	Nitrites (mg/litre) as N	0.003	0.002	0.002
1070	Carbonates (mg/litre)	NR	-	-	1200	Total Nitrogen (mg/litre) as N	N.R	0.448	-
1070	Bicarbonates (mg/litre)	120	-	-	1210	Reactive Phosphorous (mg/litre) as P	<0.08	0.023	0.04
1080	Total Hardness (mg/litre) as $CaCO_3$	70	2.21	-0.8	1220	Total Phosphorous (mg/litre) as P	N.R	0.017	-
1080	Calcium (mg/litre)	18	-	-	2070	Dissolved Oxygen (mg/litre)	ND	-	-
1080	Magnesium (mg/litre)	14	-	-	1240	Biochemical Oxygen Demand (mg/litre)	N.R	0.152	-
1090	Sodium (mg/litre)	34	0.432	1	1250	Chemical Oxygen Demand (mg/litre)	N.R	8.77	-
1100	Potassium (mg/litre)	5.9	0.093	0.0	1230	Chlorophyll-a (mg/litre)	N.R	-	-
2190	Ferrous Iron(mg/litre)	ND	-	-	1260	Oil & grease (mg/litre)	N.R	-	-
1110	Total Iron (mg/litre)	1.37	0.039	0.04	1270	Phenol (mg/litre)	N.R	-	-
1120	Manganese (mg/litre)	ND	-	-	1280	Surfactants (mg/litre)	N.R	-	-

Note:

1. S.D = Standard Deviation; AQC = Analytical Quality Control Standar NR = Not Required ND = Note Done
2. S.D values have been quoted only for methods that have been validated in our laboratory.
3. The type of sample container and sample holding time affect the integrity of the sample and hence the results of analysis.

CHECKED:

for Laboratory Manager

Date 9.7.99

WATER QUALITY & POLLUTION CONTROL LABORATORY

ISSUED: PRINCIPAL ANALYST

Principal Analyst

DATE REMARK Date 9.7.99

Directorate of Water Development
Water Resources Management Department
P.O. Box 19, Entebbe
Tel: 041-321342
Fax: 041-321368

APPENDIX A_2 Certificate of Groundwater Analysis of MB4, Pallisa

Form A

WATER QUALITY & POLLUTION CONTROL LABORATORY - ENTEBBE

Certificate of Analysis

NAME OF CLIENT: COWI	SOURCE NAME & TYPE: MB4 Pallisa , Ground Water	DATE SAMPLED:	04/07/1999
ADDRESS OF CLIENT KAMPALA	SOURCE LOCATION: Pallisa	DATE RECEIVED:	08/07/1999
LABORATORY NO: E0940	SAMPLED BY: Client	ANALYSIS COMPLETION DATE:	25/07/1999

METHOD CODE	PARAMETER	TEST RESULT	Total S.D of AQC(±)	Deviation from Control(mg/litre)	METHOD CODE	PARAMETER	TEST RESULT	Total S.D. of AQC(±)	Deviation from Control(mg/litre)
1000	Colour (Hazen Units)	1.5	0.303	0.58	2050	Free Carbondioxide(mg/litre)	NR	-	-
2000	Temperature (°C)	NR	-	-	2060	Total Residual Chlorine(mg/litre)	N.R	-	-
1020	pH (pH Units)	7.0	0.015	0.02	2060	Combined Chlorine(mg/litre)	N.R	-	-
1030	Electrical Conductivity (uS/cm)	510	2.22	-3.6	2060	Free Chlorine(mg/litre)	N.R	-	-
1040	Total Dissolved Solids (mg/litre)	NR	-	-	1130	Fluoride (mg/litre)	1.00	0.084	0.12
1041	Total Dissolved Solids (mg/litre)	375	-	-28	1140	Chloride (mg/litre)	13	2.68	2
1050	Suspended Solids at 105°C(mg/litre)	2.0	1.25	-0.7	1150	Sulphates (mg/litre)	18	1.05	0
1051	Suspended Solids at 500°C (mg/litre)	NR	1.44	-	1160	Sulphide (mg/litre) as HS	N.R	-	-
1060	Turbidity (NTU)	0.39	0.052	0.02	1170	Ammonia (mg/litre) as N	N.R	0.023	-
1070	Phenophthalein Alkalinity(mg/litre) as $CaCO_3$	NR	-	-	1180	Nitrates (mg/litre) as N	0.26	0.018	-0.02
1070	Total Alkalinity (mg/litre) as $CaCO_3$	220	0.949	0.6	1190	Nitrites (mg/litre) as N	0.005	0.002	-0.001
1070	Carbonates (mg/litre)	NR	-	-	1200	Total Nitrogen (mg/litre) as N	N.R	0.448	-
1070	Bicarbonates (mg/litre)	270	-	-	1210	Reactive Phosphorous (mg/litre) as P	<0.08	0.023	0.01
1080	Total Hardness (mg/litre) as $CaCO_3$	230	2.21	0.4	1220	Total Phosphorous (mg/litre) as P	N.R	0.017	-
1080	Calcium (mg/litre)	56	-	-	2070	Dissolved Oxygen (mg/litre)	NR	-	-
1080	Magnesium (mg/litre)	22	-	-	1240	Biochemical Oxygen Demand (mg/litre)	N.R	0.152	-
1090	Sodium (mg/litre)	32	0.432	1	1250	Chemical Oxygen Demand (mg/litre)	N.R	8.77	-
1100	Potassium (mg/litre)	7.7	0.093	0.1	1230	Chlorophyll-a (mg/litre)	N.R	-	-
2190	Ferrous Iron(mg/litre)	ND	-	-	1260	Oil & grease (mg/litre)	N.R	-	-
1110	Total Iron (mg/litre)	1.06	0.039	0.00	1270	Phenol (mg/litre)	N.R	-	-
1120	Manganese (mg/litre)	ND	-	-	1280	Surfactants (mg/litre)	N.R	-	-

Note:

1. S.D = Standard Deviation; AQC = Analytical Quality Control Standar NR = Not Required ND = Note Done
2. S.D values have been quoted only for methods that have been validated in our laboratory.
3. The type of sample container and sample holding time affect the integrity of the sample and hence the results of analysis.

