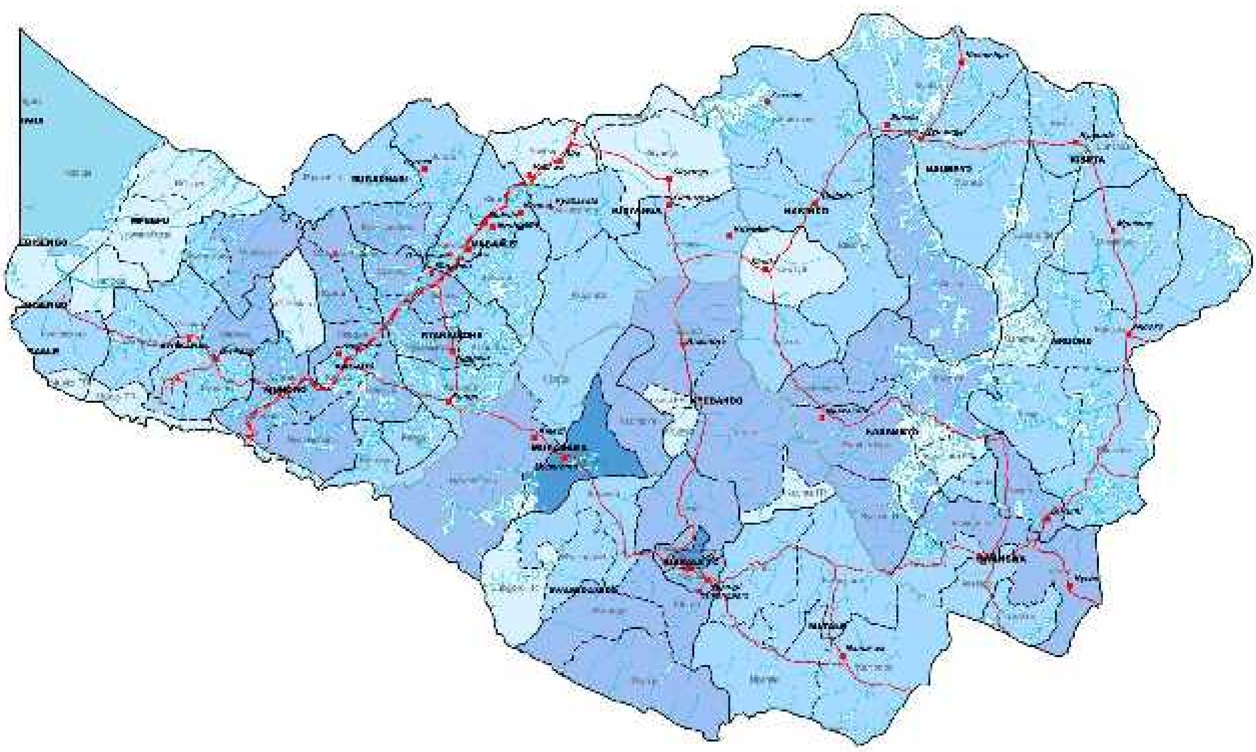
Republic of Uganda

MINISTRY OF WATER AND ENVIRONMENT
DIRECTORATE OF WATER RESOURCES MANAGEMENT

EU Water Facility

KIBAALE DISTRICT GROUNDWATER REPORT



Mapping of Groundwater Resources in Uganda

June 2012

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LAHMEYER INTERNATIONAL

EXECUTIVE SUMMARY

This report has been prepared by Consultant Lahmeyer International GmbH under the supervision of the Directorate of Water Resources Management to accompany the groundwater resources planning maps for Kibaale District. It reviews groundwater occurrence, development, potential and use in the District, based on data and information from various sources.

The Mapping Groundwater Resources in Uganda Programme provides this set of maps to aid planning of groundwater development activities at the district level. It aims to reduce the costs of groundwater development and increase the success rates. This district report outlines the procedures used to prepare the maps and provides the analysis and interpretation of the maps.

The data collection does include the consultation of the National Groundwater Database (NGWDB), the updated WATSUP database and Water Atlas and drilling data. Further data have been collected in the field by the Consultant in the framework of the present Project in close cooperation with the District personnel. All data have been verified and filtered. Duplicates have been removed, corrections made, missing data added.

To describe the hydrogeological characteristics of the groundwater resources, six parameters have been analysed: Depth to bedrock, depth to first water strike, to main water strike, to static water level, airlift yield and specific capacity. Generally the target zone for boreholes and wells is the top of the weathered bedrock.

Summary of results for Kibaale District:

Kibaale District is located approximately 200 km west of Kampala with an area of approximately 4,368 km^2 and a population of 613,300 (UBOS projection for 2010).

Most of the district lies in the Lake Albert catchment, with rivers either draining directly into Lake Albert, or north to the River Nkusi and south to the River Muzizi, which then flow into the lake. A small area in the north east of the district drains into the Victoria Nile catchment. Part of Lake Albert lies within the administrative boundary of the district.

Most of the district is underlain by fractured Precambrian metamorphic and sedimentary rocks and intrusive granites with a variable thickness of weathered overburden. A small part of the district is underlain by thick Rift Valley sediments.

In the Rift Valley bedrock is found at depths exceeding 1,000 m. In the area underlain by Basement rocks, the bedrock is between 3.8 and 73.8 m deep with an average of 31 m and shallow aquifers at the overburden/bedrock interface may be in reach of mechanized auger drilling.

Deep boreholes are present across the district, while shallow wells are well distributed except in the north east, where their coverage is lower. Protected springs are more common in the south and west of the district.

The Technology Options map shows that most of the district is suitable for deep well technology. In the north east, shallow well and borehole technology is suitable in a limited number of areas, but are more widely applicable elsewhere in the district. Potential for shallow wells exists in the east of the district and patchily in the south.

The overburden is generally thinner in the western third of the district where it is often less than 15 m thick. In the western two thirds the overburden is generally over than 30 m thick.

The First Water Strike Map indicates that in most of the district the FWS is more than 30 m deep with a few areas where it is less than 15 m deep. The MWS is generally deeper than 30 mbgl.

The Static Water Level Map indicates that over most of the district the static water level is less than 25 mbgl. In a few places the SWL is less than 15 mbgl.

The Groundwater Quality Map shows that groundwater is generally of acceptable quality except for a few areas classified as either marginal or poor. These classifications are due to concentrations of total iron being above guideline or maximum acceptable values, possible as a consequence of pump corrosion.

The Groundwater Potential Map shows that yields are generally good throughout the district. Overall, approximately 58 % of the existing sources had airlift yields greater than 1.0 m^3/h. Drilling success rates vary from 25 to 50 % in some parishes to over 75 % in others.

The Water Supply Coverage per Parish Map shows that coverage ranges from over 75 % to less than 25 % in some parishes. These will need additional sources to be constructed.

The population density is generally fairly low in the central and eastern parts of the district at less than 200 persons/km^2. In the west population density is higher reaching 400 persons/km^2. Service Area coverage appears reasonable except for the parishes of Ndaiga, Nyamukara, and Galiboleka.

The **implications for borehole siting and drilling** and shallow well development are:

Borehole siting should be guided by the identified groundwater potential of an area. Drilling should always be preceded by a desk study to analyse the results of previous drilling and (in the basement areas) to identify promising geological structures, such as lineaments. Areas with low potential will require a more extensive geophysical survey than high potential areas. The drilling method should be guided by the technology options. Borehole drilling should be supervised by an experienced hydrogeologist, particularly critical when drilling the rift valley sediments.

Areas identified as having good potential for shallow wells should be studied to understand the occurrence of groundwater and its quality.

The **reliability of the maps** is limited by the assumption that the various characteristics can be interpolated from the point data available. The spatial density of the data is also important as, in most cases, more data will result in higher reliability of the interpolation. Data density must be considered when making use of the maps. The maps also represent data available at the time of production, and some parameters, such as water levels and water quality, will change over time. Most importantly they are a generalisation of the hydrogeological conditions and cannot be expected to specify conditions at a particular point.

The **future development** of the National groundwater database is essential for the quality and reliability of the maps. Data collection and processing should continue, which relies on cooperation between the various stakeholders.

The **roles of the stakeholders** are: DWRM maintains the National Groundwater Database and ensures centralized and standardized data collection. The Districts enforce compliance with the Water Resources Regulation (1998) under contracts with contractors and ensure the collection of complete and correct sets of data, including those from dry wells and, critically, valid coordinates.

The private sector and NGO’s should ensure adequate data compilation, archiving and reporting.

ACRONYMS AND ABBREVIATIONS

CBOs	Community based organisation
DTB	Depth To Bedrock
DWD	Directorate of Water Development
DWO	District Water Officer
DWRM	Directorate of Water Resources Management
FWS	First Water Strike
ID	Identification Number
mbd	Metre below datum
mbgl	Metre below ground level
MWS	Main Water Strike
MIS	Management Information System
NGWDB	National Ground Water Data Base
NGO	Non Governmental Organisation
Qair	Airlift yield or drillers yield
S/C	Sub-County
SA	Service Area
SR	Service Radius
SWL	Static Water Level
TDS	Total Dissolved Solids
TSU	Technical Support Unit
UBOS	Uganda Bureau of Statistics
UTM	Universal Transverse Mercator
WHO	World Health Organisation
WSC	Water Supply Coverage

ACKNOWLEDGEMENTS

Many people and organisations have contributed to the production of the groundwater maps and report for this District. This has enhanced the quality and value of the maps and reports. The contributions of District Water Officers and their staff and the various NGOs operating in Kibaale District in the field data collection and verification of the draft maps, are highly appreciated.

The preparation of the district maps and reports was undertaken by Lahmeyer International, Germany, under the supervision of the Directorate of Water Resources Management.

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1. INTRODUCTION

1.1 Background information

Since 1997, Uganda has been implementing the Poverty Eradication Action Plan (PEAP). The PEAP is Uganda's national development framework and medium-term planning tool. It has been recognized under PEAP, that water resources have a significant contribution to make to poverty eradication through a number of programmes, in particular the provision of water and sanitation services. The success and sustainability of all the water related poverty eradication programmes depend on the availability of adequate water resources of the appropriate quality.

Water resources management is the responsibility of the Directorate of Water Resources Management (DWRM) within the Ministry of Water and Environment. The overall objective of the water resources management sector in Uganda is to manage and develop the water resources of the country in an integrated and sustainable manner, so as to secure and provide water of adequate quantity and quality for all social and economic needs of the present and future generations with the full participation of all stakeholders. Groundwater resources are particularly significant as over 80 % of the rural population depends on groundwater for clean water supplies.

Safe water coverage in Uganda currently stands at 65 % for rural water supplies and 66 % for urban supplies (Water and Environment Sector Performance Report, 2009). Groundwater development has been identified as the most feasible source of water to develop in order to increase safe water coverage to over 95 % by 2015. However, shortcomings have been identified in:

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

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

Recognising these problems, the Government of Uganda, through the DWRM, initiated a Groundwater Resources Mapping Programme to provide a set of tools to aid the planning of groundwater development activities at a District and National level. The main output from this programme was to be a set of maps that would represent groundwater resources in terms of their quality and quantity.

The project was initiated at a pilot level in 2001 under which 17 Districts were mapped. Maps were accompanied by a District Report to provide a background to the mapping process and to aid interpretation of the maps. Sub-sequent mapping of a further 16 Districts was completed by 2008.

The current phase of the mapping programme commenced in May 2010 and aims to complete the map coverage in the remaining unmapped Districts.

1.2 Objectives

The overall objective of groundwater resources mapping is to provide tools for guiding planning and implementation of groundwater development activities at both the national and district levels. This will significantly reduce the costs of groundwater development and increase success rates and hence safe water supply coverage.

1.3 This report

This report outlines the procedure used to prepare the maps as well as an analysis and interpretation of the maps that have been produced for this district. It provides guidance in the use and interpretation of the data displayed on the maps for planning of future groundwater development programmes.

The report comprises six sections. Section 1 (this section) provides an introduction and sets the District in its context within Uganda in terms of population, physiography, climate, geology and hydrogeology. Section 2 describes the data sources used and the methods of data cleaning and verification. Section 3 describes the data collected in detail in terms of statistics and spatial distribution and in Section 4 a detailed description is provided on the methodology used to generate the groundwater maps together with a description of each map. The reliability and limitations of each map are reviewed in Section 5. Future activities following the issue of the maps are discussed in Section 6 together with the responsibilities of various government, non-government and private organizations in ensuring that maps can be updated in the future.

1.4 Physical characteristics of the district

1.4.1 Location

Kibaale District lies approximately 200 km west of Kampala in the Western Region of Uganda. The District is bordered by Hoima District to the north, Kiboga District to the north-east, Mubende District to the south-east, Kyenjojo District to the south and Kabarole and Ntoroko Districts to the west (Figure 1). Lake Albert lies on the western border of Kibaale, separating it from the neighbouring District of Ntoroko.

The District has an area of approximately 4,386 km^2 and a total population that was projected to reach an estimated 613,300 by 2010 (UBOS projection from the 2002 census).

Administratively, the District comprises three Sub-counties, Bugangaizi, Buyaga and Buyanja. The administrative headquarters is located in Kibaale Town. The Sub--counties are listed on Table 1 with their estimated population figures for 2010. The spatial distribution of the population by Sub--county is shown on Figure 2.

Table 1 Population numbers per Sub-county

County	Sub-County	Population (2010)
Bugangaizi	Bwanswa	26,800
	Kakindo	30,800
	Kasambya	25,300
	Kisiita	18,300
	Nalweyo	31,400
	Nkooko	31,300
Buyaga	Bwikara	43,500
	Kagadi	50,600
	Kiryanga	39,500
	Kyanaisoke	37,300
	Mabaale	28,900
	Mpeefu	63,300
	Muhoro	45,100
	Rugashari	36,600

County	Sub-County	Population (2010)
Buyanja	Bwamiramira	26,600
	Kibaale TC	7,200
	Kyebando	15,600
	Matale	27,700
	Mugarama	27,500

Source: UBOS

1.4.2 Physiography /Drainage

The topography and main physical features of the district are shown on Figure 3.

Ground level elevation in the district varies between approximately 610 and 1,500 masl (metres above sea level). The lowest areas are those adjacent to Lake Albert in the west of the district and only represent a small part of this district. Most of the district lies above 1,000 masl. The highest ground is in the east of the district in Kasambya Sub-county (Magoma Hills) and in Bwamiramira and Matale Sub-counties.

A small part of the district, comprising the Sub-counties of Nalwayo Kissita and Nkooko and the northern most part of Kakindo, drains into the Victoria Nile catchment. The remainder of the district lies within the Albert Nile catchment. Over most of this area the drainage is northwards into the River Nkusi, which flows westwards into Lake Albert. In the west of the district the river either drain directly into Lake Albert, or south into the River Muzizi, which then flows westwards along the southern border of the district and into Lake Albert at Ndaiga.

There are many permanent and seasonal wetlands within the district associated with the main rivers, Muzizi, Nkusi and Kafu, and their tributaries. They are reported to cover approximately 12 % of the district area (www.kibaale.go.ug).

The largest water body in the district is the part of Lake Albert that lies within the district's administrative boundary.

1.4.3 Climate

The climatic conditions in Kibaale have been described based on a Hydroclimatic study undertaken by DWRM in 2007 (DWRM, 2007, unpublished report). The study was based on 14 climatological zones defined by Basalirwa et al (1993) using an analysis of monthly rainfall records at 102 rain gauges for the period 1940-75. The DWRM study subdivided three zones (C, M and A) to give a total of 17 climatological zones, as shown on Figure 4(a).

Kibaale lies in Climatological Zone L for which an average annual rainfall of 1,270 mm has been estimated. The rainfall shows a bi-modal distribution with two rainy seasons, as shown on Figure **4**(b). The main season extends from August to November with peak rainfall in October, while the secondary season lasts from March to May with a peak in April. The western part of the district bordering the Rift Valley (Lake Albert) is generally drier.

The main dry season is from December to mid March, with a secondary season in June and July.

Evaporation exceeds rainfall in the driest months by a factor of 5. During the peak of the rainy seasons, rainfall is greater than evaporation.

It should be noted that the above description is based on historical data and climate change processes will result in modifications to the local climate.

1.4.4 Geology

Geological maps of the District are available at 1:250,000-scale and at 1:1,500,000-scale (Uganda) map. According to the 1:1,500,000-scale geological map, there are six geological units represented in Kibaale, as indicated on Table 2.

Table 2 Geological units underlying Kibaale District

System	Description	Area (km^2)	%
Pleistocene to Recent	Sediments: alluvium, black soils and moraines	41	1.0
Tertiary to early Pleistocene	Rift valley sediments	42	1.0
	Mobilized and intrusive granites	1,741	40.9
Precambrian	Buganda-Toro: Phyllites and schists with basal quartzites and amphibolites	379	8.9
	Bunyoro Series: Shales arkoses and quartzites	46	1.1
	Basement complex: Undifferentiated gneisses and granulite facies	2,003	47.1

The spatial distribution of these units is shown on Figure 5. Most of the district is underlain by Precambrian metamorphic rocks, but there are also large areas of granite, mainly in the Sub-counties of Bwikara, Muhoro and Kagadi in the west and Bwamiramira, Matale, Bwanswa, Nkooko and Kasambya in the east. A small part of the district lies within the Rift Valley, but this is largely occupied by Lake Albert, which conceals a thick sequence of Rift valley sediments.

1.4.5 Hydrogeology

Regional

In Uganda, four main geological environments can be identified in terms of groundwater occurrence:

- Precambrian 'basement', which underlies most of Uganda and, therefore, of most significance for rural water supplies.
- Tertiary - Quaternary sediments within the Rift Valley system in western Uganda (distribution shown on Figure 6(a)),
- Volcanic rocks, the largest occurrence of which is in the southern Karamoja region, close to the Kenyan border (distribution shown on Figure 6(a)), and
- River/alluvial sediments located along valley floors.

Kibaale District is largely underlain by Precambrian basement and intrusive rocks. Alluvial sediments and black soils are present along the river valleys, but little is recorded about their properties and structure. Although they are likely to provide a locally significant aquifer in this District, suitable for hand dug wells, they are not discussed further in this report due to the lack of data. The rift valley sediments only occupy a small area of the district (less than 1 %) and may contain good aquifers.

Basement aquifers:

Negligible groundwater occurs in unweathered basement. However, significant aquifers can develop within the weathered overburden (regolith) and in fractured bedrock. The weathered zone varies significantly in thickness.

The hydrogeological characteristics of the weathered zone vary with depth, as shown on Figure 7. Porosity shows a decrease with depth, while the variation of hydraulic conductivity is more complex, depending on clay content and the extent of fracturing. Hydraulic conductivity tends to be high in the soil zone, but groundwater is generally not present outside the rainy season. Beneath the soil zone, the regolith is often clay-rich with a correspondingly low hydraulic conductivity. At the base of the regolith, the clay content is significantly reduced and the hydraulic conductivity increases significantly. This is the target horizon for shallow wells and boreholes.

Fractures present in the upper 20 to 40 m of the basement rocks are also an important water source, particularly where the weathered zone is thin.

Research undertaken by Taylor and Howard (2000) has suggested that the development of the basement regolith has been controlled by the tectonic history of Post-Palaeozoic Uganda. The tectonic model developed by Taylor and Howard shows that until the mid Cretaceous, there was a period of tectonic stability coinciding with a warmer climate which encouraged a deep weathering cycle. The development of the Western, Albertine, rift system coincided with a general zone of uplift to the east of the rift. This uplift started a period of erosional stripping in the west and north of Uganda, which continued until the early Miocene. Erosional stripping has continued adjacent to the western rift up to the present day, while the rest of Uganda is still undergoing deep weathering.

The distribution of the zone of deep weathering and the zone of active stripping is shown on Figure 6(a). The conceptual models of regional hydrogeology within these two zones are shown on Figure 6(b). The values for various parameters shown on the Figure are derived from a study of the Nyabisheki and Aroca catchments in Uganda (Hydrogeology Uganda, Phase II, 1994). Where the land surface is being deeply weathered, Taylor and Howard suggested the aquifer in the weathered regolith would be regionally extensive, while where the land surface is being actively stripped, the aquifer occurrence would be localized.

As indicated on Figure 6(a), most of Kibaale lies within the zone of Pleistocene stripping. It might be expected, therefore, that although aquifers would be present within the weathered zone in the District, they may not be laterally extensive. The eastern part of the district, that lying in the Victoria Nile catchment, lies in the zone of deep weathering and that shallow weathered zone aquifer should be thicker and more extensive.

<u>Rift Valley Sediments</u>

Details of the Rift Valley Sediments within the Albertine Graben are not widely available, particularly now as they are commercially sensitive due to the discovery of commercial quantities of oil. The following description has largely been taken from the NEMA publication 'Environmental sensitivity atlas for the Albertine Graben' (published by NEMA, 2009).

The Albertine Graben forms the Northern - most part of the Western arm of the East African Rift System (EARS). It stretches from the border between Uganda and Sudan in the north to Lake Edward in the south, a total distance of over 500 km with a variable width of 45 km (including the Democratic Republic of Congo). The Graben trends in a NE-SW direction through most of its length. Each of the rift basins in the Albertine Graben is bounded by steep border faults and broad uplifted flanks (escarpments) that are predominantly Precambrian basement composed of metamorphic rocks such as gneisses, quartzite, schist and varying amounts of mafic intrusions.

The available geological and geophysical data suggest that the Albertine Graben has undergone substantial tectonic movements and thick sediments (approximately 6 km) have been deposited in fluvial deltaic and lacustrine environments. Surface geological mapping undertaken by the Petroleum Exploration and Production Department and the wells drilled by the Licensees so far indicate these sediments to be predominantly sandstones, siltstones, claystones and shales. The sandstones and siltstones are mostly of high porosity and permeability.

Aquifers suitable for the supply of potable water might be expected in these sediments

District area

Although no local hydrogeological studies have been undertaken within the district, there is some documented work on rehabilitating boreholes with high iron concentrations.

Fader (2011) reported on the investigation of a number of wells in Bwanswa Sub-county that had become disused due to reddish colouring in the water, foul taste and discolouration of cloths and food when washing and cooking. Iron concentrations in the wells were reported to be less than 1 mg/L at the time of drilling, but when tested prior to rehabilitation had concentrations ranging from 2.5 mg/L to 40 mg/L.

Rehabilitation consisted of disinfection of the wells with chlorine and replacement of iron pump components with plastic and stainless steel. After rehabilitation, iron concentrations were again below 1 mg/L.

An interesting feature of the tests undertaken was the identification of the presence of Iron Related Bacteria (IRB), which act to accelerate the corrosion of iron components. This highlights the importance of chlorination of wells. One pump mechanic had reported that the boreholes improved after periodic chlorination, suggesting that corrosion due to the IRB could be reduced, but not stopped, by chlorination.