CHECKED:

Laboratory Manager: ....

Date: ....

ISSUED:

Principal Analyst: ....

Date: 26/7/99

Directorate of Water Development
Water Resources Management Department
P.O. Box 19, Entebbe
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APPENDIX A_3 Certificate of Groundwater Analysis MB2, Pallisa.

Form A

WATER QUALITY & POLLUTION CONTROL LABORATORY - ENTEBBE

Certificate of Analysis

NAME OF CLIENT: COWI	SOURCE NAME & TYPE: MB2 Palisa, Ground Water	DATE SAMPLED:	29/06/1999
ADDRESS OF CLIENT KAMPALA	SOURCE LOCATION: Palisa	DATE RECEIVED:	30/06/1999
LABORATORY NO: E0918	SAMPLED BY: Client	ANALYSIS COMPLETION DATE:	08/07/1999

METHOD CODE	PARAMETER	TEST RESULT	Total S.D of AQC(±)	Deviation from Control(mg/litre)	METHOD CODE	PARAMETER	TEST RESULT	Total S.D. of AQC(±)	Deviation from Control(mg/litre)
1000	Colour (Hazen Units)	0.43	0.303	0.58	2050	Free Carbondioxide(mg/litre)	ND	-	-
2000	Temperature (°C)	ND	-	-	2060	Total Residual Chlorine(mg/litre)	N.R	-	-
1020	pH (pH Units)	8.8	0.015	0.02	2060	Combined Chlorine(mg/litre)	N.R	-	-
1030	Electrical Conductivity (uS/cm)	419	2.22	-9	2060	Free Chlorine(mg/litre)	N.R	-	-
1040	Total Dissolved Solids (mg/litre)	NR	-	-	1130	Fluoride (mg/litre)	0.43	0.084	0.21
1041	Total Dissolved Solids (mg/litre)	350	-	4	1140	Chloride (mg/litre)	61	2.68	5
1050	Suspended Solids at 105°C(mg/litre)	<1.0	1.25	0.3	1150	Sulphates (mg/litre)	18	1.05	0
1051	Suspended Solids at 500°C (mg/litre)	NR	1.44	-	1160	Sulphide (mg/litre) as HS	N.R	-	-
1060	Turbidity (NTU)	0.15	0.052	0.1	1170	Ammonia (mg/litre) as N	N.R	0.023	-
1070	Phenophthalein Alkalinity(mg/litre) as CaCO	NR	-	-	1180	Nitrates (mg/litre) as N	0.32	0.018	0.04
1070	Total Alkalinity (mg/litre) as $CaCO_3$	140	0.949	1.2	1190	Nitrites (mg/litre) as N	0.004	0.002	0.002
1070	Carbonates (mg/litre)	NR	-	-	1200	Total Nitrogen (mg/litre) as N	N.R	0.448	-
1070	Bicarbonates (mg/litre)	170	-	-	1210	Reactive Phosphorous (mg/litre) as P	0.16	0.023	0.04
1080	Total Hardness (mg/litre) as $CaCO_3$	140	2.21	-0.6	1220	Total Phosphorous (mg/litre) as P	N.R	0.017	-
1080	Calcium (mg/litre)	32	-	-	2070	Dissolved Oxygen (mg/litre)	ND	-	-
1080	Magnesium (mg/litre)	15	-	-	1240	Biochemical Oxygen Demand (mg/litre)	N.R	0.152	-
1090	Sodium (mg/litre)	34	0.432	1	1250	Chemical Oxygen Demand (mg/litre)	N.R	8.77	-
1100	Potassium (mg/litre)	4.8	0.093	0.0	1230	Chlorophyll-a (mg/litre)	N.R	-	-
2190	Ferrous Iron(mg/litre)	ND	-	-	1260	Oil & grease (mg/litre)	N.R	-	-
1110	Total Iron (mg/litre)	<0.03	0.039	0.04	1270	Phenol (mg/litre)	N.R	-	-
1120	Manganese (mg/litre)	ND	-	-	1280	Surfactants (mg/litre)	N.R	-	-

Note:

1. S.D = Standard Deviation; AQC = Analytical Quality Control Standar NR = Not Required ND = Note Done
2. S.D values have been quoted only for methods that have been validated in our laboratory.
3. The type of sample container and sample holding time affect the integrity of the sample and hence the results of analysis.

CHECKED:

Laboratory Manager:

Date:

MANAGER

WATER QUALITY & POLLUTION CONTROL LABORATORY

ISSUED:

Principal Analyst:

PRINCIPAL ANALYST

Date:

DATE	REMARK.

Directorate of Water Development
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APPENDIX B$_3$ Resistivity Data

Pallisa	VES18			
On Profile EM09, STN 112				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	49.9		313.53	
2.1	29.1		380.31	
3	15.16		416.73	
4.4	6.89		413.65	
6.3	2.75		340.74	
9.1	0.892		231.36	
13.2	0.306	6.24	167.26	292.56
19	0.043	0.0796	48.733	84.024
27.5	0.006	0.077	14.25	17.689
40	0.004	0.048	20.103	23.75
58		0.039		40.91
83		0.0336		72.455
120		0.028		126.45
175				

Pallisa	VES19			
On Profile EM09, STN 84				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	58		364.42	
2.1	27.3		356.78	
3	11.56		317.77	
4.4	4.51		270.76	
6.3	1.986		246.07	
9.1	0.747		193.75	
13.2	0.18	3.95	98.389	185.2
19	0.037	0.579	41.933	61.118
27.5	0.0175	0.22	41.563	50.54
40	0.008	0.093	40.206	46.016
58		0.065		68.184
83		0.043		92.725
120		0.03		135.48
175				

Pallisa		VES19		
On Profile EM09, STN 84				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	22.1		138.86	
2.1	7.44		97.234	
3	1.724		47.391	
4.4	0.342		20.532	
6.3	0.121		14.992	
9.1	0.068		17.637	
13.2	0.0415	0.477	22.684	22.364
19	0.028	0.294	31.733	31.034
27.5	0.02	0.212	47.501	48.703
40	0.0152	0.154	76.392	76.199
58		0.0936		98.184
83		0.0582		125.5
120		0.034		153.55
175		0.0214		205.72

Pallisa		VES33		
On Profile EM07, STN 281				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	68.9		432.91	
2.1	36.6		478.33	
3	18.37		504.97	
4.4	8.5		510.3	
6.3	4.02		498.1	
9.1	1.64		425.37	
13.2	0.46	6.12	251.44	286.94
19	0.096	1.13	108.8	119.28
27.5	0.025	0.24	59.376	55.135
40	0.011	0.105	55.283	51.954
58		0.068		71.33
83		0.0487		105.02
120		0.034		153.55
175		0.021		201.88

Pallisa		VES39		
On Profile EM10, STN 49				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	31.7		199.18	
2.1	18.48		241.52	
3	9.7		266.64	
4.4	4.53		271.96	
6.3	1.524		188.83	
9.1	0.566		146.8	
13.2	0.167	4.25	91.283	199.26
19	0.032	0.614	36.267	64.812
27.5	0.01	0.148	23.75	34
40	0.006	0.069	30.155	34.141
58		0.035		36.714
83		0.022		47.441
120		0.014		63.225
175				

Pallisa		VES01		
On Profile EM06, STN 3				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	31.7		199.68	
2.1	18.48		221.52	
3	9.7		236.64	
4.4	4.53		231.96	
6.3	1.524		184.63	
9.1	0.566		124.4	
13.2	0.167	4.25	59.683	70.262
19	0.032	0.614	51.967	51.812
27.5	0.01	0.148	59.75	56
40	0.006	0.069	50.155	55.141
58		0.035		101.71
83		0.022		144.84
120		0.014		172.82
175				270.52

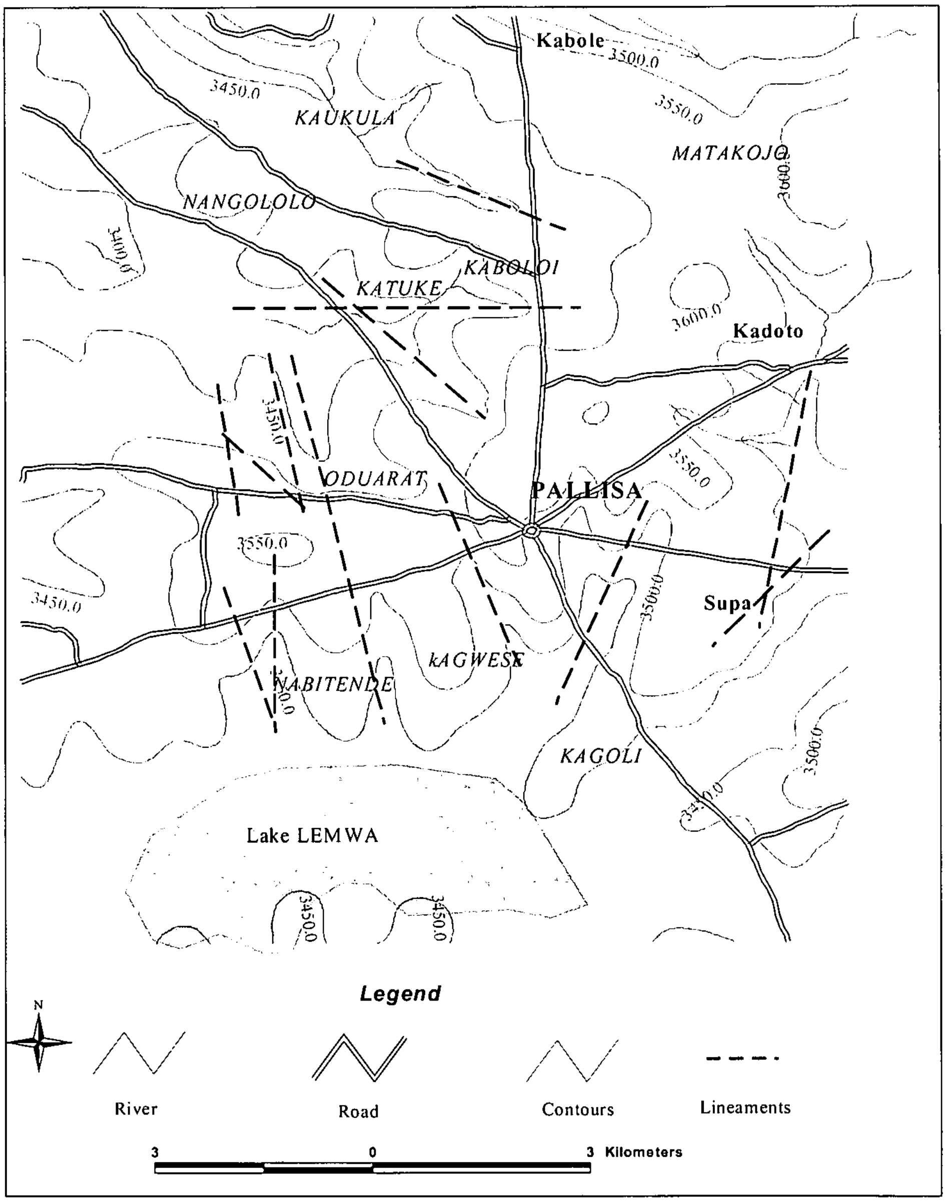
Pallisa		VES29		
On Profile EM07, STN 161				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	39		245.04	
2.1	21.3		278.37	
3	10.44		286.98	
4.4	3.89		233.54	
6.3	1.398		173.22	
9.1	0.381		98.82	
13.2	0.095	1.601	51.928	75.063
19	0.038	0.516	43.067	54.468
27.5	0.0155	0.196	36.813	45.027
40	0.0088	0.0936	44.227	46.313
58		0.044		46.155
83		0.032		69.004
120		0.022		99.353
175				