2. METHODOLOGY

2.1 Data Sources

The following data sources were consulted:

- National Groundwater Database (NGWDB), held at the Directorate of Water Resource Management, Entebbe.
- Data collected during 2009/10 for the update of the Water Atlas (WATSUP),
- Data collected as part of the 2002 Water Atlas project (MIS2002),
- Data stored in the DRILCON database (collected by a now defunct drilling company),
- Sources located from field mapping undertaken by Lahmeyer International,
- Data held by the District Water Office.

No data were available from NGOs operating in the District.

2.2 Data processing

To consolidate the database and ensure the data content the following quality control procedures have been used to filter and clean the initial database prior to data analysis:

Stage 1: Review of NGWDB

> As the primary source of hydrogeological and water quality data, the database was reviewed at an initial stage to remove duplicated records, correct invalid Source IDs and add missing data, where this was applicable. This involved identifying boreholes with these errors and then accessing the original hard copy records to verify the correct data.
>
> Care has been taken to ensure that records in the NGWDB were also corrected to ensure that future users of the database would benefit from the data review.
>
> Due to time constraints, a complete evaluation was not possible and some errors and omissions were only picked up after data had been downloaded into the District database.

Stage 2: Coordinate assignment

> A significant number of the data points held in the NGWDB have either,
>
> - No coordinates,
> - Coordinates in geographical format (lat/long) of varying accuracy,
> - Coordinates with obvious errors (for example too few digits),
> - The same coordinates applied to multiple boreholes, or
> - Coordinates plotting outside Uganda or in a District different from that entered for the borehole.
>
> Boreholes with no coordinates, or coordinates plotting outside the District boundary were prioritized for assessment against the WATSUP and/or MIS2002 data. Boreholes in the databases were matched using Source ID numbers (as issued by the DWRM), Source Names or Village Names, or a combination of these. It should be noted that the WATSUP database contained only a limited number of records with Source ID numbers and only a limited number of matches were possible using these numbers.

Coordinates presented in geographic format were projected to UTM coordinates (assuming a WGS84 datum) and then compared with WATSUP and /or MIS2002 data.

Boreholes with coordinates assigned in the NGWDB were initially assumed to be correct. Those plotting outside the Parish or Sub-county in which they were assigned in the database were checked against WATSUP and/or MIS2002 records.

Where boreholes had incorrect, or missing coordinates, attempts were made to obtain these from either data held by the District Water Officer, or by physically locating them in the field by GPS. Some borehole remained without coordinates as they could not be positively identified in the field, because, for example, identification marks on the well head were missing following rehabilitation.

Stage 3: Data Cleaning and Filtering

Records exported to the District database were evaluated by for accuracy and additional interpreted data fields added:

Hydrogeological data.

- The Main Water Strike (MWS) is an interpreted data field and not contained in the NGWDB. The MWS, in terms of depth below datum, in each borehole was selected based on an assessment of yield per water strike.
- The Depth to Bedrock in each borehole was interpreted based on the lithological record in the NGWDB. If this could not be ascertained due to the poor record, then the total casing length was used as this was considered likely to represent the base of the poorly consolidated (weathered) zone.
- Depth to base of overburden (superficial deposits) is also an interpreted data field. This value (as depth below datum) was interpreted from the lithology records.
- Zero values entered for total yield were checked as in some cases the boreholes were not ‘dry’ according to water strike yields or pumping test data. If a boreholes was confirmed as ‘dry’ from comments in the database, or from hard copy records, then a zero total yield was entered.
- For boreholes reported as ‘low yield abandoned’, but with no yield recorded, a zero value was assigned for total yield.
- Data were evaluated by plotting their statistical distributions. Significant outliers were investigated further and, where necessary, checked against hard copy records.

Water Quality data:

- It appears to be common practice for laboratories in Uganda to report concentrations of determinands below the detection limit as zero (except for the DWRM laboratory in Entebbe which reports the detection limit prefixed by ‘<’). Zero values have, therefore, not been removed from the water quality dataset.
- The national groundwater database does not have the facility to record when an analysis is below the detection limit (e.g. < 0.01). Only the numerical value is entered. It is, therefore, not known when analyses are below the detection limit.
- For statistical analysis and interpolation, the detection limit was used.

Stage 4: Coordinate Validation

Following the initial coordinate assignment, borehole locations were checked using GIS. In addition, coordinates measured in the field were used to check the validity of WATSUP coordinates. According to the WATSUP data collection manual, all coordinates were measured using GPS instruments set to use the WGS84 datum. Data collected during the mapping project were also collected with instruments set to the WGS84 datum. Matching data points ‘confirm that the correct datum has been used.

For boreholes without coordinate information, it was also important to establish at least the Sub- County in which the borehole was located as this information was important in data analysis for the Groundwater Potential Map. As a significant number of boreholes did not have this information, a number of other data sources were consulted.

Stage 5: Water Quality

During the data evaluation, NGWDB records with a full record of water quality data were plotted using GIS to establish the spatial coverage. It is important to note that water quality analysis undertaken on newly completed boreholes has not always comprised a comprehensive suite of determinands. A full suite was considered to be one where the main determinands required for the map production had been included (egg. Total dissolved solids, electrical conductivity, pH, nitrate, sulphate, chloride, fluoride and total iron).

Areas within the District where the data coverage was sparse were prioritized for sampling during the field visits. Potential sources where sampling could be undertaken were identified using information from MIS2002 and/or WATSUP data.

Samples taken in the field were transported back to the selected laboratories in chilled cool boxes. Care was taken to ensure bottles were completely filled so no air was entrained in the bottles. No on-site preservation or filtering was undertaken. Samplers were instructed to take the samples after pumping for at least 20 minutes, unless the well was being actively pumped at the time of the visit, in which case the sample could be taken immediately.

Samples from Kibaale were analysed at the National Water and Sewerage Corporation’s (NWSC) laboratory in Kampala.

2.3 Data Quality

There are a number of issues with data quality that need to be commented on. It should be emphasized that none of these issues invalidate the use of the data for producing groundwater maps. They have been noted so that users of the maps are aware of the inherent uncertainties in the data and adjust their expectation accordingly. Further related comment on data uncertainty is made in Section 7 on map reliability.

2.3.1 Location

Data held in the national groundwater database have been assigned coordinate locations by the drilling companies or consultants associated with particular water development projects. The information provided to the DWRM does not include details of the GPS settings selected when taking these readings. This leads to uncertainty in location as for example a location recorded using the WGS84 datum will be displaced by approximately 310 m when compared to a location recorded using the ARC60 datum.

The recent mapping exercise to produce the updated Water Atlas of Uganda (WATSUP) used GPS instruments set to the WGS84 datum. Some of these data have been used to populate the database used for this project.

On a District-scale map intended for use as a planning document, these errors are not considered to be significant, given other uncertainties in the data.

2.3.2 Hydrogeological data

Hydrogeological data, such as water strikes, lithological records and pumping test data are supplied to the DWRM in the form of drilling completion reports. The following comments can be made:

Lithological details are recorded by the driller and cannot, therefore, be expected to be of the same quality as those recorded by a geologist. In particular, changes in lithology often recorded only at drill rod changes. There will, therefore, be inevitable errors in figures such as depth to bedrock. However, gross errors in these data will have been picked up in the data assessment and corrected where necessary.

Data on water strikes and the yield at each strike rely on all water strikes together with a yield estimate being noted in the completion report.

2.3.3 Water quality data

Water quality data have been taken from information stored in the NGWDB supplemented with new samples where the spatial spread of data was poor. Therefore, the data represent the water quality over a period of time from the first entry in the data base to samples taken in 2010/11. Inspection of the results has not indicated any significant changes over this time, with the exception of iron concentrations in some areas. This is addressed specifically in Section 3.3.8.

Borehole construction also needs to be considered when interpreting results. While some boreholes may be completed in either the weathered zone aquifer or the deep basement aquifer, a significant number have screens in both aquifers.

The other important factor to consider is the laboratories used for analysis. Two important facts need to be considered:

Detection limits

- Some laboratories used by drilling companies do not record when parameters tested fall below the method detection limit. Instead a value of zero is reported. This zero value is generally entered into the NGWDB.
- The NGWDB is not currently structured to indicate when laboratory results are below the detection limit. Therefore, even if the detection limit is reported by the laboratory, it is not possible to record this other than entering the detection limit.
- As zeros therefore represent a true value rather than ‘no data’ they have been retained in the data for analysis and mapping.

Reporting units

- Nitrate concentrations are currently reported by laboratories as nitrate-nitrogen (NO_3-N). Unfortunately, until approximately 2008, one laboratory reported results as nitrate (NO_3), but no account was taken of this in the NGWDB. The records therefore contain concentrations reported in a mixture of reporting units. This is significant as a concentration reported as NO_3 is a factor of 4 times larger than if it is reported as N. This is addressed specifically in Section 3.3.8.
- Calcium and magnesium concentrations are currently reported as Ca^{2+} or Mg^{2+}. In the past some laboratories have reported these concentrations in terms of mg/L $CaCO_3$.

2.4 Final database

The final District database can be summarized as follows:

- 400 records in total, of which 305 (76 %) have coordinates

- 182 records (45 %) have complete or partial sets of chemistry data.

A more detailed breakdown of the number of data points available for analysis is given in Section 3.

The majority of the records (88 %) in the database represent deep boreholes (i.e. those completed to depths greater than 30 mbgl). There are eight boreholes drilled to a depths of less than 30 m. Thirty-eight records (9.5 %) do not have a final drilled depth recorded, although some of these represent locations where samples have been taken, but not matched to locations in the NGWDB.

It should be noted that this database is biased towards shallow and deep borehole technology and data on shallow wells is lacking. The WATSUP database recorded a total of 645 shallow wells within the district (*Uganda Water Supply Atlas, 2010*). The implications of this are discussed in Section 3.

A digital copy of the database is provided on a CD accompanying this report.

3. DISTRICT DATA

3.1 Introduction

During meetings held between various members of the mapping team and District officials during the course of the project, various specific problems were discussed. Generally these referred to water quality issues and these are considered in more detail in Section 3.3.

It should be noted that for statistical analysis in Sections 3.2 and 3.3, all data have been included, whether or not they have been allocated coordinates. This has been done so that potentially significant information, such as poor quality water, from boreholes with no coordinates can be taken into account in the description of the aquifer conditions.

3.2 Hydrogeological characteristics

3.2.1 General

Summary statistics for six parameters, Depth to bedrock, depth to first water strike (FWS), depth to main water strike (MWS), depth to static water level (SWL), airlift yield and specific capacity are provided on Table 3 for boreholes located on the Rift Valley Sediments and on Table 4 for those located on basement.

More detailed descriptions of each parameter are provided in the subsequent sections.

Table 3 Summary statistics for hydrogeological characteristics

	Depth to Bedrock (m)	Depth to FWS (m)	Depth to MWS (m)	Depth to SWL (m)	Airlift Yield (m^3/h)	Specific Capacity (L/h/min)
Min	3.8	2.00	1.00	3.8	0.10	4
Max	73.5	108.30	117.70	73.5	20.00	10,526
Average	30.7	35.85	44.15	30.7	2.03	305
Median	30	33.00	40.00	30	1.40	127
No. Data Points	335	314	303	335	279	213

For discussion purposes in the following sections, depth to bedrock, FWS, MWS and SWL have been described with reference to categories used to define for water source technology options:

- Less than 15 mbgl - Shallow well construction technology,
- Less than 30 mbgl – Shallow borehole technology. Conventional rotary drilling or mechanized auger machine, and
- Greater than 30 mbgl - Deep borehole technology

3.2.2 Depth to bedrock

Depth to bedrock has been recorded for 335 sources. Depths range from 3.8 mbgl to 73.5 mbgl, with an average depth of 30.7 mbgl and a median of 30 mbgl. A statistical distribution of the data is shown in Figure 8(a). In 50 % of the boreholes the depth to bedrock is less than 30 mbgl, while it is less than 15 mbgl in only 11 % of boreholes.

The spatial distribution of depth to bedrock is shown on Figure 8(b). No pattern to the distribution is apparent.

3.2.3 First Water Strike

The depth at which water is first struck during drilling is termed the First Water Strike (FWS). In Kibaale, the depth of the first water strike varied from 2 mbgl to 108.3 mbgl, with an average depth of 35.85 mbgl and a median of 33 mbgl. The statistical distribution is presented on Figure 9(a). The data show that the FWS was less than 30 mbgl in 44 % of the boreholes and less than 15 mbgl in 9 % of the boreholes.

However, it should be noted that the database is biased towards shallow and deep boreholes. The WATSUP 2010 database recorded 645 shallow wells in the district. The presence of these wells suggests water strikes within 10 m of the ground surface in significant areas of the district.

Figure 9(b) shows the spatial distribution of the data, from which it is clear that no particular pattern is present.

Figure 10(a) shows the relationship between the depth of the FWS and the depth to the top of the bedrock. In 40 % of the boreholes, the FWS occurs in the overburden and the remainder in the bedrock. The spatial distribution, Figure 10(b), does not indicate any pattern to the position of the FWS above or below the top of bedrock.

3.2.4 Main Water Strike

At each water strike made during drilling, the depth and yield are generally recorded. By comparing the yields recorded at each water strike, the main groundwater inflow horizon can be determined. This horizon is termed the Main Water Strike (MWS).

In Kibaale, the depth to the MWS varies between 1 mbgl and 117.7 mbgl. The statistical distribution of values (Figure 11(a)) shows a slightly skewed distribution with an average of 44.15 mbgl and a median of 40 mbgl. The MWS was encountered at depths of less than 30 mbgl in 26 % of the boreholes and at less than 15 mbgl in only 6 boreholes (2 %). The spatial distribution of the values is shown on Figure 11(b).

Figure 12(a) shows the relationship between MWS and depth to bedrock. It can be seen that only 19 % of the main water strikes are in the overburden. The locations where MWS were either in the overburden or in the bedrock are shown on Figure 12(b).

3.2.5 Static Water Level

The static water level (SWL) at a particular locality is the level at which the groundwater surface stabilizes under the influence of natural hydrostatic pressure. The static water level is used as a measure of the aquifer condition at the particular locality i.e. to denote whether the aquifer is *confined* or *unconfined* with respect to atmospheric pressure. If the groundwater is confined then it is under a pressure that is higher than normal atmospheric pressure and it will rise in the borehole to a level higher than that at which it was encountered i.e. the static water level will be shallower than the water strike depth. If the groundwater is unconfined then the groundwater pressure is equal to the atmospheric pressure and the static water level will be the same as the water strike depth. Note that in fractured aquifers with inclined fractures, the depth at which groundwater is intercepted is frequently lower than the level at which the water stabilises in a borehole. This does not mean that the aquifer is confined. The only way to reliably establish whether an aquifer is confined or not is to carry out pumping tests with observation wells.

According to borehole completion reports, static water levels are measured just prior to the pumping test taking place.

The static water level has been measured in 275 of the boreholes in Kibaale and ranges from 1.63 mbgl to 71.40 mbgl. The statistical distribution of the data is shown in Figure 13(a). The data record a mean depth to SWL of 19.95 mbgl and a median of 19.04 mbgl. In 85 % of boreholes the SWL was less than 30 mbgl and less than 15 mbgl in 35 % of boreholes. The spatial distribution is shown on Figure 13(b).

Figure 14(a) shows the relationship between SWL and depth to bedrock and illustrates that in 85 % of boreholes the position of the SWL is above the top of bedrock. As illustrated on Figure 14(b) there is no pattern to whether the SWL is above or below the top of the bedrock.

3.2.6 Airlift yield

The depth and yield of every major water strike is generally recorded by the drillers during air flush drilling together with a final yield on completion of the borehole. A final airlift yield is available for 279 of the boreholes drilled in the district. Boreholes that are confirmed as being dry are given a zero yield. Twenty six dry borehole were recorded in the NGWDB for this district. However, it is considered likely that more dry boreholes have been drilled, but the data have either not been recorded, or not submitted for entry to the NGWDB.

Airlift yield in the district have varied from 0.1 m^3/h to 20 m^3/h, with an average of 2.03 m^3/h and a median of 1.40 m^3/h. The statistical distribution is shown on Figure 15(a).

The information on borehole yields can be augmented from other sources. For example, if the final yield was not recorded, then the last water strike yield can be taken. If no airlift yield data were recorded, but a pump test was carried out, then the pumping test yield could be used. If all these data are taken into account, then yield data are available for a total of 317 boreholes.

Boreholes have been classified on the basis of their yield and the results summarized on Table 4.

Table 4 Yield categories

Yield (m^3/h)	Potential	Airlift Yield		All Yields	
		No.	%	No.	%
< 0.5	Poor	55	19.7	65	20.5
0.5 - 0.7	Moderate	19	6.8	22	6.9
0.7 – 1.0	Good	41	14.7	53	16.7
> 1.0	Very Good	164	58.8	177	55.8

Using the final airlift yield data, approximately 80 % of boreholes can be classed as successful (i.e. with a yield above 0.5 m^3/h). The distribution of boreholes in these classes using final airlift yield data is shown on Figure 15(b). There does not appear to be any pattern to the data and poorly yielding wells are found close to high yielding wells.

3.2.7 Well Performance

Airlift yields, as described above, provide an initial indication of the success of a well and whether the well should be abandoned due to low yield. However, the tests do not indicate how far the water level falls in the well when it is pumped, a critical piece of information if the pump is to be set at the correct depth. Data from pumping tests can provide this additional information.

Short-term pumping tests are undertaken on new wells, although these are sometimes not reported fully in the borehole drilling reports. The tests are commonly of a 3-hour duration, which is insufficient for a true estimate of aquifer properties as the water levels have often not yet reached a steady state. Nevertheless, the results can provide a crude indication of the well performance.

For the purpose of this report, well performance has been described in terms of the specific capacity of the well. This is simply the pumping rate divided by the drawdown and indicates the discharge rate per metre of drawdown. In this case it has been expressed as litres/hour/m.

Typical hand pumps can abstract from depths of 45 m at rates of between 660 and 1000 litres/hour, assuming they are in good condition. A well with a specific capacity of 200 L/hr/m and an abstraction rate of 660 L/h would generate a drawdown of 3.3 m, at 1,000 L/h the drawdown would be 5 m.

In Kibaale District, pumping test data were available for 213 boreholes. For these boreholes, specific capacities varied from 4 L/h/m to 10,526 L/h/m with 63 % of the values below 200 L/h/m (Figure 16(a)). The distribution of the data points with coordinates is shown on Figure 16(b).

3.3 Groundwater Quality

3.3.1 Introduction

In this report groundwater quality has been described in terms of the parameters for which national standards have been set in Uganda. There are 11 such parameters, as shown on Table 5, together with their respective Ugandan and WHO standards for Drinking Water.

The main problem reported by the DWO is the presence of saline water, which has led to the abandonment of some sources.

Table 5 National guidelines for groundwater quality

Parameter	WHO Guideline value (mg/L)	Uganda National guidelines (mg/L)		Possible impact
		Guideline Value (GV)	Maximum acceptable value (MAV)	
Total hardness as $CaCO_3$	500	600	800	Scale and scum
Total Iron	0.3	1	2	Taste, colour
Manganese	0.1	1	2	Taste, colour
Chloride	250	250	500	Taste
Fluoride	1.5	2	4	Dental/skeletal fluorosis
Sulphate	250	250	500	Taste, gastrointestinal irritation
Nitrate (as NO_3) (as NO_3-N)	50 11	20 4.5	50 11	Blue baby syndrome
Nitrite as NO_2	3	0	3	
TDS	1,500	1,000	1,500	Taste, corrosion/ encrustation
Turbidity	5	10	30	Appearance
pH	-	5.5-8.5	5.0 - 9.5	High: Taste Low: Corrosion

Summary statistics for the groundwater analyses obtained in the District are given in Table 6 and discussed in more detail in the following sections.

Table 6 Summary statistics for water quality

	pH	EC (µS/cm)	TDS (mg/L)	Hardness (mg/L $CaCO_3$)	Chloride (mg/L)	Sulphate (mg/L)
Min	2.51	23	16	8	0.03	1.00
Max	8.14	1700	851	274	60.00	69.00
Average	6.48	218	132	83	4.85	11.82
Median	6.49	190	112	73	2.50	8.00
No. of data points	197	182	183	194	170	147
	Fluoride (mg/L)	**Total iron (mg/L)**				
Min	0.01	0.01				
Max	9.00	8.22				
Average	0.42	0.31				
Median	0.24	0.05				
No. of data points	179	151				

3.3.2 pH

pH is a measure of the acidity or alkalinity of water, with pH7 representing neutral conditions. Impacts on groundwater quality are considered to be aesthetic rather than based on health risks. Alkaline (high pH) waters may have an unpleasant taste. Water with low pH (Acid) can be corrosive and should be considered when specifying pump components.

All the pH values have been measured in the laboratory and field values may be different.

pH values in the District vary between 2.51 and 8.14, with an average of 6.48 and median of 6.49, indicating slightly acidic groundwater overall. The pH values are plotted on Figure 17(a). Two samples (DCL467 and DCL468) had exceptionally low values, well below the lower GV. It was not possible to check to original data for these boreholes and the data remain suspect. Four samples (DCL483, DWD18576, Li/Kb/10 and Li/Kb/21) recorded pH values between the lower MAV and lower GV.

The spatial distribution of pH values is shown on Figure 17(b). None of the exceptionally low pH values are located in Bwanswa Sub-county, where the corrosion of pump components was noted to be a problem (Section 1.4.5).

3.3.3 Electrical conductivity

The Electrical Conductivity (EC) of water is a measure of its ability to conduct electricity. As the amount of dissolved minerals in the water increases, so does the ability of water to conduct electricity. EC is, therefore, an indicator of the dissolved mineral content of water. There are no guideline or maximum acceptable values for EC in rural water supplies in Uganda.

There are 182 EC measurements available, ranging from 23 to 1700 µS/cm with an average of 218 µS/cm and median of 190 µS/cm. The statistical distribution of the data is shown on Figure 18 (a). Ninety eight percent of the measurements are below 600 µS/cm.

The spatial distribution of EC values is shown on Figure 18(b).

3.3.4 Total Dissolved Solids

The concentration of Total Dissolved Solids (TDS) is the sum of the dissolved minerals present in the water (i.e. the sum of the cations (positively charged) and anions (negatively charged) ions). It can be used as a qualitative indicator of the quality of the water.

Elevated TDS in water supplies can originate from a number of sources such as geological conditions, sewage (latrines), urban and agricultural run-off and industrial wastewater. Limits on TDS in water supplies are specified for reasons of taste (high concentrations taste salty) rather than for adverse health effects, although certain components may have health effects. As such, a high TDS would be an indicator of the need to analyse for more specific components. Very low TDS concentrations may be corrosive.

TDS can be measured directly, or estimated from EC using a standard coefficient. Recent samples collected as part of this project have been derived from EC using a coefficient of 0.7. For earlier data, in the majority of cases the TDS/EC ratio varies between 0.5 and 0.65.