Pallisa		VES30		
On Profile EM07, STN 183				
	Resistivity			
L/2	a=0.5m	a=5m	Apparent Resistivity	
1.5	28.9		181.58	
2.1	13.3		173.82	
3	6.65		182.8	
4.4	2.34		140.48	
6.3	0.952		117.96	
9.1	0.333		86.37	
13.2	0.139	1.39	75.978	65.17
19	0.077	0.68	87.266	71.779
27.5	0.069	0.387	163.88	88.905
40	0.048	0.22	241.24	108.86
58		0.144		151.05
83		0.136		293.27
120		0.104		469.67
175				

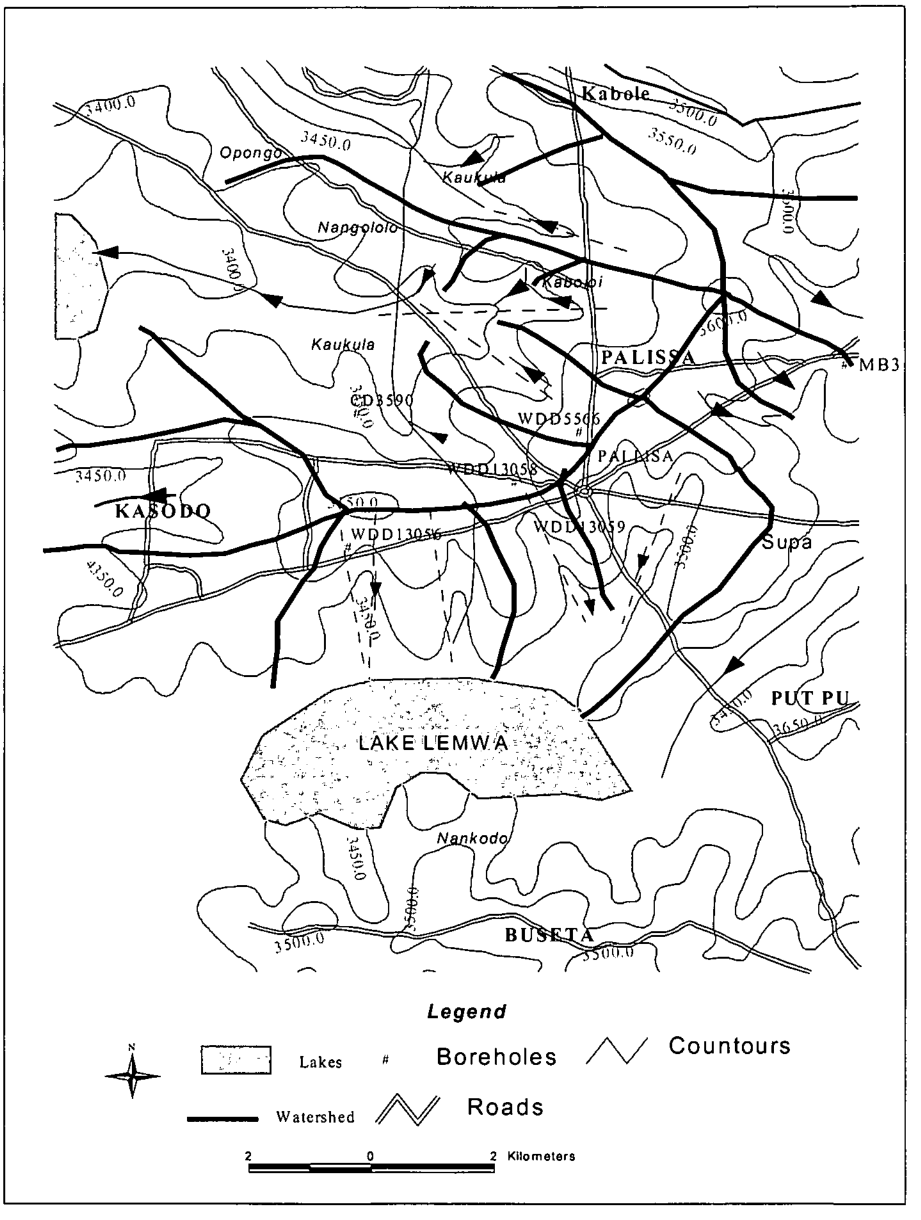
Pallisa		VES34		
On Profile EM07, STN 321				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	114.2		717.54	
2.1	69.8		912.22	
3	36.1		992.35	
4.4	14.25		855.51	
6.3	4.5		557.57	
9.1	1.247		323.43	
13.2	0.442	7.3	241.6	342.26
19	0.094	1.28	106.53	135.11
27.5	0.03	0.357	71.251	82.013
40	0.0144	0.161	72.371	79.663
58		0.093		97.555
83		0.06		129.38
120		0.047		212.25
175		0.031		298.01

Pallisa		VES40		
On Profile GEP14, STN 22.				
	Resistivity			
L/2	a=1m	a=10m	Apparent Resistivity	
1.5	153.5		964.47	
2.1	77.1		1007.6	
3	38.9		1069.3	
4.4	15.45		927.55	
6.3	5.3		656.69	
9.1	1.234		320.06	
13.2	0.179	3.5	97.842	164.1
19	0.026	0.354	29.467	37.367
27.5	0.01	0.132	23.75	30.324
40	0.0044	0.072	22.113	35.626
58		0.044		46.155
83		0.031		66.848
120		0.023		103.87
175				

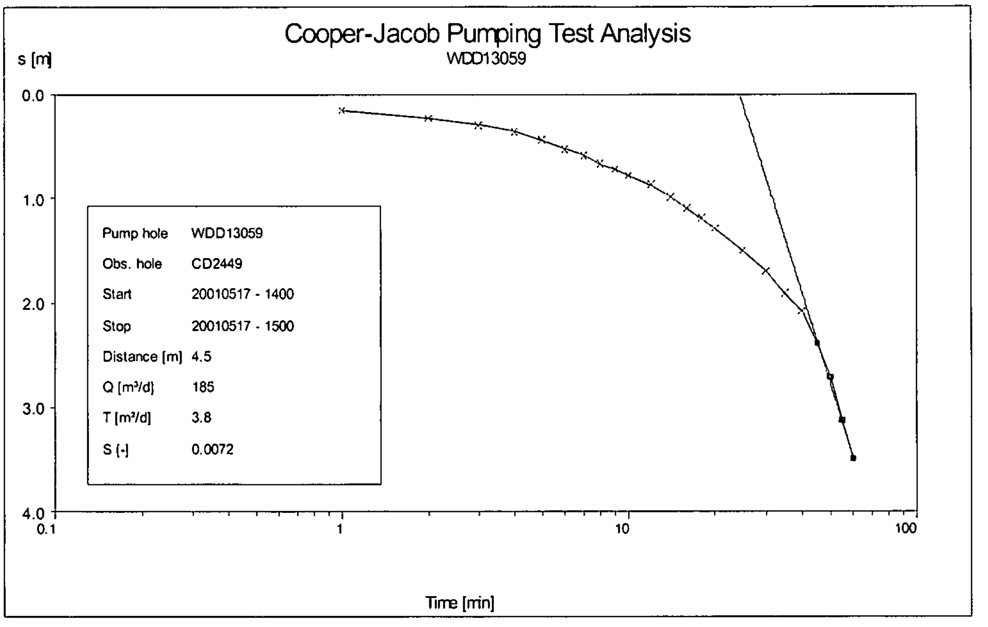
APPENDIX C_1. **Lineaments around Pallisa town**

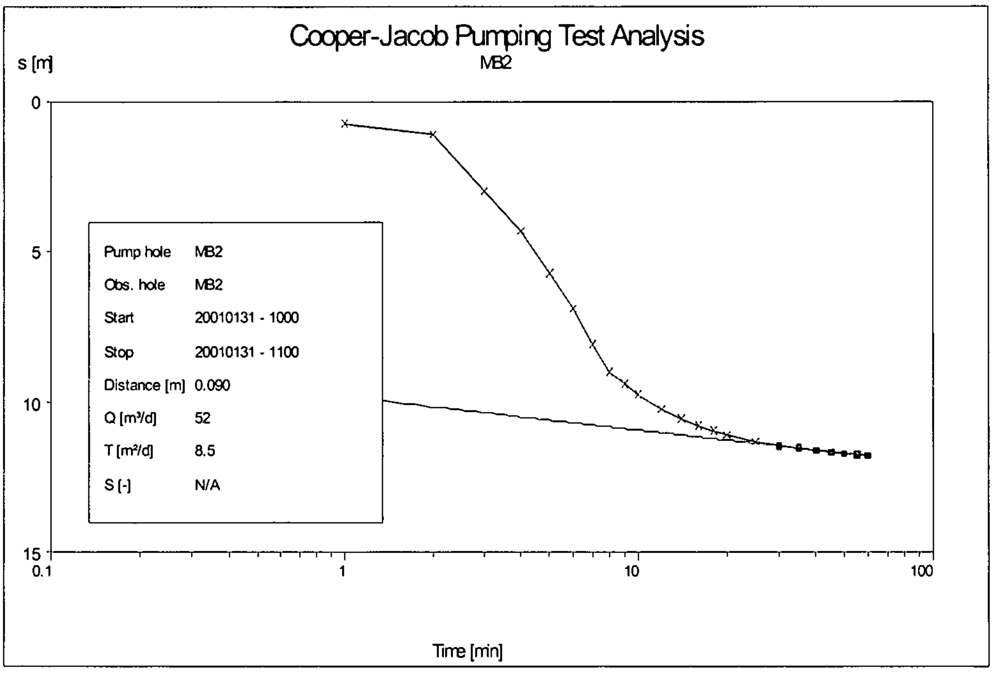


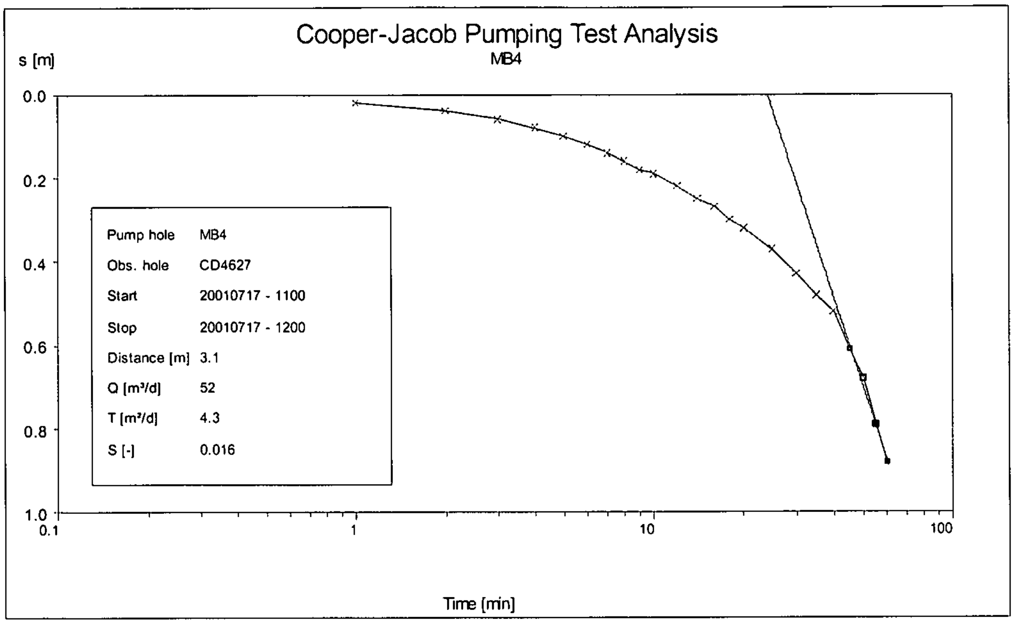
APPENDIX C_2. **Watersheds around Pallisa town**