In the district, TDS ranges from 16 mg/l to 851 mg/L, with an average of 132 mg/L and a median of 112 mg/L. The statistical distribution is shown on Figure 19(a). All the values recorded are below the GV of 1000 mg/L.

The spatial distribution is shown on Figure 19(b).

3.3.5 Hardness

Hard water is high in dissolved components, principally calcium and magnesium. It is not a health issue, but results in mineral build up in water supply systems and household equipment. Soaps and detergents perform poorly.

Hardness concentrations in Kibaale range from 8 mg/L to a maximum of 274 mg/L with a mean of 83 mg/L and a median of 73 mg/L. The statistical distribution is shown on Figure 20(a). All the concentrations recorded are below the GV of 600 mg/L.

The spatial distribution of the data is shown on Figure 20(b).

There does not appear to be a hardness classification in general use in Uganda and the following classification has been adopted from South Africa:

Class	mg/L CaCO3	% of samples
Soft	< 50	0.0
Moderately soft	50 - 100	72.2
Slightly hard	100 - 150	15.5
Moderately Hard	150 - 200	8.2
Hard	200 - 300	4.1
Very Hard	> 300	0.0

Source: http://www.waterwise.co.za/site/water/faq/quality.html

The table shows that most of the samples can be classed as hard to very hard water. Most of the samples classified as soft are located in the south of the district.

3.3.6 Chloride

The GV placed on chloride concentration is based on the limit at which there is a detectable change in taste. Elevated concentrations of chloride also increase the corrosivity of water. Man-made sources of chloride include fertilizers, septic tank effluent, industrial effluent and irrigation drainage.

Concentrations of chloride vary between 0.03 and 60 mg/L, with a mean of 4.85 mg/L and a median of 2.50 mg/L. All concentrations are well below the GV of 250 mg/L. The statistical distribution shown on Figure 21(a) shows a positively skewed distribution with a number of outliers. Eighty nine percent of samples have chloride concentrations below 10 mg/L.

The spatial distribution is shown on Figure 21(b).

Using a classification of chloride concentrations from Stuyfzand (1989), the samples can be classified as follows:

Class	mg/L	% of samples
extremely fresh	<5	70.6
very fresh	5 - 30	27.6
Fresh	30 - 150	1.8
fresh - brackish	150 - 300	0.0
Brackish	300 - 1,000	0.0
brackish – salt	1,000 - 10,000	0.0

All the samples indicate fresh groundwater.

3.3.7 Sulphate

Limits on sulphate concentrations have been set on the basis of taste as there are no significant health effects, although at elevated concentrations there may be gastro intestinal irritation.

Sulphate concentrations in the district range from 1 mg/L to 69 mg/L, with an average of 11.82 mg/L and a median of 8 mg/L. All concentrations recorded are well below the GV of 250 mg/L. The statistical distribution of concentrations shown on Figure 22(a). Eighty seven percent of the data have concentrations below 15 mg/L.

The spatial distribution of these data is shown on Figure 22(b). The distribution of sulphate concentrations tends to mirror the distribution of chloride concentrations.

3.3.8 Fluoride

Fluoride is an essential mineral for healthy living and can be a cause for concern if it is present at high concentrations as well as if they are too low. The presence of fluoride acts to prevent tooth decay, but at high concentrations results in dental fluorosis and, in extreme cases, skeletal fluorosis. Dental fluorosis the most common effect of high fluoride concentrations and has the greatest impact on children under 7 years.

The presence of fluoride in groundwater is controlled by

- Geology. Granites are a potential source due to presence of fluoride-bearing minerals. Fluoride is also present in groundwaters associated with volcanic rocks in the rift valley areas of Ethiopia, Kenya and Tanzania.
- Contact times with fluoride minerals, older (deeper) groundwaters are at risk,
- Groundwater chemical composition, low calcium and magnesium concentrations, and
- Climate, arid areas at greater risk due to slow groundwater flow.

Fluoride concentrations in the analyses available have a range of concentrations between 0.01 and 9 mg/L with an average of 0.42 and median of 0.24 mg/L. The statistical distribution of fluoride concentrations is shown on Figure 23(a). Of the 186 boreholes with fluoride analyses, 98 % have concentration below the GV of 2 mg/L. Two (DWD17966 and DWD17978) had concentrations between the GV and MAV and one (DWD15208) had a concentration above the MAV.

The spatial distribution is shown on Figure 23(b). The three boreholes with elevated fluoride concentrations are located in the south east portion of the district where the geology map shows granites are present. These may be the source of the elevated fluoride concentrations measured in the groundwater.

3.3.9 Total iron

The presence of iron in drinking water is not generally considered to be a health problem, but at elevated concentrations it causes a number of aesthetic problems from a sour metallic taste to staining of clothes and discolouration of food cooked in the water. The result is often the abandonment of relatively newly constructed water sources. The problem is most visible when discoloured water is pumped from boreholes, or after a period of rest, previously clear water becomes turbid as iron precipitates out of solution.

High iron concentrations are a common problem in rural water supplies across Africa and there has been well documented research into the issue.

Iron dissolved in groundwater is in the reduced Ferrous (Fe^{2+}) form, which is soluble and normally does not cause any problems by itself. Ferrous iron is oxidised to the Ferric (Fe^{3+}) form on contact with oxygen in the air or by the action of iron related bacteria. Ferric iron forms insoluble hydroxides in water. These are rusty red and cause staining and blockage of screens, pumps, pipes, reticulation systems etc. If the iron hydroxide deposits are produced by iron bacteria then they are also sticky and the problems of stain and blockage are many times worse. The presence of iron bacteria may be indicated by rusty slime inside headwork's, reduced water flow from the bore and unpleasant odour from water pumped from the bore, slimy deposits blocking main and lateral lines, severe staining on pavements, walls foliage.

If corrosion of the pump components is the cause of the high iron content, then concentrations of iron will decrease after a few minutes of pumping. In this case the problem may be solved by replacing components of the pump with corrosion-resistant parts. Research undertaken in Ghana (Langenegger, 1998) suggests that where the pH of groundwater is <6.5, galvanised and mild steel components should not be used.

Analysis for total iron was available for 153 locations. Recorded concentrations range from 0.01 mg/L up to 8.22 mg/L, with an average of 0.31 mg/L and median of 0.05 mg/L. The statistical distribution is shown on Figure 24(a). Ninety three percent of the values are less than the GV of 1 mg/L. Eight boreholes had concentrations between the GV and MAV and three had concentrations above the MAV.

The spatial distribution is shown on Figure 24(b).

3.3.10 Nitrate

The presence of elevated concentrations of nitrate (above 10 mg/L NO_3) in groundwater is generally taken to indicate pollution from human (anthropogenic) activities. However, under some conditions, high nitrate concentrations may be present naturally (geogenic sources).

Geogenic sources of nitrate include caliche and playa lake evaporate deposits, and desert vadose zone soils.

Anthropogenic sources of nitrate include:

- Fertilisers, particularly if associated with irrigation,
- Areas of livestock concentration,
- Sewage and waste water disposal (septic tanks, cesspits and latrines), and
- Industry

In Uganda anthropogenic sources are considered the most likely cause of an elevated nitrate concentration in groundwater.

Nitrate concentrations have been shown to be extremely variable in response to recharge events and can, therefore, change relatively rapidly. Sampling for nitrate should take place at the same time each year and preferably after the rainy season when concentrations of nitrate leached from the soil will be highest.

Limits on nitrate concentration in groundwater are specified due to health risks, particularly for babies where a condition known as ‘blue baby syndrome’ can occur.

Due to the use of inconsistent units in the groundwater database (see Section 2.3.3), it is not possible to analyse the data quantitatively. However, a qualitative assessment has been undertaken by comparing all concentrations to the GV expressed as mg/L NO_3-N (5 mg/L). Where concentrations have been reported above this level, the hard copy records have been consulted to check the units.

There are 169 boreholes in the database that have nitrate analyses. Twelve of these have concentrations above 5 mg/L, i.e. at the GV, assuming the results are quoted as NO_3-N. None of the data could be checked due to the age of the borehole construction and testing, but all boreholes were constructed over 15 years ago.

Due to the likelihood that nitrate concentrations will have changed significantly since then, it is considered unlikely that these are representative of the current aquifer conditions. All the nitrate concentrations from boreholes sampled in 2011 were less than 0.2 mg/L as NO_3-N. It is recommended that sampling and testing for nitrate is continued at selected wells as a precautionary measure.

3.3.11 Water Types

It is possible to classify groundwater by the relative proportions of the major ions using a so-called Piper Diagram. Unfortunately, only a small proportion of the water quality data recorded for Kibaale have had an analysis for a full suite of major ions. Nevertheless, these have been presented on a Piper Diagram (Figure 25) to illustrate the characteristics in the district. Only data where the ionic balance was ±10 % have been plotted.

On the anion plot (HCO_3-Cl-SO4) all the data points plot in the area showing that bicarbonate (HCO_3) is the dominant (>50 %) anion. On the cation plot (Ca-Mg-Na+K), most of the samples tested had no dominant ion.

3.3.12 Summary

The water quality data collated from samples taken during pumping tests following construction and subsequently as part of this project do not indicate any general problem with groundwater quality in the district. The groundwater is moderately soft and fresh with bicarbonate as the dominant anion.

It is important to note that most water quality samples are from deep boreholes. Shallow boreholes are potentially more at risk from pollution from human activities. It is recommended that nitrate is monitored regularly at selected sites.

Iron concentrations in some wells are above the GV and MAV for rural water supplies. The origin of this is uncertain, but is considered likely to be a consequence of the use of poor quality galvanised iron in the pump components. Careful consideration of pump specifications is required. Some on site testing of pH is recommended to establish if the groundwater is more corrosive than is indicated from laboratory results. Some local studies have indicated that Iron Related Bacteria play an important role in promoting well corrosion and regular chlorination may reduce this, although this should not be regarded as a permanent solution. It also emphasizes the need to sterilize a well on completion and prior to installing the pump.

4. GROUNDWATER MAPS

4.1 General Approach and Methodology

A Geographical Information System (GIS) has been used to evaluate, interpret and present the groundwater data that is available for each district. The GIS proprietary software chosen for use during the map production was ESRI ArcGIS 9.2 (www.esri.com).

It should be emphasized that the meaningful use of a GIS in the interpretation of spatial information is entirely dependent on the completeness and reliability of the input data.

The information for the maps was derived from the following sources:

- **National Groundwater Database (NGWDB):** borehole, administrative, hydrogeological and hydrochemical data, some with GPS coordinates.
- **MIS database:** data on administrative location, GPS location and ownership of functional and non-functional safe water sources. This was collected by DWD and can be more than 5 years old. It has occasionally been updated through the districts.
- **WATSUP database:** data on water source locations, including shallow wells and deep boreholes, springs and taps.
- **Field database:** data on protected and unprotected water sources including administrative data and GPS coordinates collected by the current project, especially in areas where there was need for a higher data density. Functionality information was collected in the field by extension workers and later updated by other officials. Static water levels have been measured where possible in some districts.
- **Uganda National Bureau of Statistics (UBOS):** population data from 2002 projected to 2010, and administrative boundaries.
- **National Forestry Department (NFD):** map layers for the GIS including infrastructure and land use (wetlands & protected areas).
- **Department of Geological Survey and Mines:** regional geological units, faults and lineaments.

The data sources and their processing are described for each map in Section 4.2.

4.2 Data Analysis and Interpretation

The interpretation and interpolation of hydrogeological and hydrochemical information relied entirely on point source data. From the point source data a surface was created using a mathematical interpolation technique. As noted above the accuracy of this surface is a function of the density of the data, and also its accuracy. In order to gain a better appreciation of data density and spatial variability, the data points have been plotted on the maps together with their point values.

The Kriging technique was used to interpolate the surfaces of the various hydrogeological and hydrochemical characteristics. Kriging is a stochastic, global interpolation technique that estimates the value at an unknown location using spatial attributes of the entire dataset. These spatial attributes are described using a statistical model known as the variogram. The input data used to estimate the values at an unsampled location are weighted based on the variogram, search parameters and the number of samples used to estimate the point. In kriging the sum of the weights is adjusted to be equal to one. This reduces the effect of bias towards input sample values.

While Kriging and IDW can produce comparable results, the main advantage of Kriging is that it is less prone to the '*bull's eye*' effect around anomalous data values.

The interpolation of the *depth to bedrock* data illustrates some of the issues involved in the interpretation and spatial interpolation of point source data for the purposes of this district groundwater report and accompanying maps.

The *depth to bedrock* or *depth of weathering* can vary over short distances. In order to produce the *depth to bedrock map*, it has been assumed that the siting techniques were the same for each borehole, that each site reflects the characteristics of the surrounding area and that the sites selected represent the points of maximum depth of weathering. These assumptions mean that the map produced by interpolation of the data should reflect the relative, but not necessarily the absolute thickness of overburden for the area. In other words, the map should be used to give an indication of the approximate depth to bedrock in an area, but there may be local variations within that area.

As mentioned above, the accuracy of the maps is entirely dependent on the density and accuracy of the data available for their production. As new boreholes are drilled in the district and our knowledge of the area improves, the data should be re-interpolated and used in the production of future editions of the maps.

4.3 Map 1: Water Sources Location Map

This map gives an overview of all groundwater sources in the district, based on data acquired by the WATSUP project. The map shows the regional geological as its background, enhanced by the hill shade derived from the digital elevation model (DEM).

Water sources are depicted on the map by means of different symbols designating *deep boreholes, shallow wells, protected springs* and *taps*. The Water Sources Location Map provides a reference for all the water sources in the District, plus an indication of the density of sources in relation to population centres and other physical developments. The geological base map layer is used to show any relationships which may exist between existing groundwater source occurrence and underlying lithologies and lineations.

4.4 Map 2: Water Supply Technology Options Map

This map is very important with respect to groundwater development planning as it serves to indicate the type of technology that may be appropriate in different parts of the District. This in turn influences the groundwater investigation process and the selection of siting methods. In terms of financial planning, the choice of technical option will also have a significant impact on the overall cost of water source development.

The map was produced by combining several sets of spatial data into a single interpretation that is depicted on the map. The definition of a particular technology option was determined by the suitability of an area for the application of a particular construction technique. The technique to be applied must have the ability to penetrate the groundwater body to a sufficient depth to enable groundwater to be extracted in adequate quantities by a hand pump or other acceptable method.

Four technology options have been identified for Uganda as shown in Table 7. Some, but not necessarily all categories will be appropriate within the District. In order to maintain consistency for the map layouts for the whole of Uganda, some technology options shown in the legend may not occur in the District.

The factors which determine the appropriate technology option in an area are the depth or thickness of the aquifer and the level at which sufficient groundwater is struck to make the well or borehole successful. For hand pumps this is generally taken as a yield of at least 0.5 m^3/h.

Table 7 Technology options categories

No.	Technology Option	Depth	Construction Method
1	Shallow well zone	< 15 m	Shallow well construction technology (dug wells or hand auger)
2	Shallow borehole zone	< 30 m	Conventional rotary drilling or mechanized auger machine
3	Deep borehole zone	> 30 m	Deep borehole technology
4	Spring zone	At ground surface	Spring capture

The data required for data analysis are the depth of the weathering profile as the primary control on the shallow regolith aquifer, and the level of the water strike. If either the first or the main water strike occurs within the regolith and thus above the level of the basement bedrock this indicates that there may be potential for shallow well technology. If the first water strike is used in this decision making process, it has to be assumed that it is also sufficient to supply a successful well. Where yield data is lacking, the main water strike depth may have to be used instead. If the water strike is at or below the base of the regolith then the borehole technology should be applied.

As shallow wells are not generally dug below 15 metres, any water strike below this depth would require the use of boreholes. Up to depths of 30 metres, the boreholes are designated as shallow boreholes. Below 30 metres they are known as deep boreholes. Note that there can be some confusion in the naming of boreholes, and in some districts any drilled borehole has been recorded as a deep borehole even if it does not exceed a depth of 30 metres.

A Decision Support System (DSS) was applied to the NWGDB data. It was used to designate whether a borehole could have been successful as a shallow well, shallow borehole or deep borehole if it had been constructed at the location of the recorded data point. The data layers used for this DSS were the depth to weathered rock, the depth to bedrock, the first water strike and the main water strike. Unfortunately the NGWDB does not have a complete record of all these data for all locations, and it generally also does not include data from shallow wells. The NGWDB DSS determines the technology options in order of data availability, with preference given to the main water strike, followed by the first water strike, depth to bedrock and finally overburden thickness. All data points were then subjected to a quality control. For example, where the current static water level is below the water strike used to determine the technology option, the data point was removed from the analysis.

A comparison between the technology option determined by the above methodology and the WATSUP database showed that the available data is biased towards deep boreholes. As discussed above, shallow wells are not generally included in the NGWDB. In order to balance this, borehole data from WATSUP were included in the final analysis.

The WATSUP database classifies the groundwater sources with hand pumps into shallow wells (<30m) and deep boreholes (>30m). It does not include a classification for shallow wells with a depth of <15m, and it has therefore been assumed that all shallow wells are included in this category. The WATSUP database also does not include information on well drilling and therefore the DSS discussed above could not be applied to the WATSUP data.

In order to maintain a consistent approach in combining the NGWDB DSS and the WATSUP database, all data points were classified into either shallow boreholes (<30m) or deep boreholes (>30m). Note that many of the data points included in the NGWDB DSS would also have been recorded in the WATSUP database. Where two data points coincide, preference was given to the NGWDB DSS during the interpolation of the data.

The Technology Options Map was constructed by interpolating the two data sets as discussed above. The District was divided into either a shallow borehole zone or a deep borehole zone. Part of the shallow borehole zone was then further subdivided into a shallow well zone where static water levels and productive groundwater zones are expected to occur within 15m of the ground surface. These areas would be expected to occur in the valleys in the vicinity of lakes and wetlands, which are surface expressions of locations where the groundwater level is at or very close to the ground surface.

The Technology Options Map depicts the spatial distribution of the three groundwater source construction options by means of colour coding applied to each option. A spring zone was overlain on top of these zones based on the location of existing springs from the WATSUP database.

The Technology Options Map gives an indication of the type of technology option which should be appropriate for a particular area. However, it is not exclusive. For example, a deep borehole could still be successful in a shallow borehole zone. In shallow borehole zones where there are water quality problems, deeper boreholes may be the only viable alternative. The Technology Options Map does not replace the detailed baseline survey and geophysical investigations that should precede any new groundwater development.

4.5 Map 3: Hydrogeological Characteristics Map

These maps display key hydrogeological parameters as interpolated surfaces. Point source data from boreholes was used to construct a continuous interpolated grid that was then subdivided into ranges of values using graduated colour to display the various range intervals.

The hydrogeological characteristics of an aquifer should include calculated parameters such as transmissivity and storativity. Transmissivity values have been calculated by drilling contractors for a limited number of boreholes. However, the reliability of these is uncertain given the short duration of the pumping tests and the absence of observation boreholes. However, it was deemed useful to illustrate certain aquifer characteristics by means of parameters measured during the drilling process. These measured parameters are thus presented as separate insert maps, namely *overburden depth*, *first water strike*, *main water strike*, and *static water level*, and are discussed individually below.

4.5.1 Overburden Thickness

This map gives an indication of how the depth of weathering and hence the thickness of the potential regolith aquifer varies across the District. The depth to the base of the weathered zone or the overburden depth was taken from the borehole lithology logs. In most cases the depth to the competent bedrock is easily identified. However, in some cases there is a risk of misinterpretation as the interface between the regolith and the bedrock is very gradational and the ‘saprock’ zone can be indistinct. For example, fracture zones in the basement below the bedrock interface may be highly weathered, giving the impression of a much greater thickness of the overburden. The recognition of the overburden/bedrock interface can also be complicated by the percussion drilling method that produces only fine drilling cuttings that are often not easily identified.

In boreholes that did not conclusively reach the bedrock, the weathering profile generally follows an identifiable pattern. Towards the base of the profile the characteristic ‘saprock’ zone contains the lithological components most resistant to weathering, usually quartz. Therefore if there was evidence from the borehole log that the borehole reached a zone with a greater proportion of quartz then the borehole depth was taken as the depth of weathering.

The Overburden Thickness Map will be useful when planning future drilling campaigns, as it will enable estimates of the amount of casing required, as well as assisting in defining the drilling method that may be most appropriate.

4.5.2 First Water Strike and Main Water Strike

The depth at which the driller encounters water during drilling, generally called the *water strike* is noted and recorded in the borehole completion report. The shallowest depth at which water is encountered is designated the *first water strike (FWS)* and the depth at which the principal inflow occurs into the borehole is designated the *main water strike (MWS).* These depths may be coincident, or they may be completely different, depending on the nature of the aquifer at the particular locality. Frequently a minor First Water Strike is noted in the regolith aquifer, with subsequent, and generally greater, water strikes noted in the fractured bedrock. In this case one of these latter water strikes would be the *main water strike*, distinguished by the largest incremental increase in yield as noted from the airlift yield during drilling.

The First and Main Water Strike Map were compiled from the database records recorded as metres below ground level (mbgl). All data was included in the construction of the interpolated surface for the two maps, which are displayed in a gradational colour scheme. The data points and their values are also shown on the maps.

The Water Strike Map will assist in planning drilling contracts as they give an indication of the likely depth that should be drilled to, in order to encounter groundwater. However, it should be noted that there can be considerable variations in water strikes even between locations in close proximity to each other.

4.5.3 Static Water Level (SWL)

The NGWDB contains static water level information as metres below ground level or mbgl (Section3.2.3). These data were used to compile the Static Water Level Map. The map was constructed in the same manner as the Water Strike Maps by interpolation of the static water level data and then designating different ranges of values by means of a gradational colour scheme.

It should be noted that the Static Water Level (SWL) Map shows the depth of the static water table below ground level and not the piezometric surface. A piezometric surface map was not attempted, as the true elevation of each of the boreholes is not reliably known. Another issue is that the piezometric surfaces in basement aquifer terrain can be highly complex, since many preferential flow zones occur according to fracture intensity, interconnectivity and depth of weathering. The construction of such a surface requires considerably more detailed hydrogeological information.

The Static Water Level Map is useful in depicting the general depth of groundwater and indicates how groundwater levels vary over the district. The Static Water Level Map will assist in planning future pumping equipment requirements as it indicates the level at which the groundwater will stand in the borehole, and hence the minimum depth that the pump should to be installed..

4.6 Map 4: Groundwater Quality Map

The national guidelines developed by DWD for potability of groundwater were drawn up based on the concentration of individual natural chemical constituents and their influence on health, taste, colour and general acceptability as shown in Table 5. In addition, the guidelines also include important recommendations on the permissible bacteriological content of groundwater as this may have very significant health implications. Note that the bacterial water quality was not included in the groundwater quality maps as bacteria are usually the result of local pollution sources (e.g. nearby septic tanks). This means that the amount of bacteria in a well are only representative of that particular well and this should not be extrapolated to other areas. Nitrate is also a parameter which can be affected by local pollution sources. It has not been selected for mapping output for the reasons given in Sections 2.3.3 and 3.3.10.