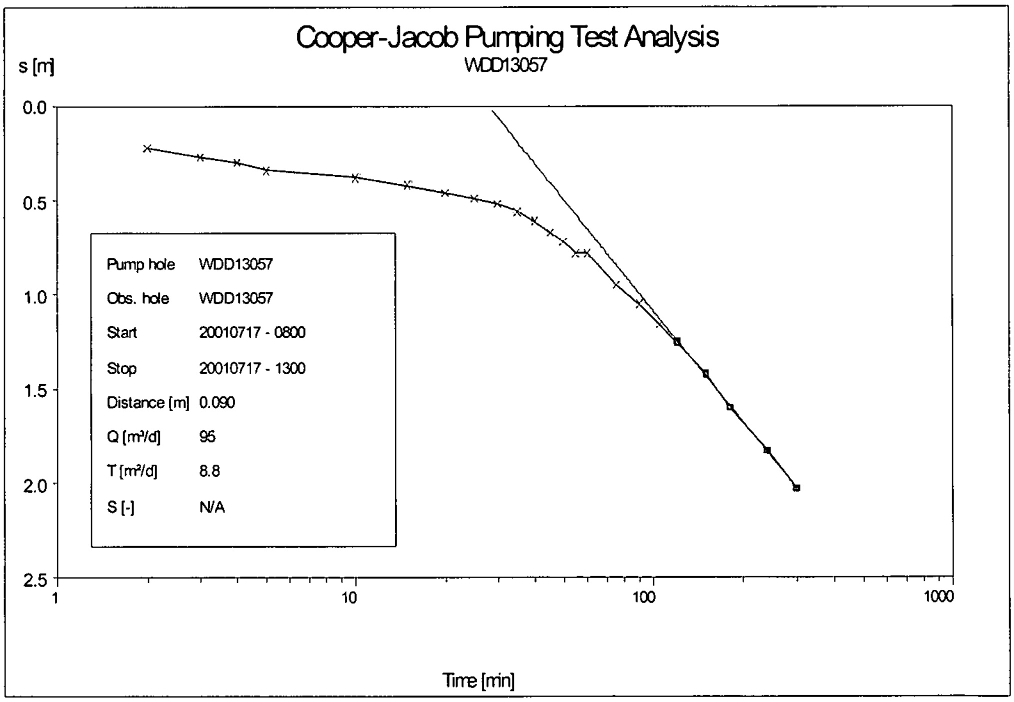


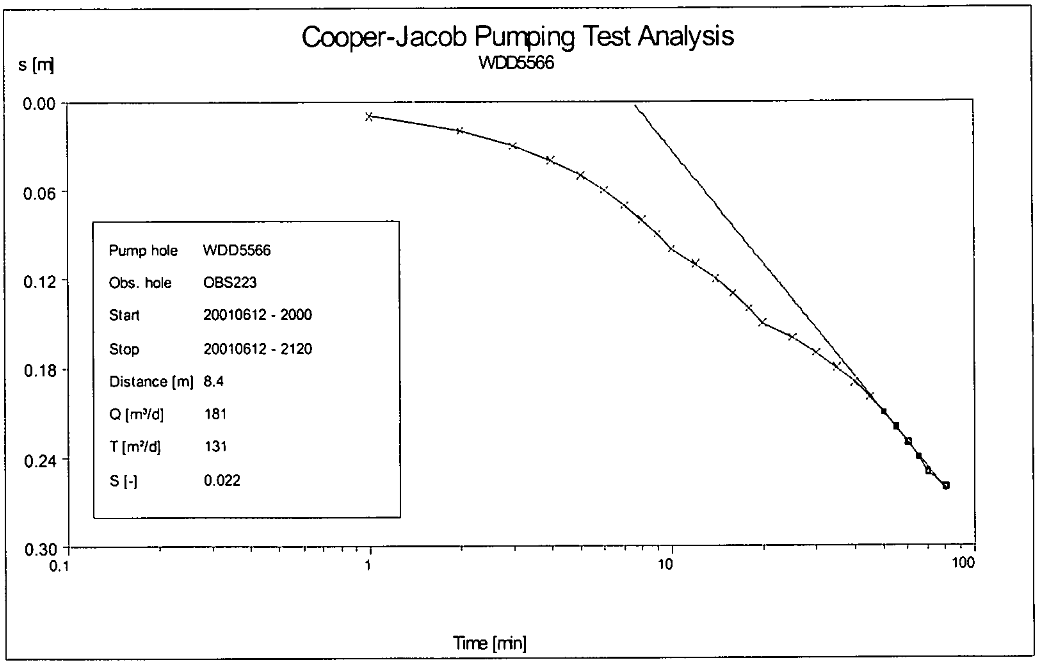
APPENDIX D_1 **Analyses of Pumping Test Data Using Cooper Jacob Method.**