For the purpose of compiling the Groundwater Quality Map three quality categories were defined. These can be summarized as potable water, water of acceptable quality but above Guideline Value (GV) and water above the Maximum Acceptable Value (MAV). These categories are shown in Table 8.

Table 8 Groundwater quality categories

Quality Category	Comments
All parameter values below Guideline Value (GV).	Water is of potable quality for all analysed parameters.
Some parameter values above Guideline Value and below Maximum Acceptable Value.	Water is generally of acceptable quality but some parameters may be above the Guideline Value, and adverse taste or usage problems may arise.
Some parameter values above Maximum Acceptable Value (MAV).	Water is not acceptable for human consumption due to high levels of adverse chemical constituents.

The Groundwater Quality Map was produced by means of a number of intermediate thematic maps that depict zones of parameters such as fluoride, sulphate, total iron, total dissolved solids (TDS) and hardness that either exceed GV or exceed MAV. These water quality maps illustrate the spatial distribution of particular groundwater quality problems that occur in each District. These maps were then integrated using the GIS to provide a single map layer that indicates overall water quality that is either below the GV, between GV and MAV or exceeds the MAV. The water quality categories are depicted on the map by three colour codes.

4.7 Map 5: Hydrochemical Characteristics Map

The Hydrochemical Characteristics Maps indicate the distribution of specific groundwater quality problems for each district. Such problems vary from district to district. The spatial distribution of various specific hydrochemical parameters that have influence on the potability of groundwater are important in understanding the non-acceptability of water sources, or the occurrence of water-related health phenomena.

The hydrochemical parameters were utilized to compile the Groundwater Quality Map as well as insert maps depicting the four key parameter contents in milligrammes per litre (mg/l). The parameters selected vary from district to district and include Fluoride, Total Iron, Sulphate, Total Dissolved Solids (TDS), and Hardness. Also indicated on the maps are the Maximum Accepted Value (MAV) and the Guideline Value (GV) for each of the parameters. These quality standards were discussed in Section 3.

The series of Hydrochemical Characteristics Maps will assist District Planners by indicating zones that may require more substantial or different forms of groundwater investigation and development if fully potable groundwater sources are to be installed.

4.8 Map 6: Groundwater Potential Map

One of the most important groundwater maps is the Groundwater Potential Map of the District. Groundwater potential is a very broad term and may be influenced by many factors such as type of aquifer (i.e. geological and structural characteristics of an area), availability of groundwater recharge (i.e. rainfall patterns, nature of material overlying the aquifer etc.), groundwater quality (i.e. natural hydrochemical characteristics of the groundwater, susceptibility of the groundwater to pollution etc.) and abstraction potential (transmission and storage capacity of the aquifer, ability of boreholes or wells to abstract groundwater). The definition of ‘potential’ can also be influenced by the ultimate usage and demand for the water. For example, if water is required in large quantities for urban supply then it may be that a basement aquifer with low borehole yields would be classed as ‘low potential’, whereas the same aquifer may be classed as ‘high potential’ with respect to satisfying a much smaller rural water demand.

The definition of ‘groundwater potential’ used in the development of this map is stated as:

The ability of a particular area to supply an adequate quantity of potable groundwater to satisfy the demand of that area. Adequate quantity means > 0.5 m^3/h. Potable means satisfying the limits set by DWD for key hydrochemical parameters.

Two maps have been produced to represent Groundwater Potential:

- Map 6A: This shows well yields, areas of poor groundwater quality and an estimate of drilling success rate on a Sub-county basis, and
- Map 6B: Showing well yields and areas of groundwater quality as on Map 6B, but with well yields interpolated from the well data.

The derivations of the three map components are described below:

Borehole yields: An indication of actual borehole yields is given on the Groundwater Potential Map by depicting recorded borehole yields as a 'bubble map', where the yields are categorised in circles of increasing diameters as yields increase. The yield values in m^3/h are also shown. This map illustrates the high spatial variability of well yields in fracture aquifers, where high yielding wells can be located close to unsuccessful wells. In some areas high yielding wells may be more frequent, and this could be related to the presence of regional fractures in that area. In order to investigate if there is any relationship with regional tectonics, the regional lineaments are overlain on the Groundwater Potential Map.

Groundwater quality: Those areas where there are water quality problems have been classified as zones where the overall water quality either exceeds the GV or exceeds the MAV. This is the same map layer as that shown in the Groundwater Quality Map, described in Section 4.6.

Groundwater potential is depicted on the map by a colour designation of a range of success rates at the sub-county level, overlain by hatched areas relating to the water quality characteristics. It is thus very possible to have a particular area that has a good potential with respect to yield, but a poor potential with respect to water quality. In such a case the overall groundwater potential would be designated as poor because of the water quality characteristics.

Success rate (Map 6A): In order to get an overview of the potential for an area to provide successful wells, a statistical analysis was carried out on all well yield data in the NGWDB at the sub-county level. The percentage of successful wells (i.e. with a yield exceeding 0.5m^3/h) is classified for each sub-county into one of four categories as shown in Table 9. Note that this approach permits well data to be incorporated in the analysis for which coordinates are not available, thereby providing a statistically more accurate interpretation of the area.

Table 9 Success rates of wells & boreholes with yields >0.5m^3/h

Percentage of Wells with Yields > 0.5 m^3/h	Potential
< 25 %	Very Poor
25 – 50 %	Poor
50 – 75 %	Moderate
>75 %	Good

Experience suggests that data in the NWGDB may indicate a more optimistic interpretation of success rates is actually the case. This may be the result of underreporting of dry wells by drilling contractors, or in some historical cases, that dry wells were not entered into the NGWDB. This illustrates the importance of recording all water well drilling campaigns in detail even when, or perhaps especially when, boreholes are unsuccessful.

In order to 'calibrate' the success rate categories for the perceived optimism of the statistical interpretation, they are described in more pessimistic terms in Table 9 than the data suggests.

Interpolated yields (Map 6B): This map was generated using all the available yield data for the boreholes. Due to the nature of the fractured basement aquifer, it is possible to drill an unsuccessful borehole near a high yielding well, and vice versa. Therefore, this map needs to be treated with caution.

The Groundwater Potential Maps can be used when planning future water supply activities in the District to indicate the zones of lower potential.

4.9 Water Supply Coverage Maps

In order to illustrate the coverage of water supply provision with respect to population three different types of maps were constructed. These three maps form an essential tool in planning the future groundwater development in the district as they jointly reveal which areas are better or worse served with respect to groundwater sources. The maps are based on the water source data as collected during the WATSUP project undertaken by the Ministry of Water and Environment.

Some observations need to be made with regards to the data collection. Many sources are reportedly non-working but often they may already be beyond repair and should have been reported as abandoned. Also some of the springs are reportedly low yielding during the dry season, although these sources should be considered as a functional water source. Quite a number of the sources have been reported in different parishes than where they actually plot on the GIS map. The basis of the GIS map was the UBOS parishes of the 2006 survey and apparently some changes have already been made since. Nevertheless, the database and maps give a good indication of where the need for additional new safe water sources is highest.

4.10 Map 7: Water Supply Coverage per Parish Map

This map is a simple depiction of the percentage of the population that is served by the existing water sources on a parish-by-parish basis. The map was constructed by utilizing the parish population data from the 2002 census extrapolated by UBOS to 2010, and the type and number of water sources in the parish as per the WATSUP database. A specific number of people are assumed to be served by different types of water source as indicated in Table 10.

Table 10 Water sources types and population served

Source Type	Population Served per Source
Shallow Well (SW)	300
Borehole (BH)	300
Protected Spring (PS)	200
GFS Tap	150

The percentage Water Supply Coverage (WSC) per Parish was calculated using the formula below:

$$WSC = \frac{(SW \times 300) + (BH \times 300) + (PS \times 200) + (GFS \times 150)}{Project\ Parish\ Population} \times 100\%$$

The map was then compiled by depicting the Water Supply Coverage for each Parish by a graduated sequence of colours representing the various percentage ranges.

4.11 Map 8: Water Service Areas and Population Density Map

This map was produced in order to illustrate the population density in the district and the areas that are served by a safe water source. The map brings in the concept of distance to a safe water source based upon an acceptable distance with respect to the manual collection and transport of water, as well as the total number of people that can be served by a particular type of source.

The map was constructed by utilizing the parish population data (projected by UBOS from the 2002 census to the year 2010), the type and number of water sources in the parish and an agreed water source collection distance for the different types of water source. The agreed collection distances are 1,000m for all water sources (shallow wells, boreholes, GFS taps and protected springs).

The population density of each parish was calculated by dividing the total number of people per parish by the area of the parish and is depicted by a graduated sequence of colours representing the various ranges of population density (no. per km^2).

Overlain on this thematic map are service radii (S.R.) for all the sources. For a borehole, the area that can be serviced by the borehole is dependent on the population density i.e. the greater the density, the smaller the service area (S.A.) of the borehole. Thus:

$$Service\ Area\ (SA) = \frac{300}{Population\ Density}$$

From this Service Area a Service Radius was then calculated as:

$$Service\ Radius\ (SR) = \sqrt{\frac{SA}{\pi}}$$

The GIS then depicts this Service Radius as a circular distance from a particular point source as an overlay.

However, constraints were imposed with respect to the maximum acceptable water collection and transport distance from the source. If the calculated SR is greater than 1,000m then the depicted Service Radius is shown as this maximum acceptable water collection distance. This situation occurred where the population density in a particular parish was low.

This map spatially represents the water supply coverage with respect to actual population numbers served by a particular water source. If the Service Areas overlap or are adjacent to each other then it may be assumed that the population is fully served with respect to water sources. The larger the gaps between the Service Areas, the less adequate the provision of groundwater supplies with respect to the density of the population.

4.12 Map 9: Population per Parish and Distance to Water Source Map

This map depicts where most of the people are living in the District based on Parish population data as extrapolated from the 2002 Census data.

For each of the sources a circle has been drawn, indicting the area that is covered by the water source based on a standard maximum walking distance per source being 1,000 m.

5. DESCRIPTION OF THE DISTRICT GROUNDWATER MAPS

The District Groundwater Maps provide a first compilation and interpretation of hydrogeological and related data currently available for the district. The maps illustrate groundwater conditions in the District and water supply technology options.

It should be noted that in some areas very few boreholes exist, resulting in anomalous areas around sometimes a single borehole. The isolated boreholes determine, after the interpolation exercise, the classification of a large area around the borehole. The map user should realize that this classification may not be representative for such a large area. This is especially important when the borehole has some extreme parameter values. The map user should consider this limitation when working in such an area. In future when more data become available these anomalous areas may be averaged out.

The methodology and data sources used to develop the nine different District Groundwater Maps and their use in water supply planning, are described in Section 4.

5.1 Map 1: Water Sources Location Map

Kibaale district is underlain by four geological formations, namely: Precambrian basement complex comprised of undifferentiated gneiss; Precambrian metamorphosed sediments (argillites and quartzites); granites and a small area of Rift Valley sediments in the extreme west of the district.

The deep borehole sources are patchily spread across the district, some parishes having dense clusters, others having almost none. Shallow wells have a similar distribution, with the exception of the north east, where the coverage is less dense. Protected springs are common in the west and in the south of the district. There are almost no protected springs in the north east, covering the Sub-counties of Kiryanga, Kakindo, Nalwayo, Kisiita and Nkooko. This area is generally below an elevation of 1,000 masl.

5.2 Map 2: Water Supply Technology Options Map

Deep well technology is applicable across the district, depending on the access requirements for equipment. In the north east of the district deep borehole technology is dominant with only relatively small areas suitable for shallow well technology. In the remainder of the district the map indicated that shallow well technology is a suitable alternative, as is shallow borehole technology.

Protected springs are a suitable technology option in the west of the district and in certain areas in the south. The north east part of the district is unsuitable for protected springs.

5.3 Map 3: Hydrogeological Characteristics Map

5.3.1 Overburden Thickness

Overall the overburden thickness is generally greater in the central and eastern two thirds of the district with a significant area having overburden greater than 30 m thick and only very small areas of less than 15 m thick. There are some areas where the overburden is greater than 40 m thick (Kisiita, Nkooko and Kyebando/Mugarama). Parts of the south of Bwamiramira and Matale Sub--counties are marked as ‘no data’ due to the lack of borehole information.

In the western third of the district, the overburden tends to be thinner, although there is an area where it is greater than 40 m thick in the north of Rugashari Sub-county. In a significant part of Mpeefu Sub-county the thickness is less than 15 m.

This map will help district planners estimate the likely casing depths required for borehole construction.

5.3.2 Depths to First Water and Main Water Strikes

In most of the district, the first water strike is below 30 mbgl. Significant areas where the FWS is less than 30 mbgl are found in the following locations:

- The largest area is in the west in a zone covering northern Mpeefu Sub-county, part of Bwikara Sub-county and southern Muhoro Sub-county. This includes a small area where it is less than 15 mbgl.
- In the eastern two thirds of the district, the areas where the FWS is less than 30 mbgl are patchier and less continuous. The largest areas can be found in northern Nyamarunda Parish, northern Kabamba and Kicucura parishes, Komondo, Gayaza and southern Lubaya parishes and southern Masaka and Mwitanzige and North West Kitegula parishes.

The Main Water Strike Map shows that the MWS is generally deeper than 30 mbgl. The area where it is less than 30 m is confined to the north west of Mpeefu Sub-county. Elsewhere there are only small, relatively isolated, patches.

5.3.3 Static Water Level (SWL)

The Static Water Level Map for Kibaale district shows that static water levels are generally less than 25 mbgl. The relatively small areas where it is deeper than this are in the north of Kisiita and Nkooko Sub-counties, Kiryanga and north Kyebando Sub-counties, along the boundary between Mabaale and Kyanaisoke Sub-counties and in west Rugashara Sub-county.

Shallow SWLs, less than 15 mbgl, can be found in the west in Mpeefu, across the southern parts of Buyanja and Bugangaizi counties and patches in Nkooko and Kakindo/Nalweyo Sub-counties.

5.4 Map 4: Groundwater Quality Map

The composite data shows that most of the district water resources are of good quality. However, there are some areas where one or more of the water quality parameters are above their respective permissible values. In the Sub-counties of Bwikara and Mpeefu, southern Bwamiramira and northern Nalweyo the groundwater is of marginal quality. In Kyebando and Kasambya Sub-counties water quality is poor.

The parameters responsible for the areas of poor and unacceptable water quality are identified on Map 5. In these areas various actions are required to avoid developing sources with poor water quality.

5.5 Map 5: Hydrochemical Characteristics Map

In this district the key hydrochemical parameters plotted on the map are: total iron, sulphate, total hardness and Total Dissolved Solids (TDS). The maps show that for total hardness, sulphate and total dissolved solids, no concentrations exceed the respective guideline values.

The map for total iron shows that all the marginal and poor water quality designations shown on the Groundwater Quality Map (Map 4) are due to iron concentrations exceeding either the guideline or maximum acceptable values. In the Sub-counties of Bwikara and Mpeefu, southern Bwamiramira and northern Nalweyo the groundwater has iron concentrations between the guideline and maximum acceptable value. The groundwater in Kyebando and Kasambya Sub-counties has iron concentrations above the maximum acceptable value.

There are always a few extreme cases of particular parameters. The hydrogeological explanations for these events are not always clear and should be further investigated in future. Situations in neighbouring districts should also be taken into account since these occurrences may have a more regional character. The most likely the reason for the high iron content in the water is corrosion of the steel pump rods and casing of certain pumped boreholes and wells (based on experience of well rehabilitation). In this case, these areas are likely to have acceptable water quality provided care is taken in selecting corrosion-resistant pump components. It is considered unlikely that natural groundwater contains high iron, although further investigation would clarify this.

5.6 Map 6: Groundwater Potential Map

Two Groundwater Potential Maps are shown. Both show well yields and indicate areas where water quality is designated as poor or marginal (as shown on Map 4). Map 6A shows the drilling success rate as a backdrop to the yield and water quality, while map 6B show interpolated well yields as a backdrop.

Overall, borehole yields in Kibaale are reasonable, although the percentage with yields greater than 1 m^3/h is lower than some other districts. There does not appear to be any pattern to the distribution of high yielding wells.

Map 6A shows the drilling success rate as a backdrop to the yield and water quality. This shows that success rate across the district varies from 25 to 50 % in Mpeefu, Bwikara, Mabaale, Kyanaisoke and Kyebando Sub-counties to greater than 75 % in Muhoro, Kakindo, Nalweyo and Kasambya Sub-counties.

Map 6B shows estimated yields interpolated from borehole data. Care needs to be taken when interpreting this map in the areas underlain by basement rocks as in a fractured aquifer it is possible to drill a low yielding well very close to an existing high yielding well. Nevertheless, the plot serves to highlight areas where yields may be poor, such as in the southern parts of Bwamiramira, Matale and Mabaale Sub-counties, south east Nkooko Sub-county, north east Kiryanga Sub-county and central parts of Kasambya Sub-county. Some of these areas are defined on the basis of limited borehole data and should be treated with caution. Additional work on siting boreholes in these areas is recommended.

Areas of poor and marginal water quality are shown (taken from Map 4). Note that in this district these are the result of high iron concentrations as a result of corrosion of pump components, not necessarily from iron in the aquifer. Therefore they do not indicate areas of poor groundwater potential, but do suggest that care needs to be taken in specifying corrosion-resistant pump components and ensuring wells are properly chlorinated.

5.7 Map 7: Water Supply Coverage per Parish Map

Water Supply coverage per Parish map is based on the number of people served per water source (each borehole for 300 people and spring or tap to 150 people) i.e. a representation of the percentage of the population served by existing water sources in the different parishes.

According to this map, coverage across the district varies from less than 25 % to over 75 % Parishes with the lowest coverage (<25 %) include: Ndaiga Parish in the rift valley; Rubirizi and Rwabaranga parishes in Mpeefu Sub-county, Galiboleka Parish (Muhoro Sub-county), Pachwa and Kiryanga Parishes in Kiryanga Sub-county and Kicunda Parish in Kyebando Sub-county.

It should be noted that this coverage map only represents groundwater sources, it does not include valley dams or rainwater harvesting tanks and it may therefore differ from coverage maps published elsewhere.

5.8 Map 8: Water Service Areas and Population Density Map

In central and eastern parts of the district, the population density in the parishes varies from less than 100 persons/km^2 to between 100 and 200 persons/km^2. In the western third of the district, the population density is higher and some parishes reach a density of 400 persons/km^2, particularly along the main all-weather road.

Parts of the district appear well covered, as indicated by overlapping service areas, including some parishes with low population densities. Others, identified as having low coverage in Section 5.7, have poor coverage on a service area basis. Some parishes with high population density, for example Nyamukara and Galiboleka Parishes, are shown to require long distances to be travel to water sources. Ndaiga parish in the rift valley is particularly poorly served (note that this may be because sources in this parish have not been provided with GPS coordinates).

5.9 Map 9: Population per Parish and Distance to Water Source Map

The population per parish and distance to water source map for Kibaale district indicates that; in the western side, people are fairly served but when descending into the escarpment to Ndaiga, there are people under served. Generally the data available shows a fair distribution in the District

There are several reasons that may cause poor water supply coverage and these may include:

I. Communities living on top of the hills and the sources located near the valleys.

II. Communities living on opposite side of the swamps while the sources are located on the other.

III. Communities living near non-functioning sources and therefore, need for walking longer distances to fetch water.

IV. Possibility of having less data in these areas i.e. no water sources with correct coordinates.

6. IMPLICATIONS FOR BOREHOLE SITING, DRILLING AND SHALLOW WELL DEVELOPMENT

6.1 Borehole siting

The siting methodology depends on the groundwater potential of an area. Areas with low groundwater potential should be subjected to a more extensive siting methodology than those with a high potential. For example, in areas with a low potential, the methodology should include up to 2,000 m of geophysical profiling and three Vertical Electrical Soundings, combined with a detailed desk study of the lineaments and structures in the areas and a review of previous drilling results.

Table 11 gives an overview of the recommended borehole site investigations for each groundwater potential class. The Sub-counties have been assigned classes based on the calculated success rates shown on the Groundwater Potential Map (Map 6A) and the classification shown on Table 9.

Table 11 Coverage Classification

Potential (success rate)	API[1]	Profiling (meters)	Minimum No. of VES	Sub-county
Very Poor	X	2,000[2]	3	
Poor		1,000[2]	3	Kyebando, Mabaale, Kanaisoke, Mpeefu, southern Matale and Bwamiramira, south east Nkooko
Moderate		600[2]	2	Kissita, Nkooko, Bwanswa, Matale, Bwamiramira, Mugarama, Kiryanga, Rugashari, Kagadi
Good		300	2	Muhoro, Kakindo, Nalwayo, Kasambya

1. Aerial Photograph Interpretation.

2. two profiles perpendicular to each other using Schlumberger setting with station interval 10 meter and 1/2AB of at least 70 m (1.7 x average DTB)

It should be noted that these are recommendations based on current information only. After each project, the District, together with the TSU professionals, should evaluate whether the siting method used yielded the expected results. Based on the evaluation, and results of the drilling programme, the recommendations and the maps can be revised.

6.2 Production wells for rural water supplies

Before starting the site investigations for rural growth centres water supplies, the water authorities should carry out a desk study including an analysis of existing high yielding boreholes shown on Map 6 (Groundwater Potential). The technical details of the boreholes in these areas should be investigated and boreholes selected for long term pumping tests (72 hours) based on the results of a 3-stage step test. The execution of these tests should be supervised by an experienced hydrogeologist.

6.3 Borehole drilling

The technological option determines the drilling methodology to be considered. The drilling should be supervised by an experienced hydrogeologist who makes a reliable description of the drilling samples, decides when to stop drilling (no drilling to unnecessary depths) and who prepares the design of the well.

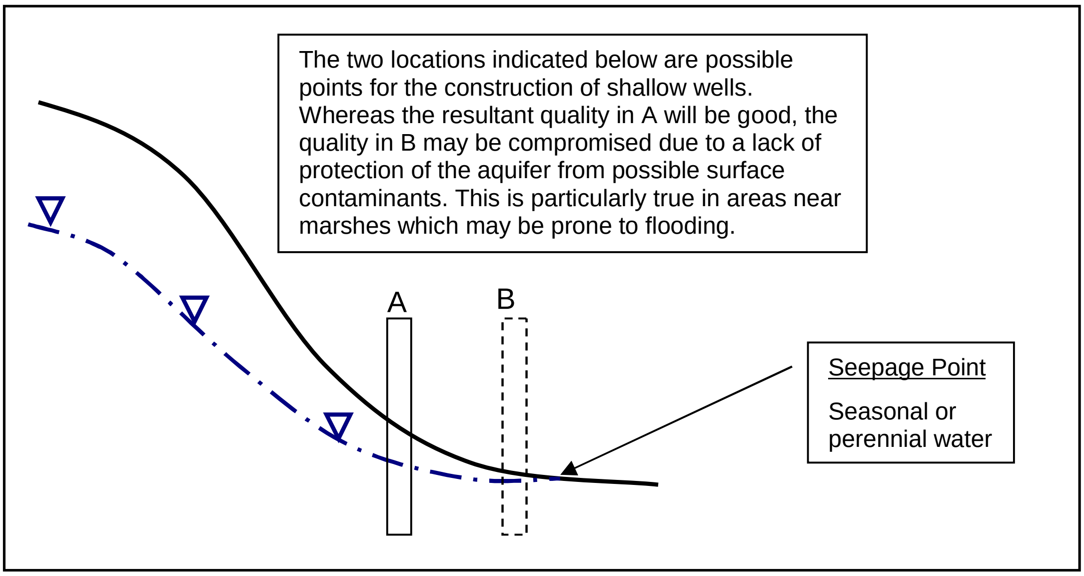
Due to reports of bacteria-enhanced corrosion of pump components, chlorination of the well after drilling and development as well as the pump components prior to installation is considered an important part of the drilling contract. Confirmation that this has been carried out should be reported by the contractor and preferably supervised by the DWO, or their representative.

6.4 Shallow well development

Because this technology aims at tapping shallow aquifers, it is important that the areas demarcated as having potential for shallow wells (regolith thickness >15m) should be studied further to understand the occurrence of ground water and the resultant quality.

Areas indicated as having shallow well potential (hand dug) are those that are located close to water courses (rivers and wetlands). In these areas, the success of the technology still depends on very good siting. It is important that the source is eventually located in an area where the groundwater table is still under a significant gradient. If this is not observed, the resultant water quality of the source is compromised as in most cases; shallow hand dug wells have been associated with “foul-smell”. A further aspect to be taken into account is the risk of inundation during periods of high water level in the nearby river or wetland.

A schematic illustration of the ideal place to locate a shallow-shallow well is indicated below.



Schematised illustration of the ideal well location points

7. LIMITATIONS AND RELIABILITY

7.1 Limitations

There are a number of limitations caused by the GIS generalization process which have an effect on the application and use of the maps. These include:

1. The whole map production process assumes that the available point source data represents groundwater characteristics that can be spatially interpolated usually in a circular way while some of the characteristics are in fact linear features (fractures).
2. None of the maps can unequivocally specify the conditions that will be found at a particular prospective water source site – they are indicative, not definitive.
3. The maps can only be used as a guide to what may be expected in terms of source construction, presence and depth of groundwater and groundwater quality.
4. The current map edition is time-bound and reflects the present state of knowledge of the hydrogeological regime in the District. It should be noted that certain parameters such as groundwater level and quality could change over time.

It should be emphasized that mis-use of the district groundwater maps and non-recognition of the essential limitations noted above during any planning exercise by staff unfamiliar with groundwater information could result in inappropriate and unnecessary expensive development programmes in the District.

7.2 Reliability

As indicated in previous sections of this report, the district groundwater maps have been compiled by GIS interpretation of point source data. By virtue of the interpretation process they can only present a generalized picture of the true hydrogeological conditions. It must be stressed that the reliability of the interpolated maps with respect to accurate representation of the natural conditions is highly dependent on the spatial density of the data on which it is based. In addition, the reliability of the maps themselves will vary over the District in relation to variations in the data density. The user of the maps must thus subjectively assess the reliability in relation to the data density as part of the utilization process.

8. LOCAL KNOWLEDGE

During the discussions with the District authorities it became clear that the available data used to produce the maps could not show all characteristics of the different areas as known by the District. Since the produced maps can only be based on available hard data, a separate map has been prepared with local knowledge where the latter deviates from the interpreted maps. Figure 25 shows the areas where the Groundwater Maps deviate from local knowledge while Table 12 shows the details for each location and the map to which the comments refer.

Table 12 Additional information per reference location

Map Type	Ref. No.	Remarks
Water Source Location map	1	Ndaiga water supply system not shown Update the administrative units/Layers
Water Supply Technology Options map	2	Not applicable for shallow wells, high cliff
Hydrogeological characteristic map and all other maps	8	The first water strike is approx. 40-52 for boreholes The FWS for shallow wells is between 3-6m applicable for the whole District. 30 to 45m for Kitutuma and Kiboja Parishes Main water strike is btn 45 - 65m Overburden thickness is btn 15 - 25m. More data for Bwamiramira and Bwanswa Sub-counties.
Hydrochemical	4	Bwanswa, Rugashaa, Burora, Bwikera and Kyakabadima are Sub-county is among the Sub-counties with above maximum acceptable Iron content Kisengwe trading centre has got a high concentration of sulphate content
Ground water Quality Map	3 4	3.Radioactive elements in Matale Sub-county 4.High iron content in Bwanswa Sub-county
Ground water Potential Map Percentage Success rate	3 7	3.Matale success rate is higher than 25 - 50 % 7.Kanaisoke needs further investigation on water potential
Water supply Coverage per parish	6 6 5	Piped water supply systems at Mahyoro TC, Nalweyo, Mabaale and Ndaiga not indicated More data with World Vision, and District water Office for Kiryanga Sub-county
Water Service area and population density map		
Population per Parish and Distance to water source Map		No comment

9. FUTURE DEVELOPMENTS

9.1 Updating of the data collection and maps

The data described in this report and used for producing the accompanying maps (Hydrogeology characteristics, Groundwater quality, Hydrochemical characteristics and Groundwater potential) are based on data available (i.e. reported by drilling contractors) to the DWRM up to the end of 2010. The coverage maps and water source location map are based on data from the WATSUP programme, which collected field data up to mid 2010.

If the maps and reports are to be improved and updated in the future there needs to be continuous gathering and processing of information on new water source construction. This will rely on the cooperation of a variety of stakeholders involved in the development of the Districts water resources. The roles of the various stakeholders in this process are laid out in Section 9.2.

9.2 Roles of various stakeholders

9.2.1 DWRM

The principal role of the DWRM, in terms of the groundwater mapping programme, is to maintain the National Groundwater Database (NGWDB). This database is used to store the basic data used for producing the maps. Currently the database stores approximately 27,000 records of deep boreholes and details of a few hundred shallow wells (less than 15 m deep).

The mechanism for ensuring the centralized collection of well construction data is the Water Resources Regulations of 1998. This requires that all groundwater development organizations and drilling companies submit data on a quarterly basis to DWRM in a standard format.

To improve data management, the DWRM intends to fund an upgrade of the database and to improve the management of incoming data.

9.2.2 Districts

In order to ensure compliance to the Water Resources Regulations, the districts are expected to assist DWRM to enforce this requirement under the contracts that they issue to private contractors. In addition, they are expected to ensure that all the NGOs, CBOs and any other organization operating in the district collect the required data and submit it to the district for onward forwarding to DWRM.

One of the biggest problems encountered in the project has been the significant number of well completion reports submitted without coordinates, or with grossly inaccurate coordinates. The districts are in a position to take a lead role in ensuring that all new boreholes have been accurately located using a GPS instrument.

The importance of recording dry wells must also be emphasised. These data will enable future drilling programmes to be better planned and areas with known problems avoided and alternative solutions implemented, or more sophisticated siting techniques used.

9.2.3 Private sector and NGOs

Updating of the NGWDB will depend on concerted efforts by all the stakeholders in groundwater development, including the private sector and NGOs. Adequate data compilation, archiving and reliable reporting practices are absolutely essential for collection and submission of good quality data in future. If this is missing, then reliable District Groundwater Maps and Reports cannot be produced.

Figures

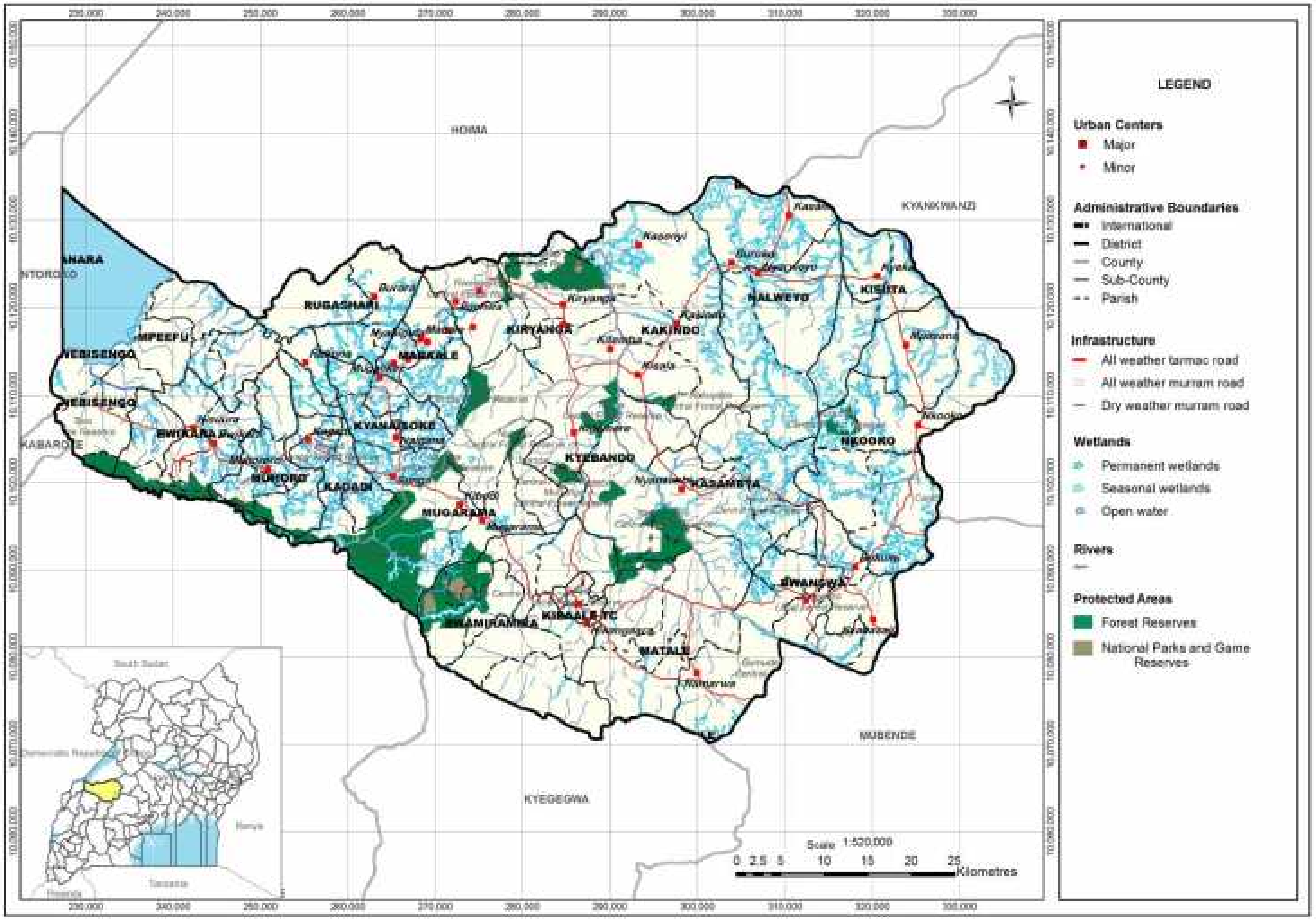


Figure 1 Location of Kibaale District

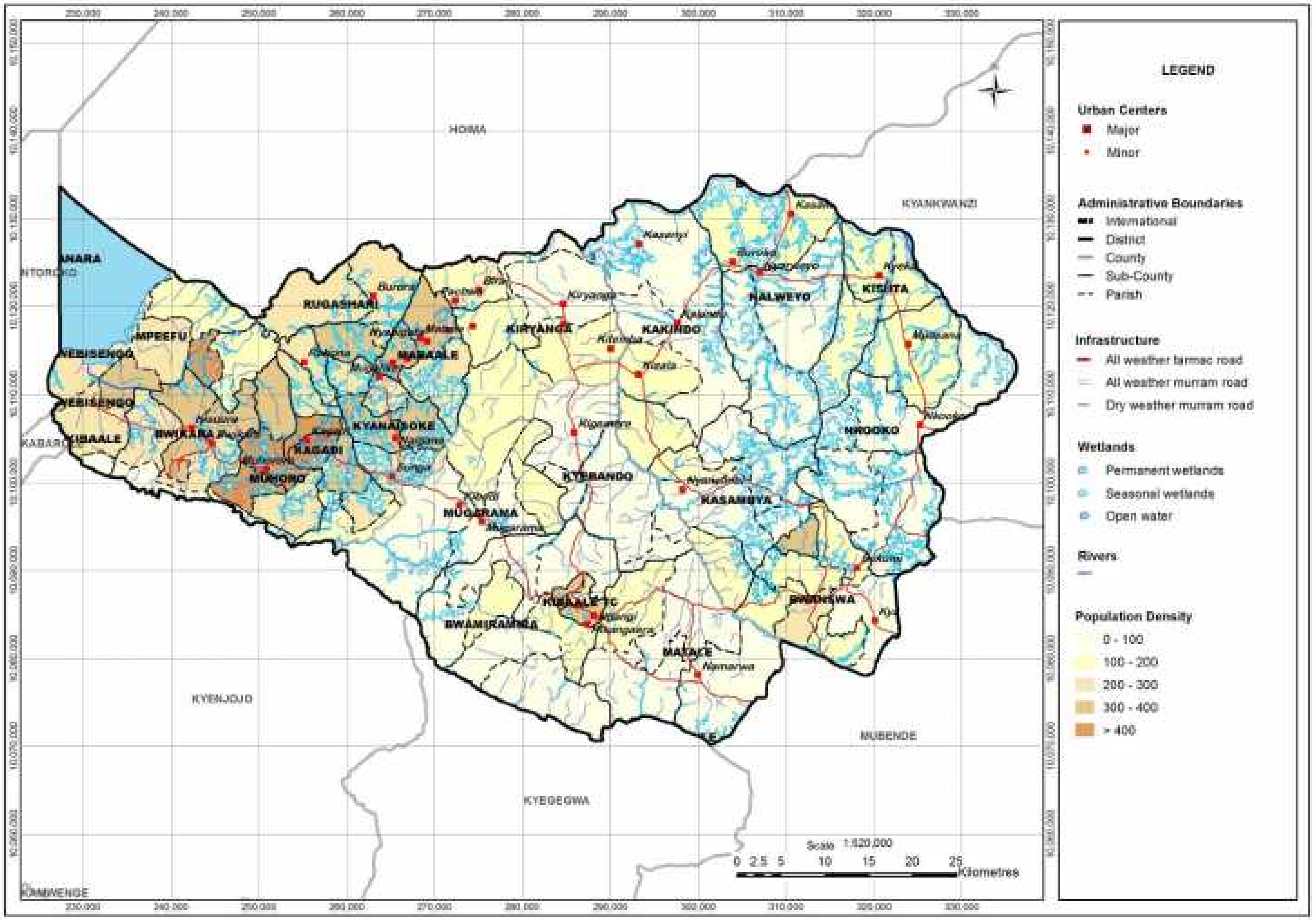


Figure 2 Population distribution for Kibaale District

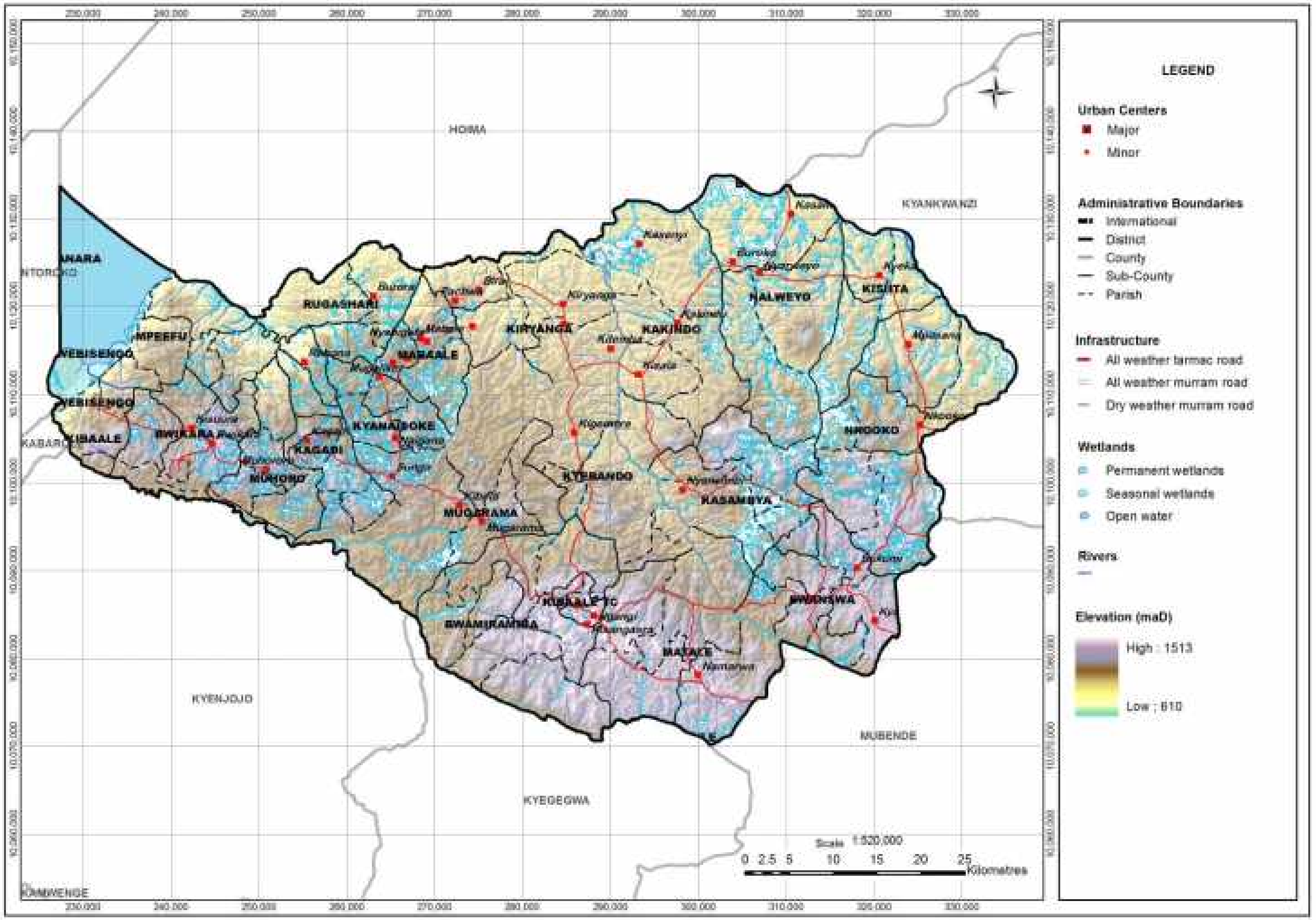
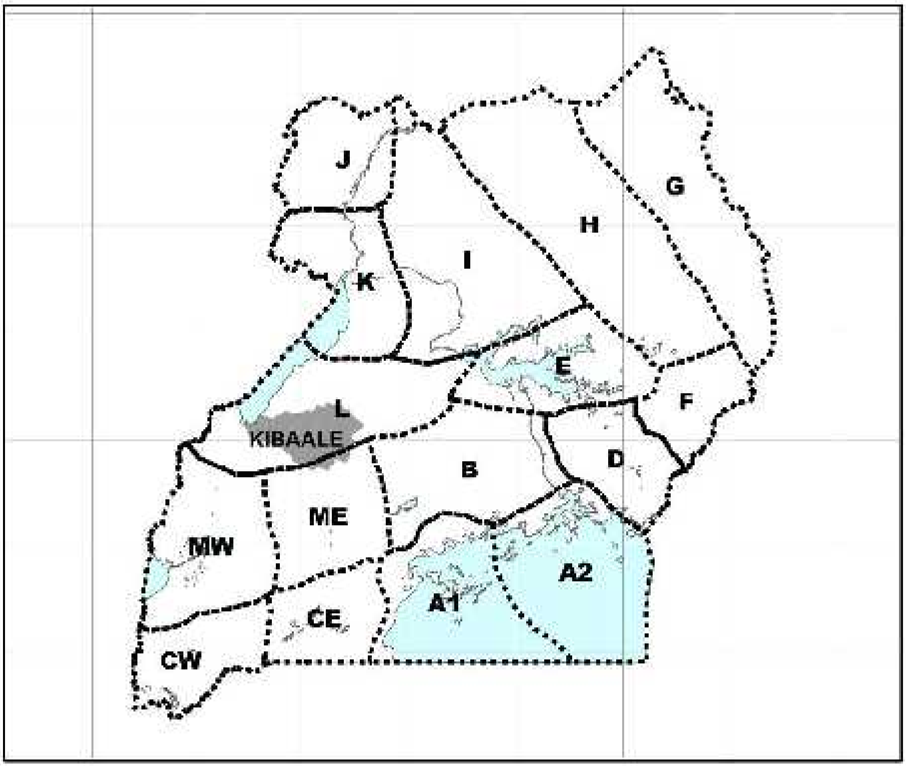
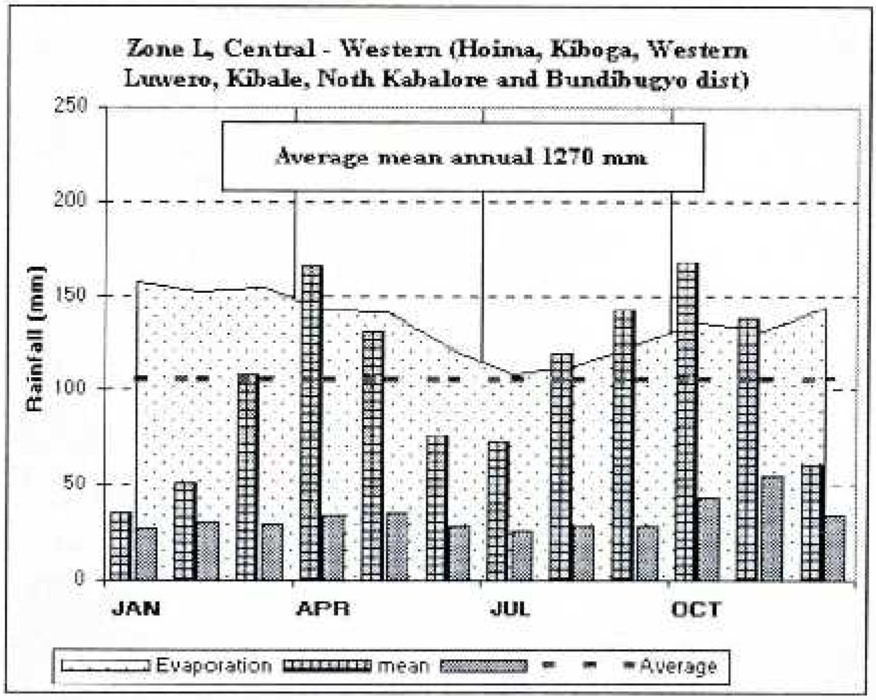