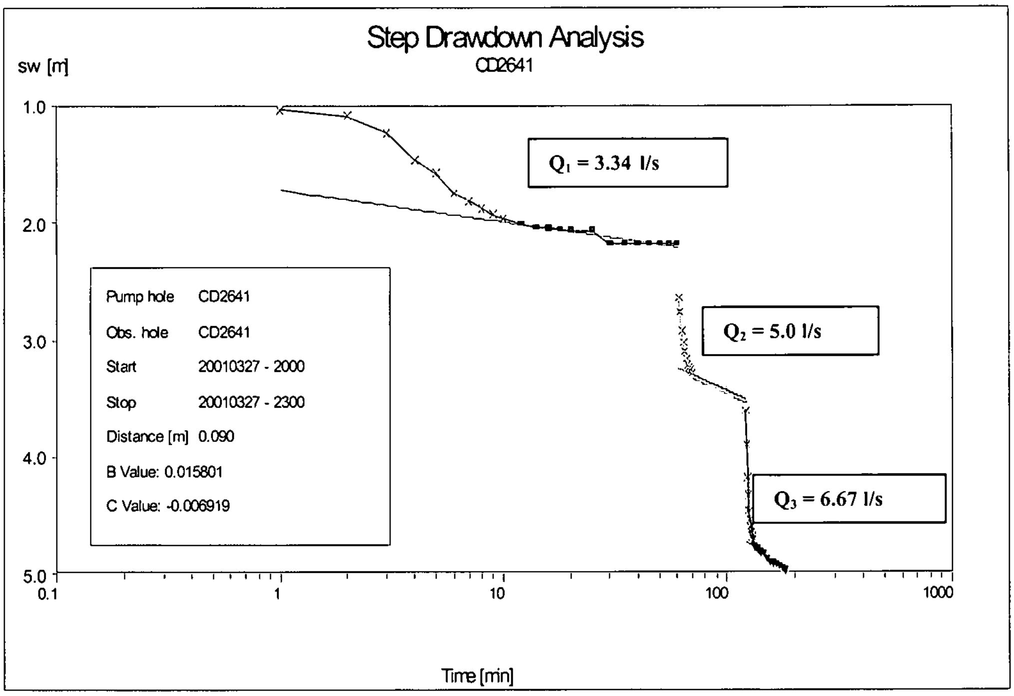

Cooper-Jacob Pumping Test Analysis
MB4
s [m]
Pump hole MB4
Obs. hole CD4627
Start 20010717 - 1100
Stop 20010717 - 1200
Distance [m] 3.1
Q [m³/d] 52
T [m²/d] 4.3
S [-] 0.016
Time [min]

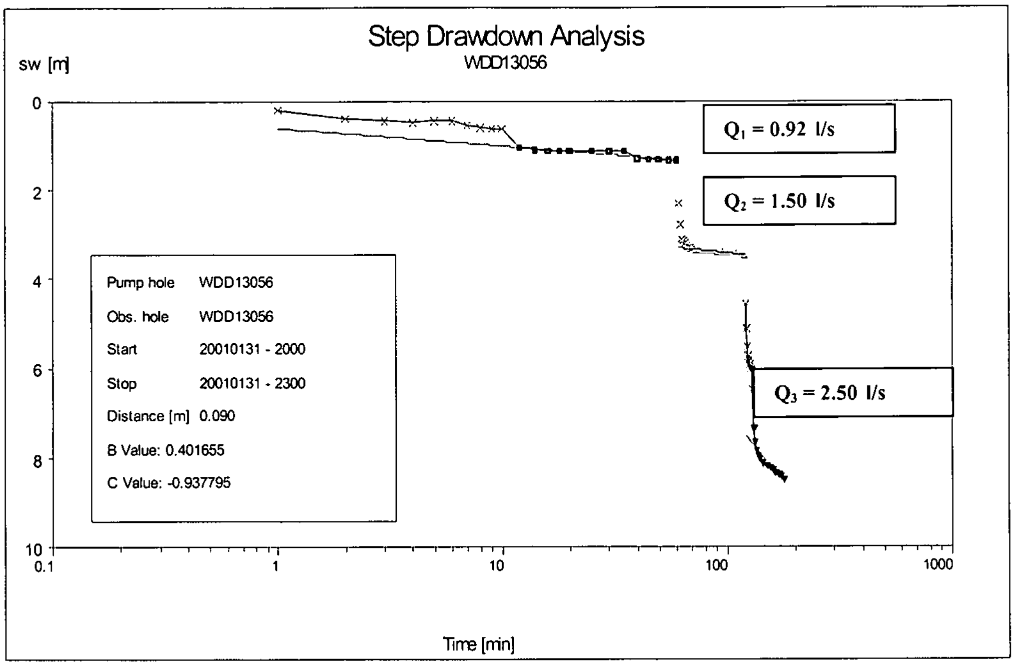

Cooper-Jacob Pumping Test Analysis
WDD13057
s [m]
Pump hole WDD13057
Obs. hole WDD13057
Start 20010717 - 0800
Stop 20010717 - 1300
Distance [m] 0.090
Q [m³/d] 95
T [m²/d] 8.8
S [-] N/A
Time [min]