Figure 3 Topography and physical features of Kibaale District



(a) Uganda Rainfall zones



(b) Long-term average rainfall for Zone L

Figure 4 Uganda Rainfall zones and long-term average rainfall for Kibaale

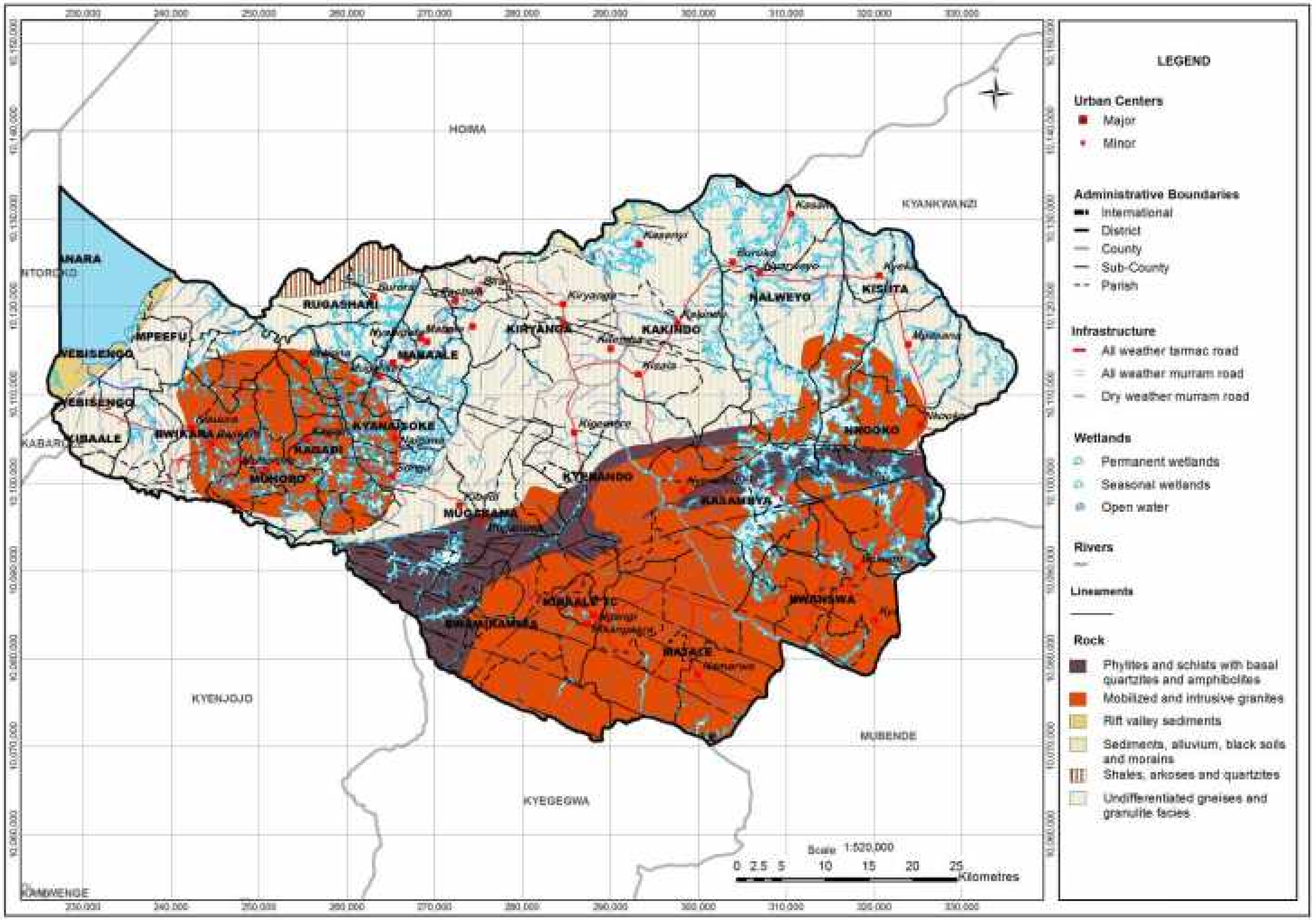
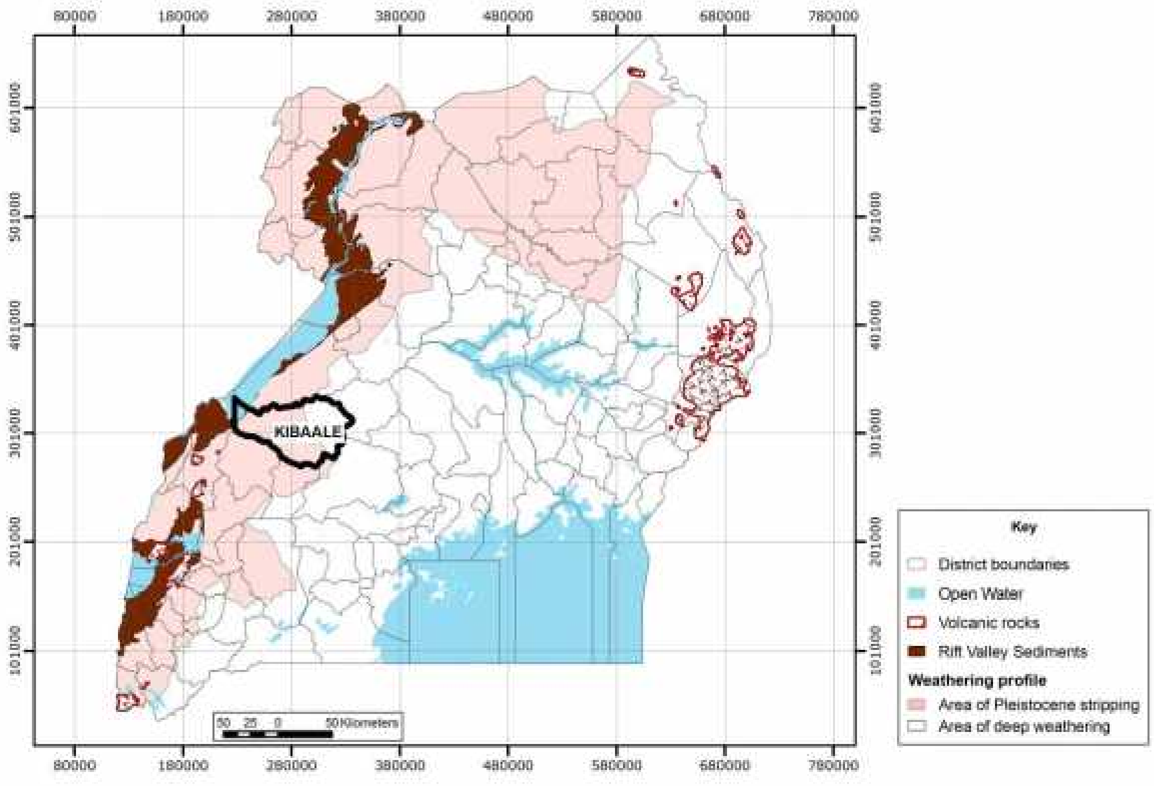
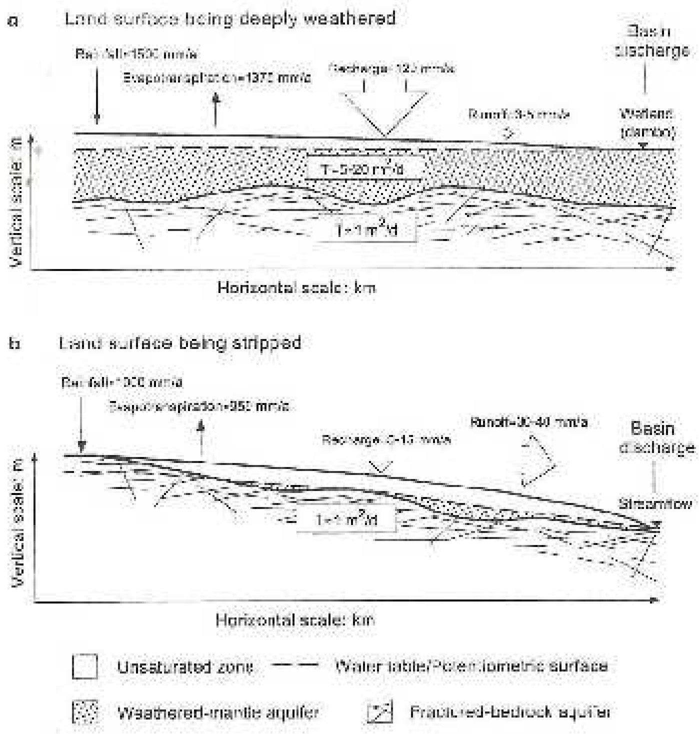


Figure 5 Geology



(a) Simplified physiographic features of Uganda based on map from Taylor and Howard (1998)



(b) Conceptual model of regional hydrogeology for deeply weathered surface and surface of stripping

Figure 6 Hydrogeology

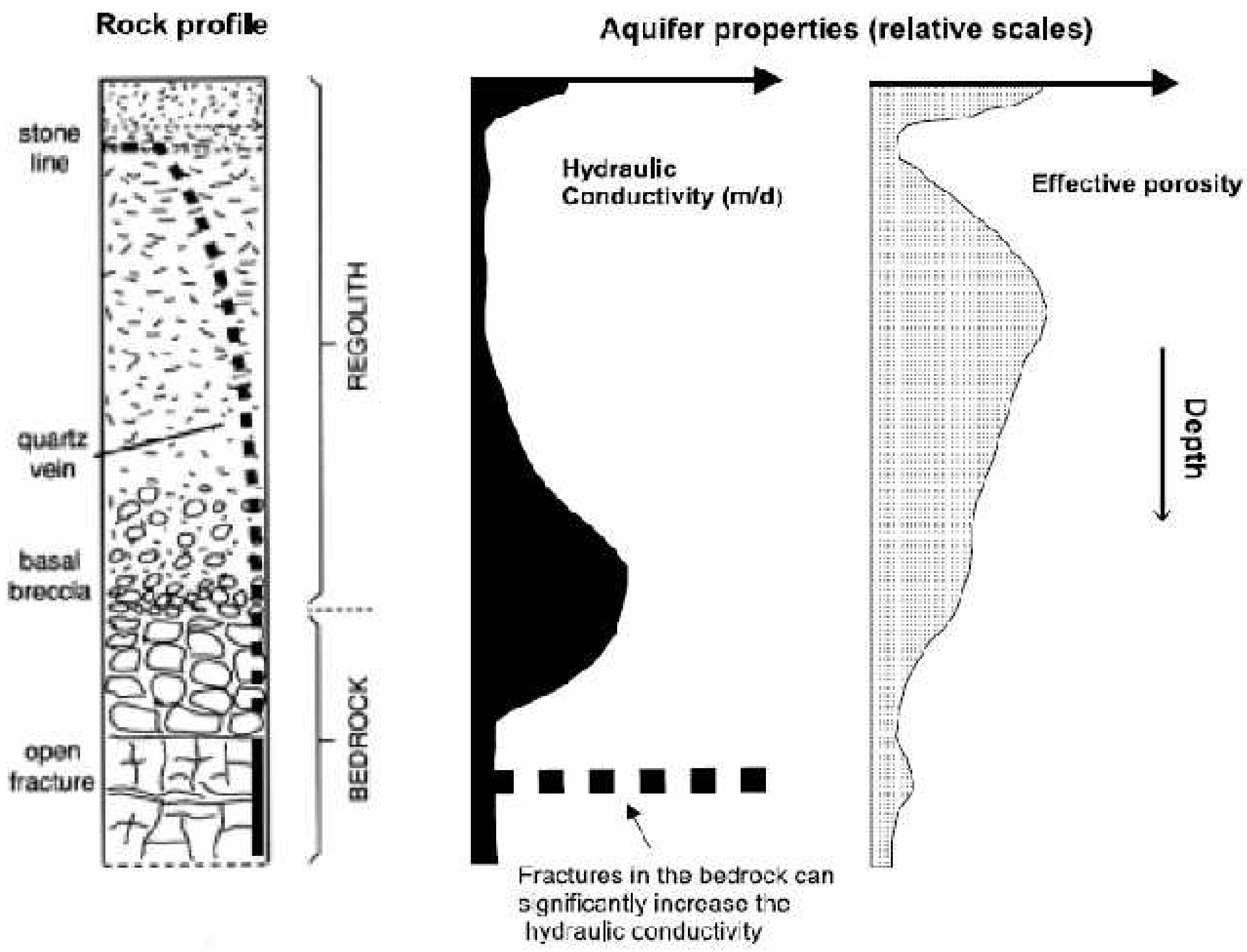
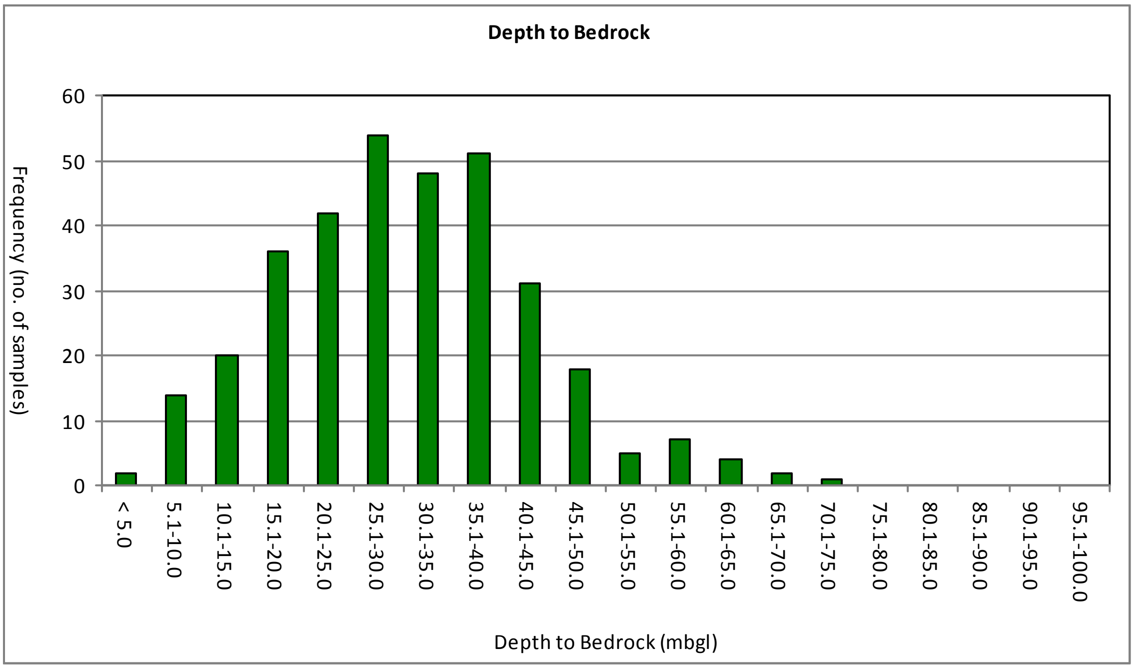
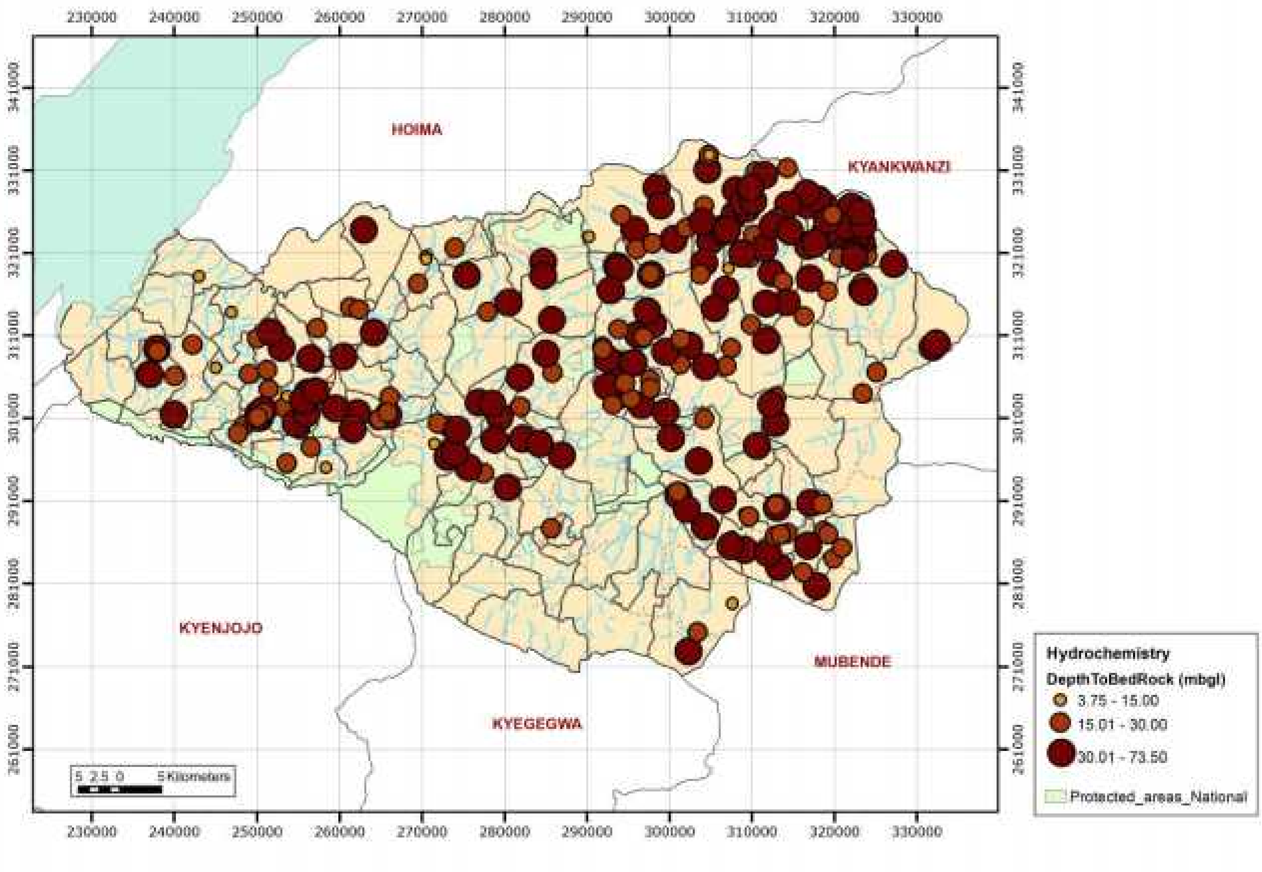


Figure 7 Basement weathering profile

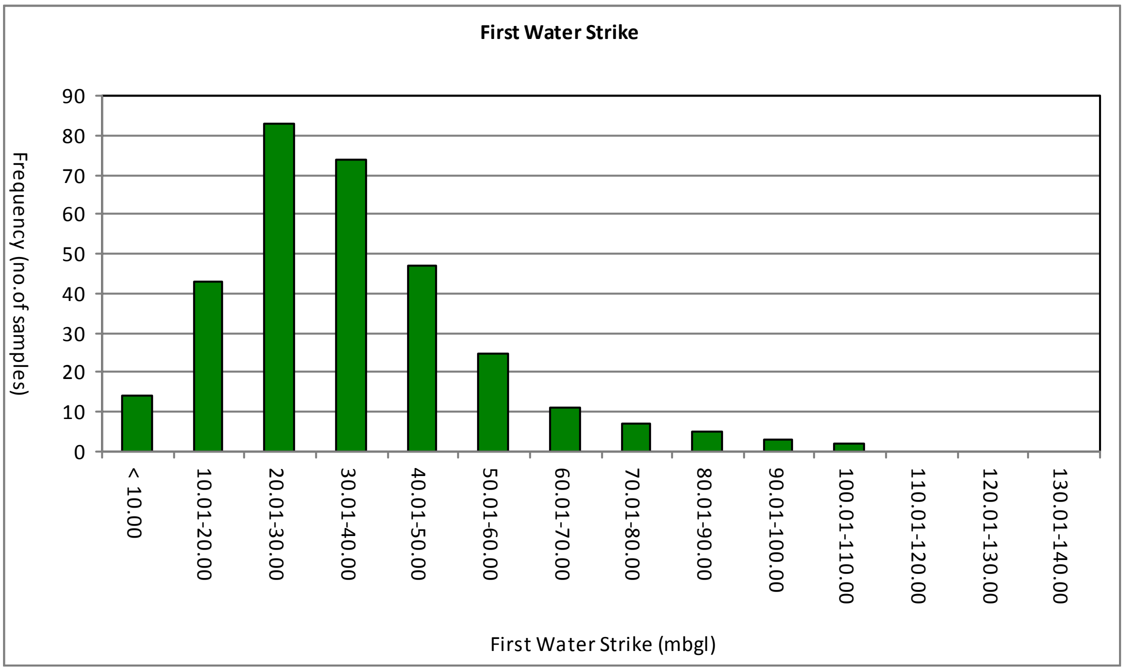


(a) Statistical Distribution



(b) Spatial Distribution

Figure 8 Depth to Bedrock



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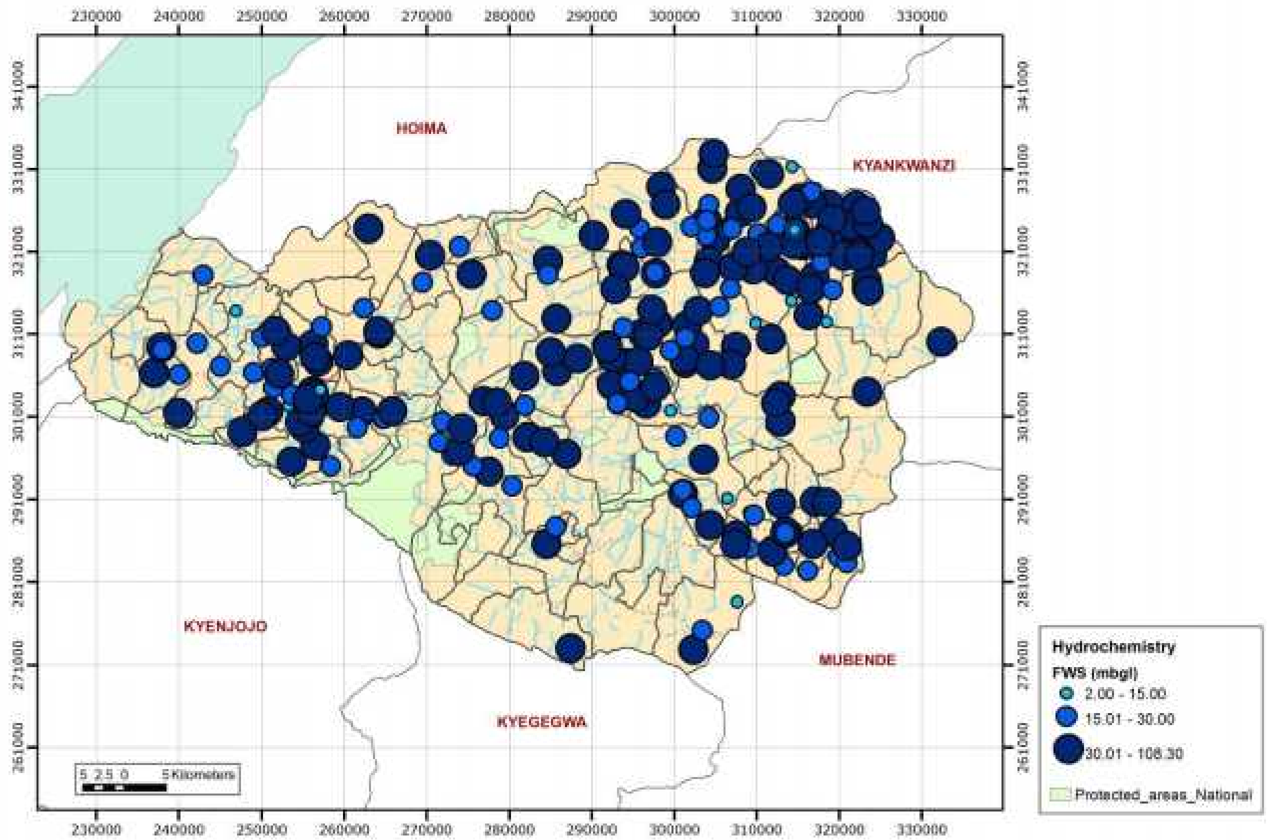
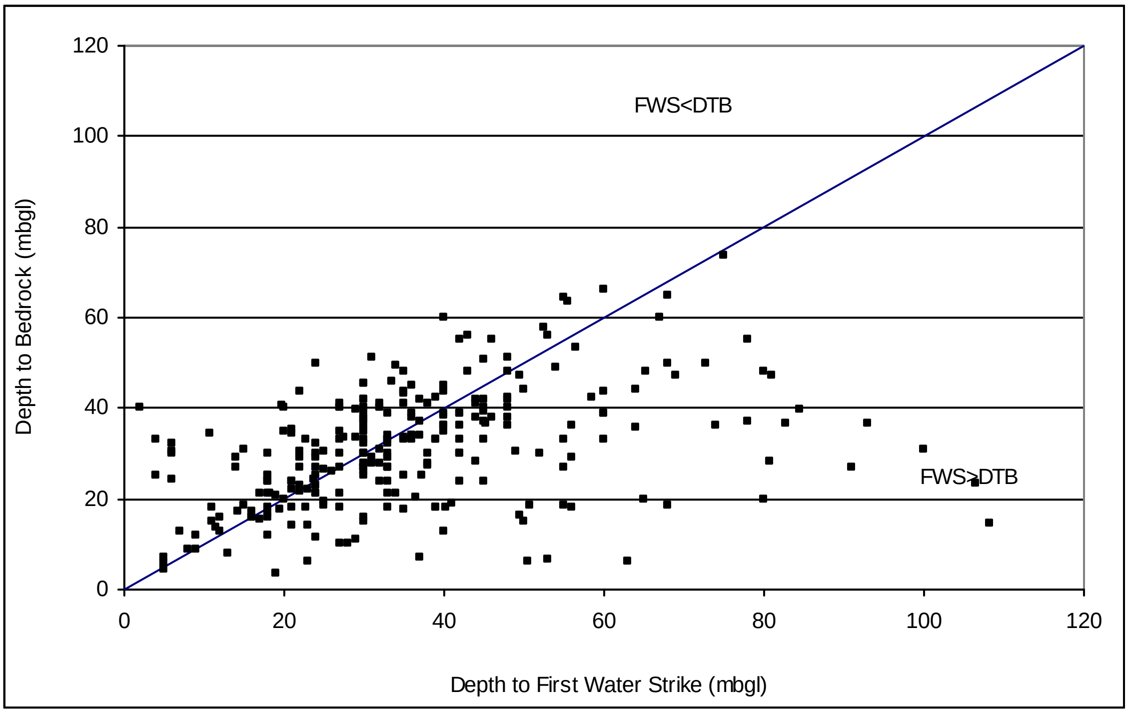
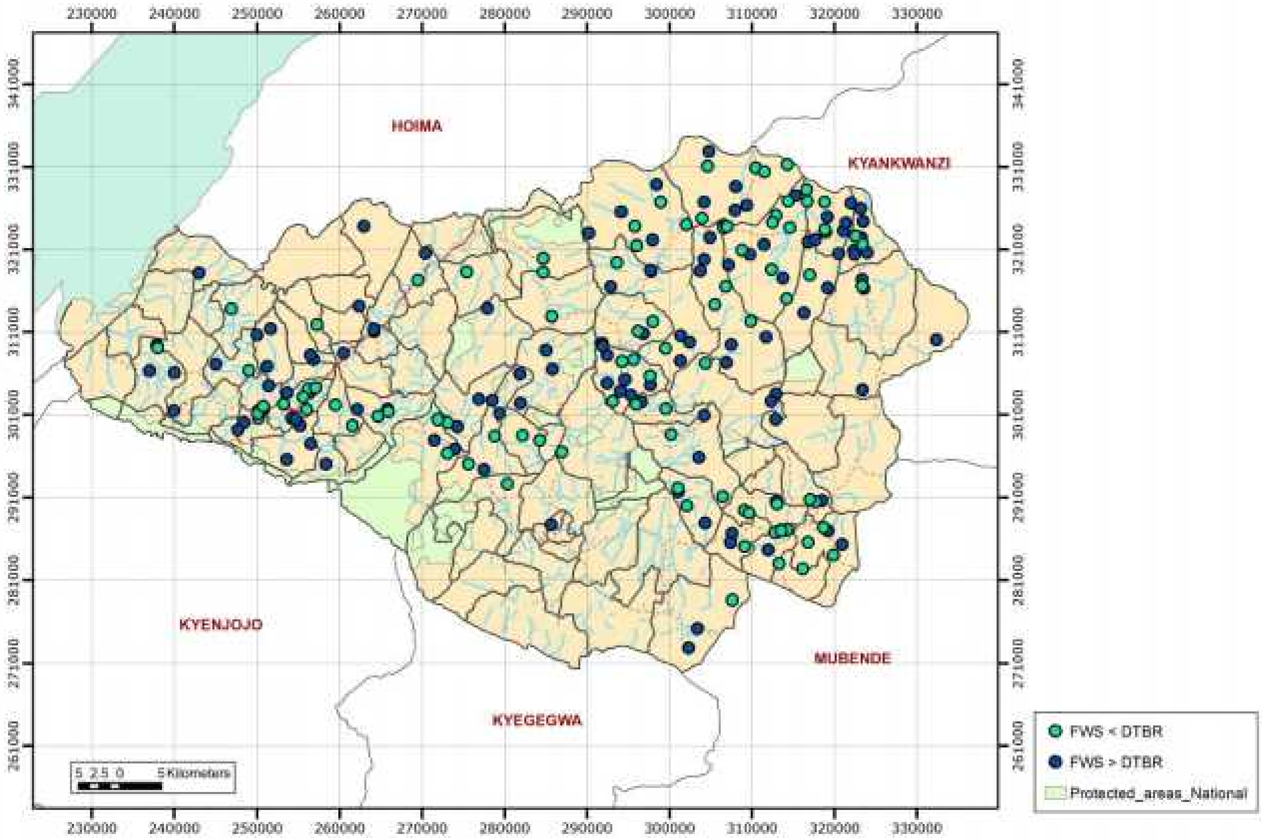


(b) Spatial Distribution

Figure 9 First Water Strike

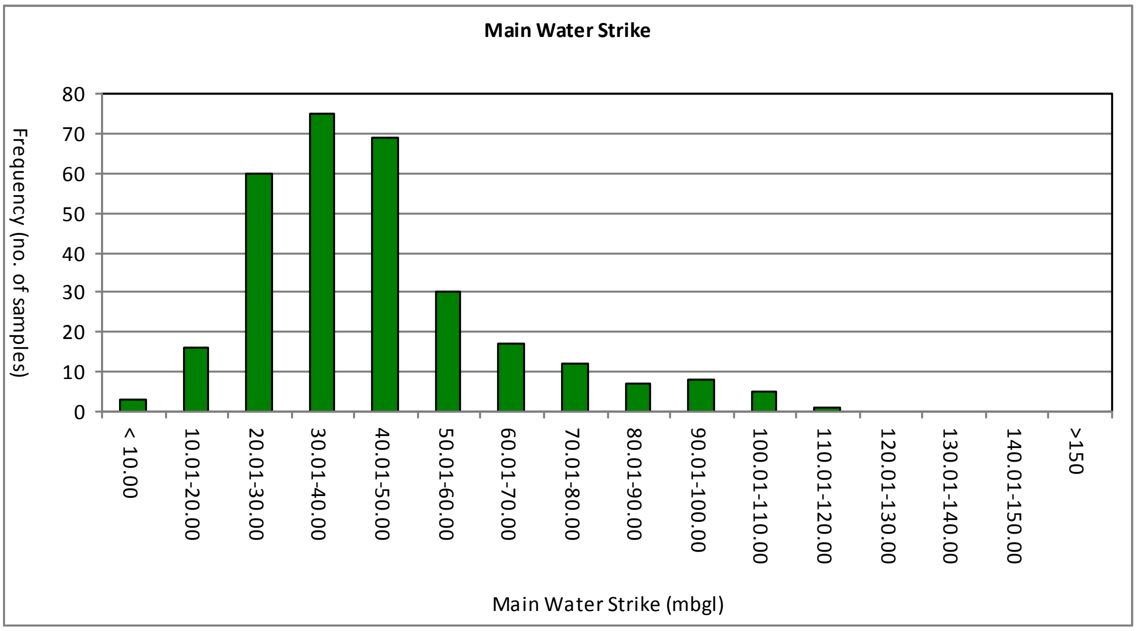


(a)



(b)

Figure 10 Relationship between depth to bedrock and first water strike



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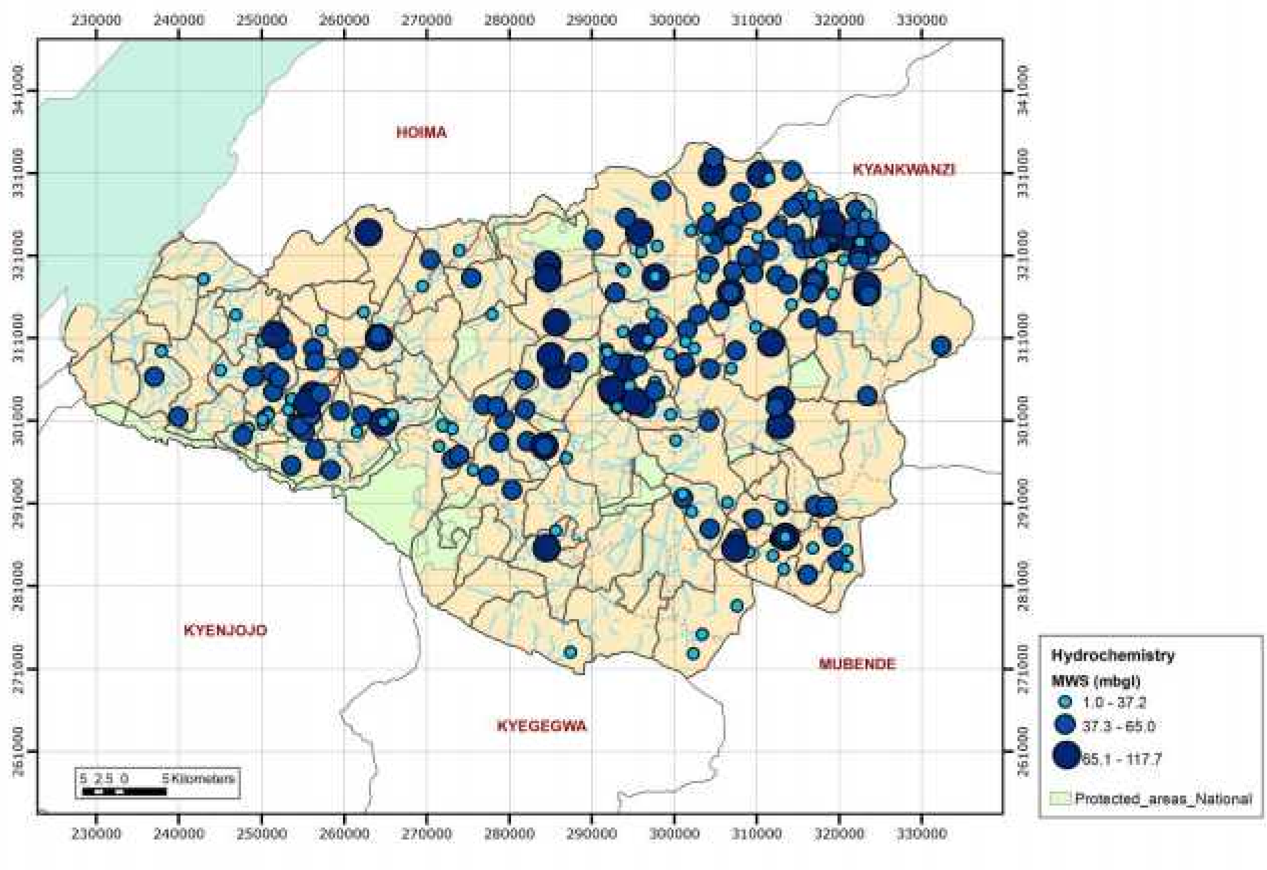
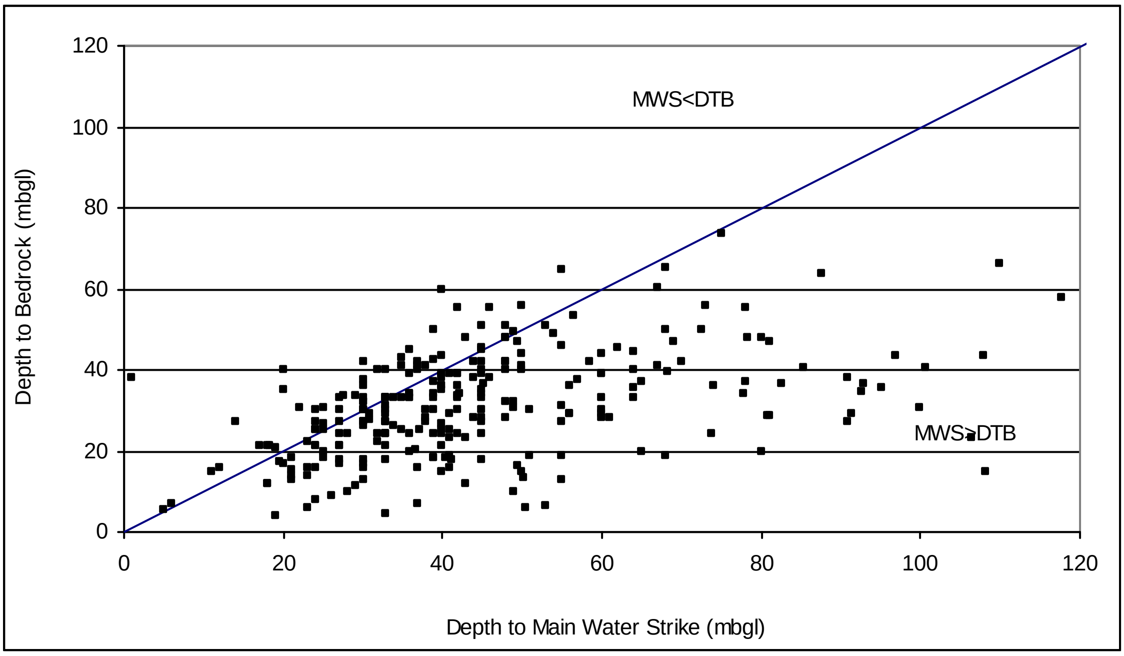
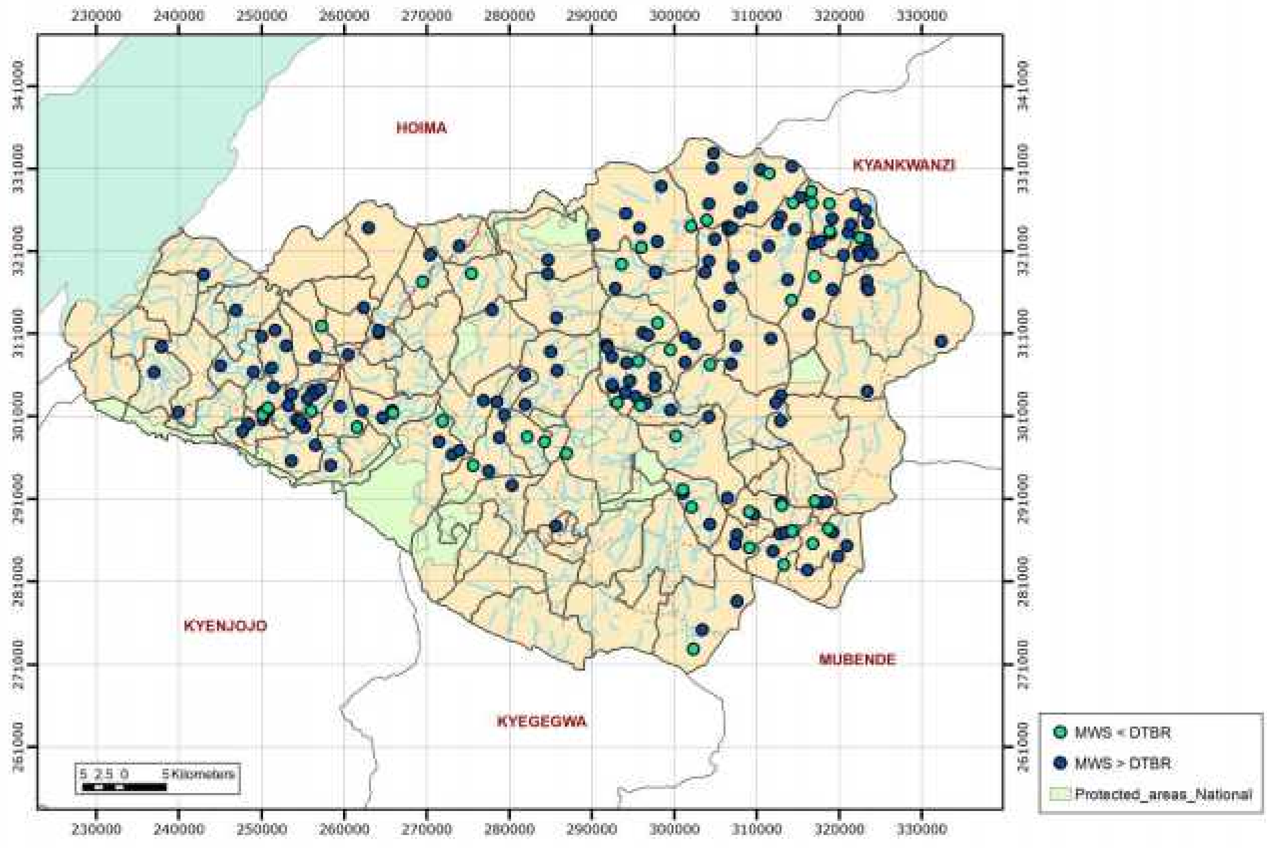


(b) Spatial Distribution

Figure 11 Main water strike

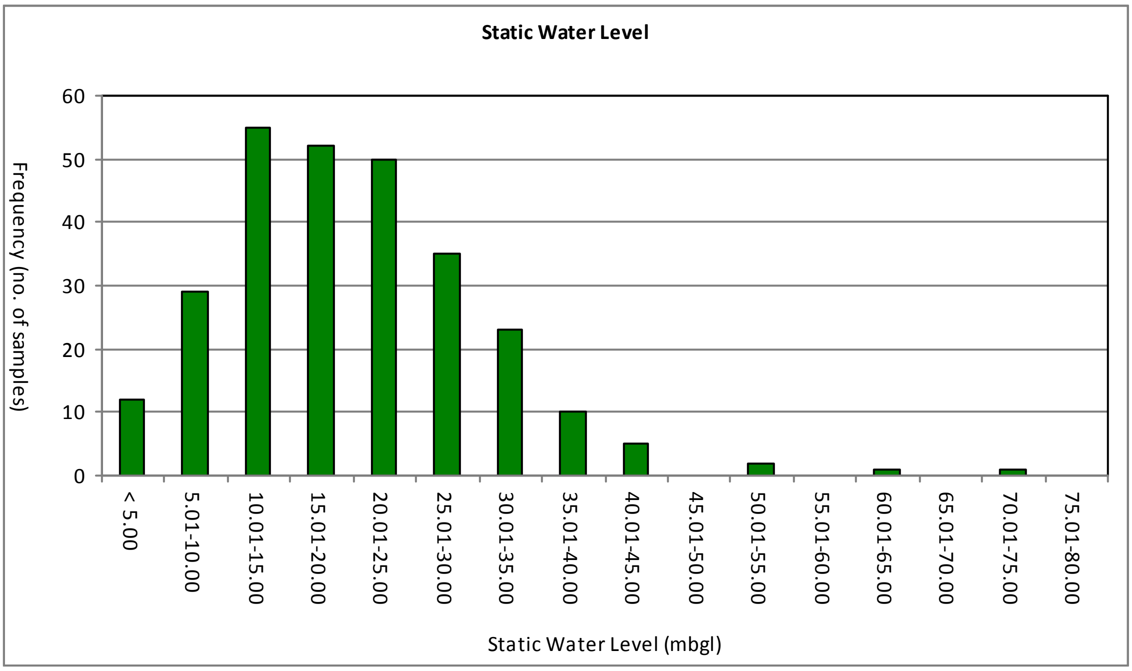


(a)