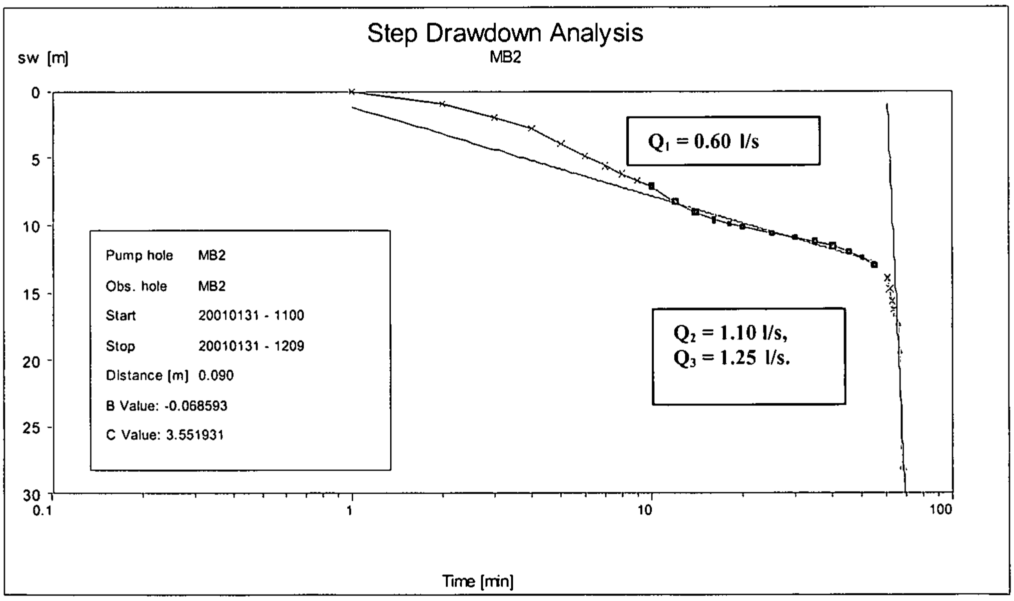


Cooper-Jacob Pumping Test Analysis
WDD5566
s [m]
0.00
0.06
0.12
0.18
0.24
0.30
0.1
1
10
100
Time [min]
Pump hole WDD5566
Obs. hole OBS223
Start 20010612 - 2000
Stop 20010612 - 2120
Distance [m] 8.4
Q [m³/d] 181
T [m²/d] 131
S [-] 0.022

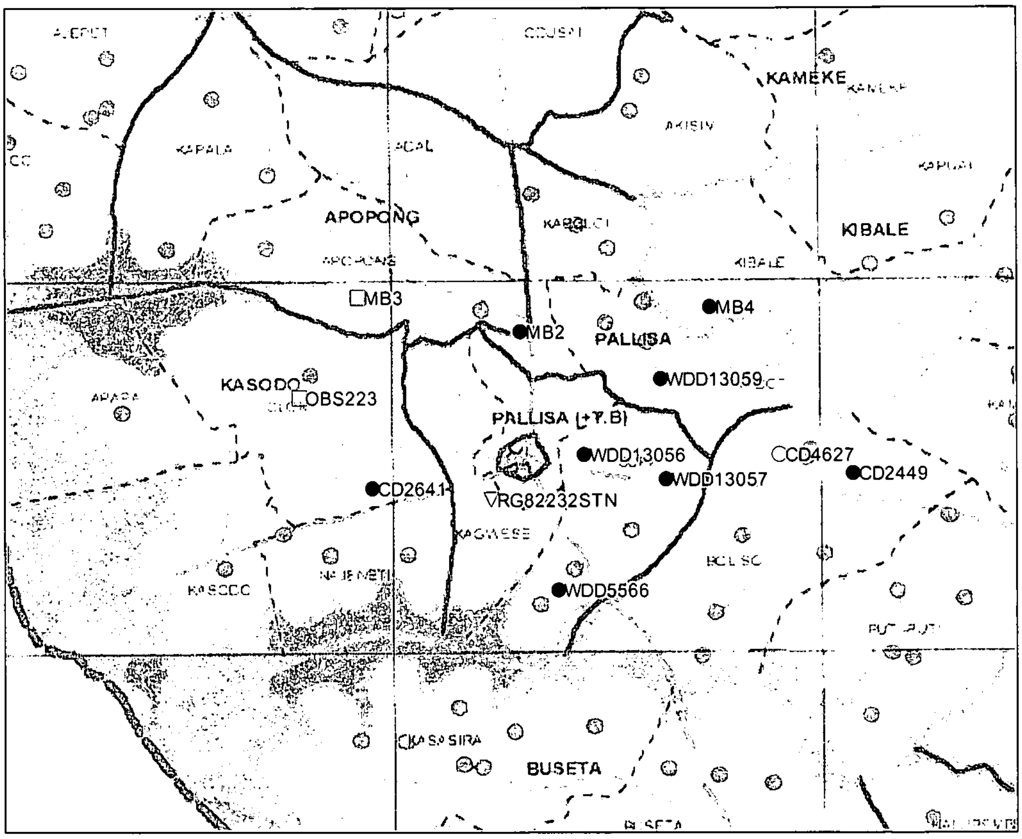
APPENDIX D_2 **Analyses of Pumping Test Data using the Step-drawdown method.**




Step Drawdown Analysis
WDD13056
sw [m]
Q1 = 0.92 l/s
Q2 = 1.50 l/s
Q3 = 2.50 l/s
Pump hole WDD13056
Obs. hole WDD13056
Start 20010131 - 2000
Stop 20010131 - 2300
Distance [m] 0.090
B Value: 0.401655
C Value: -0.937795
0
2
4
6
8
10
0.1
1
10
100
1000
Time [min]


Step Drawdown Analysis
MB2
sw [m]
Q1 = 0.60 l/s
Q2 = 1.10 l/s,
Q3 = 1.25 l/s.
Pump hole MB2
Obs. hole MB2
Start 20010131 - 1100
Stop 20010131 - 1209
Distance [m] 0.090
B Value: -0.068593
C Value: 3.551931
0
5
10
15
20
25
30
0.1
1
10
100
Time [min]

APPENDIX E1 Drilled and Pump tested boreholes



Part of the general map of Pallisa district showing the positions of some of the drilled boreholes around Pallisa town. Source: RUWASA. Scale: 1: 400 000.

N.B. INSERT A MAP SHOWING BOREHOLES DRILLED IN PALLISA DISTRICT. I.E. pal-BH.