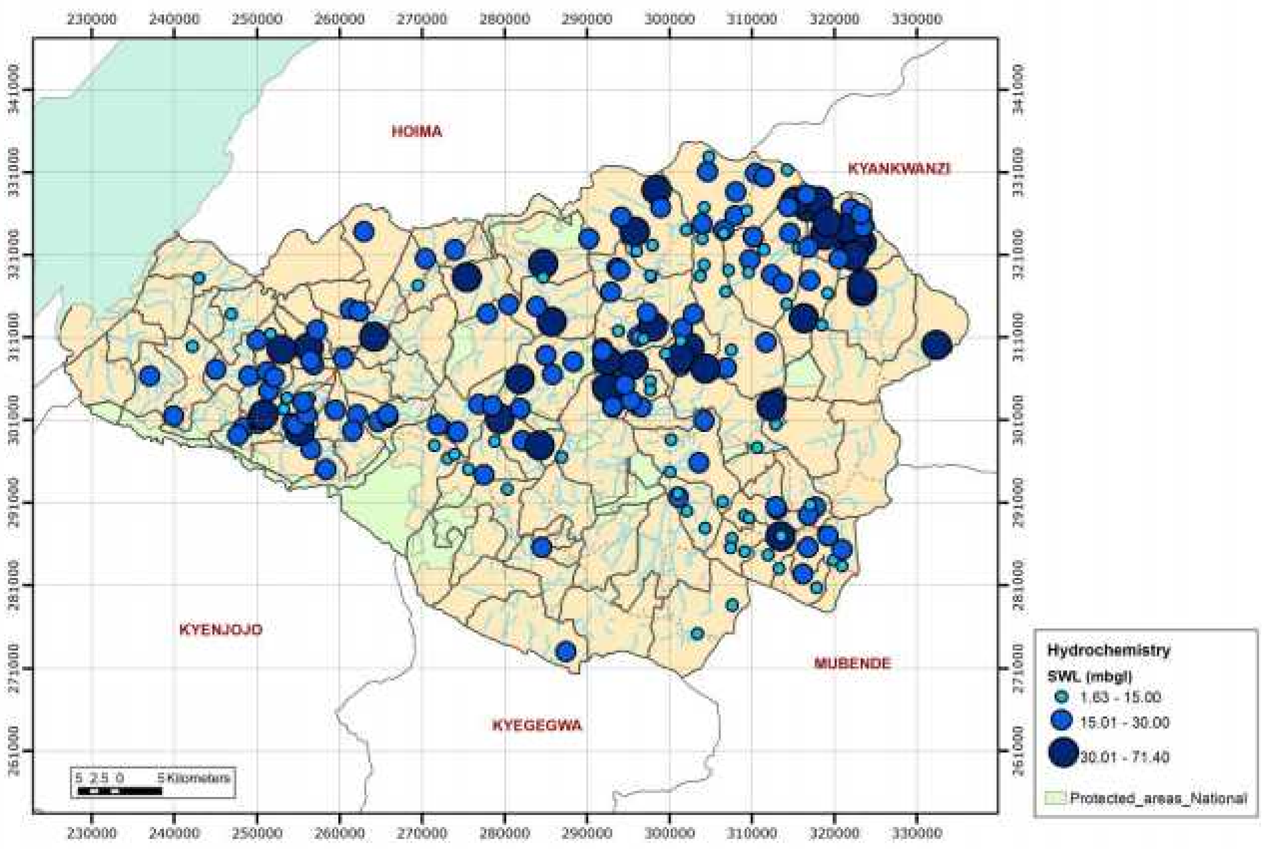


(b)

Figure 12 Relationship between depth to bedrock and main water strike

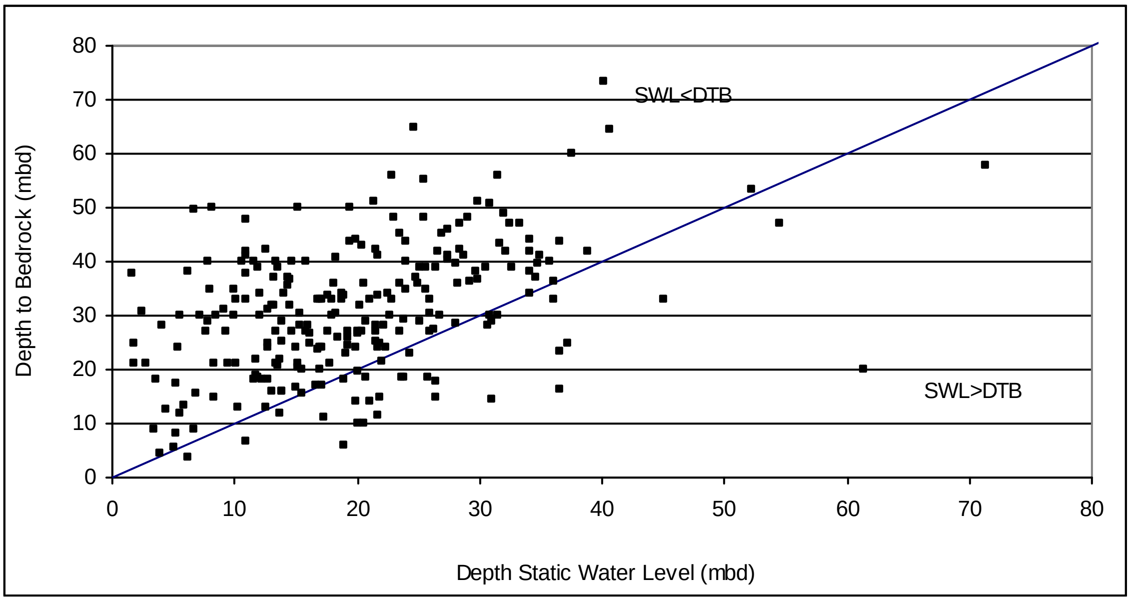


(a) Statistical Distribution



(b) Spatial Distribution

Figure 13 Static Water Level



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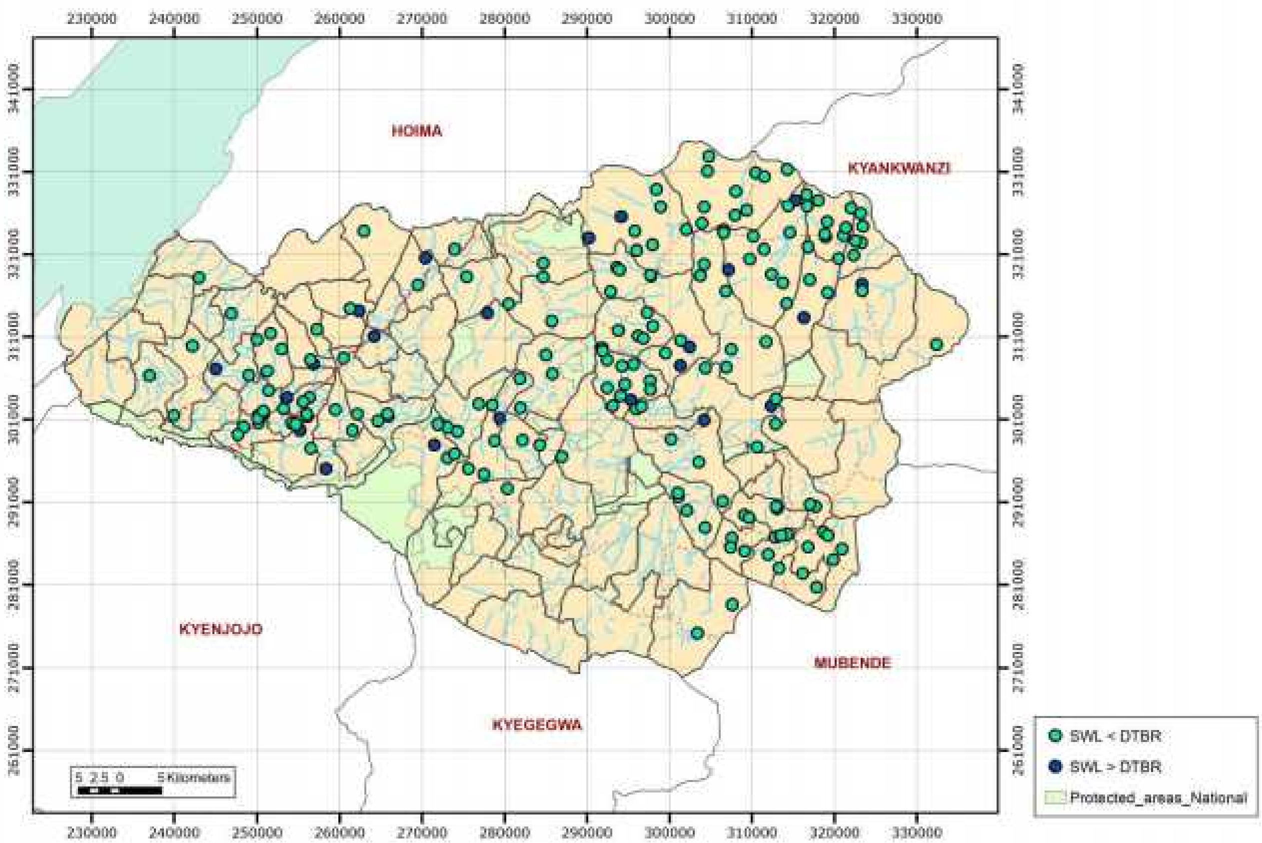
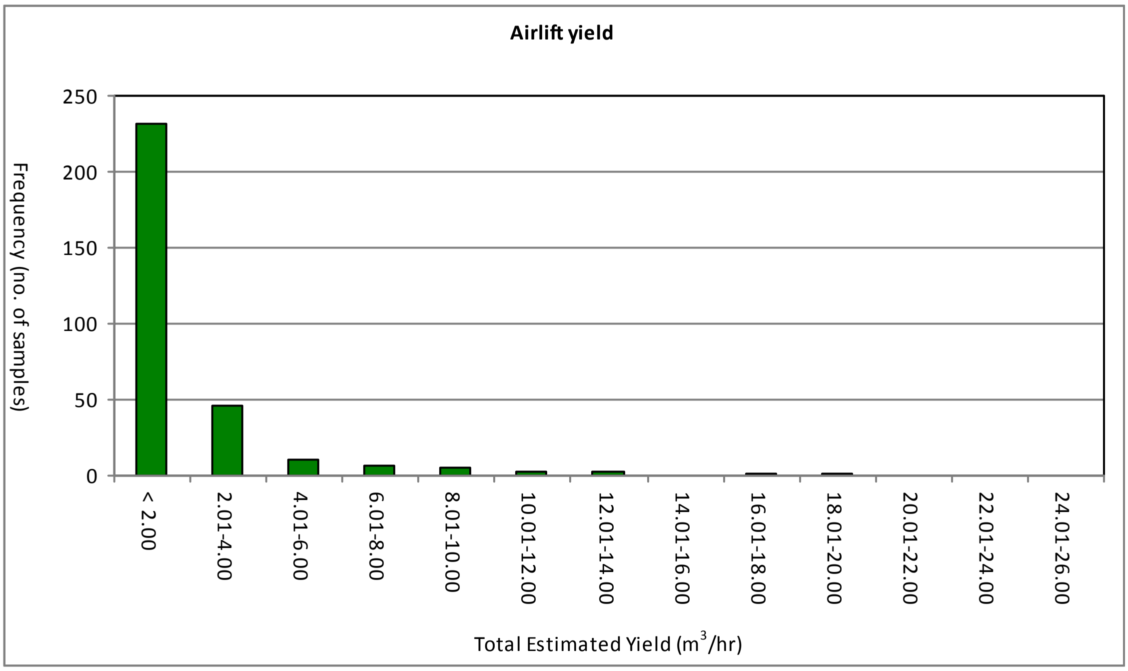


(b)

Figure 14 Relationship between Static Water Level and depth to bedrock



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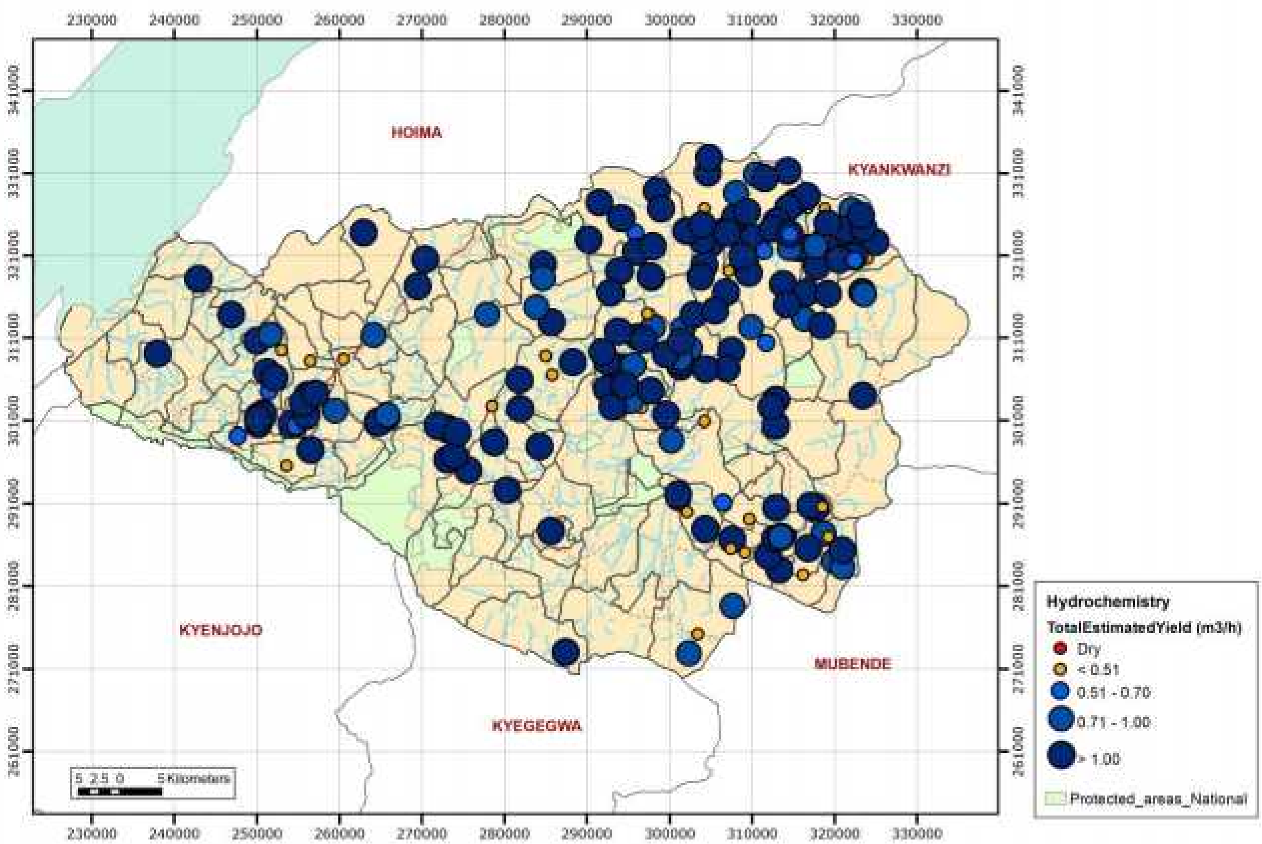
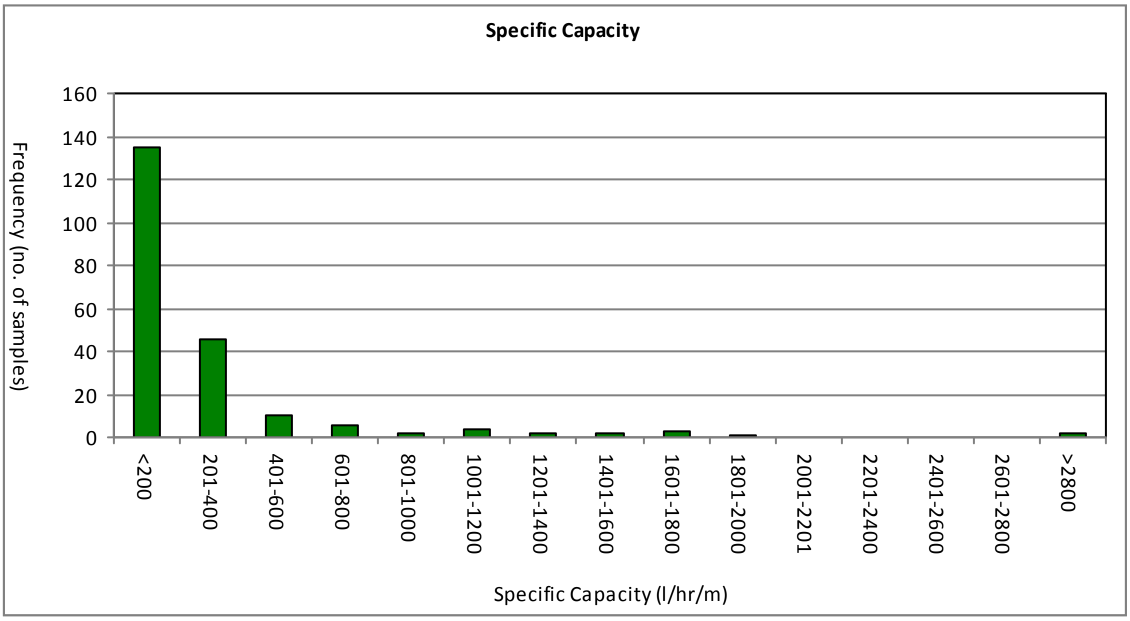


(b) Spatial Distribution

Figure 15 Airlift yield



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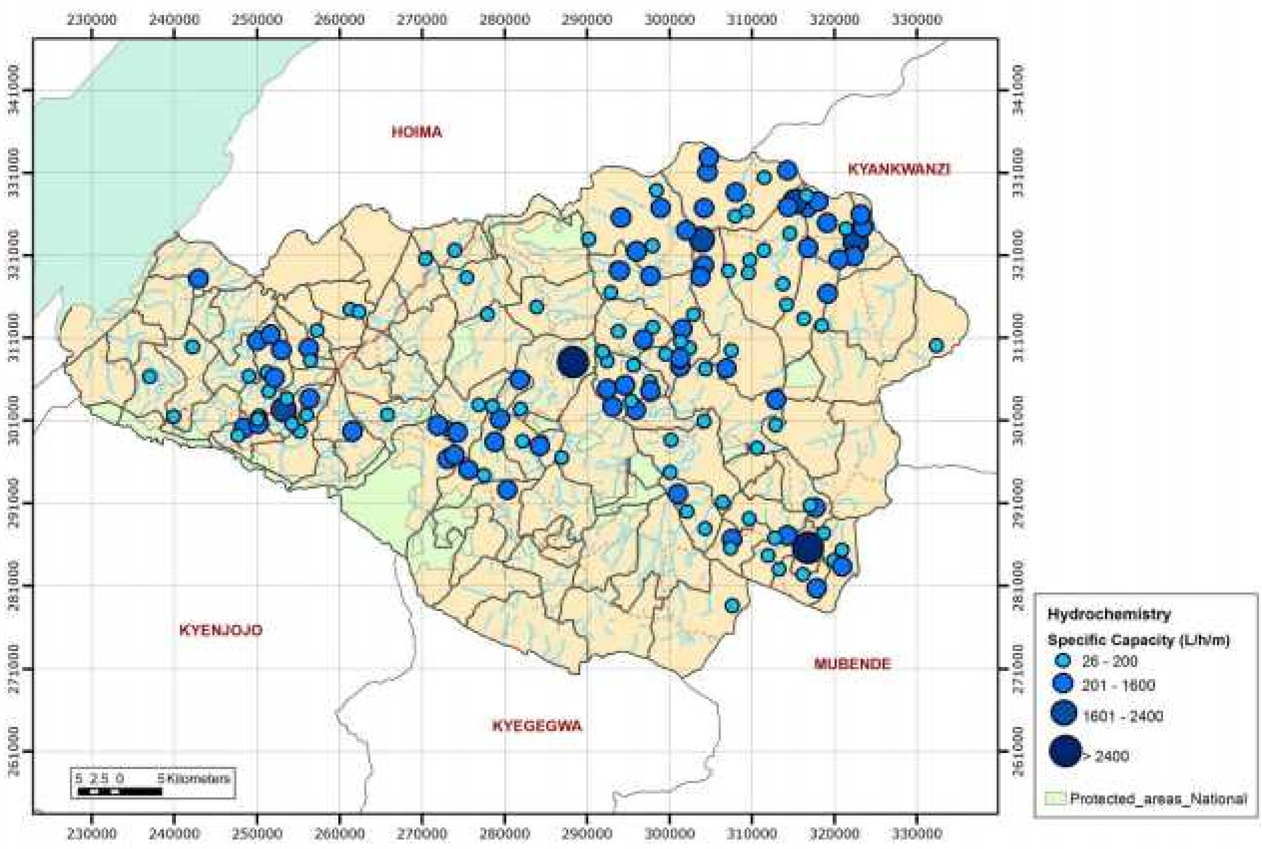
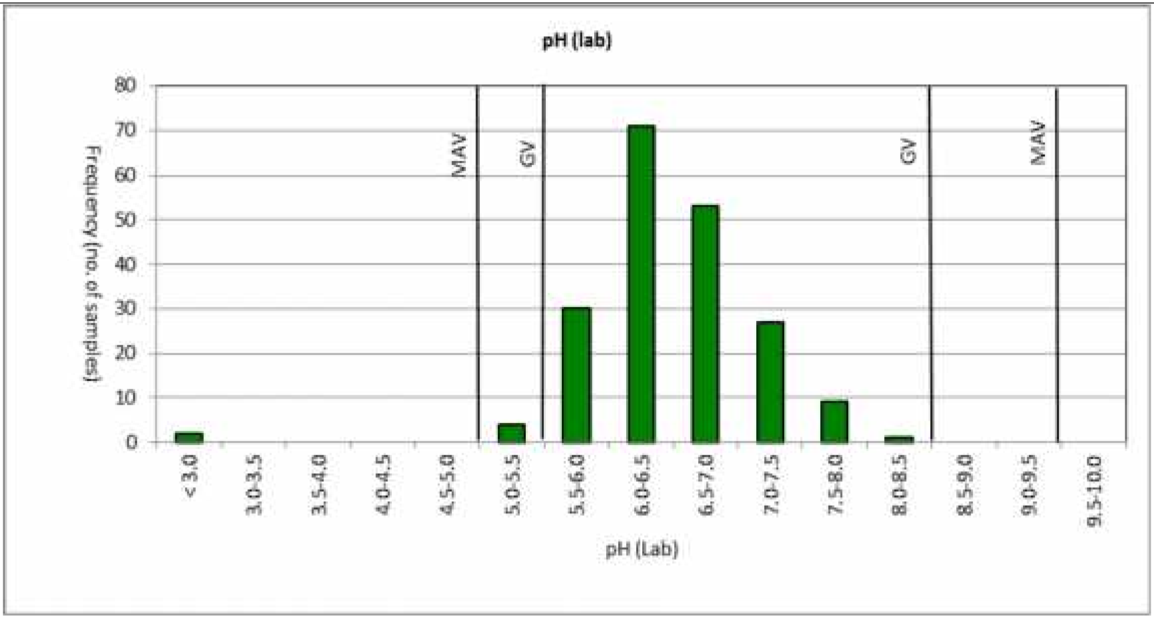


(b) Spatial Distribution

Figure 16 Specific Capacity



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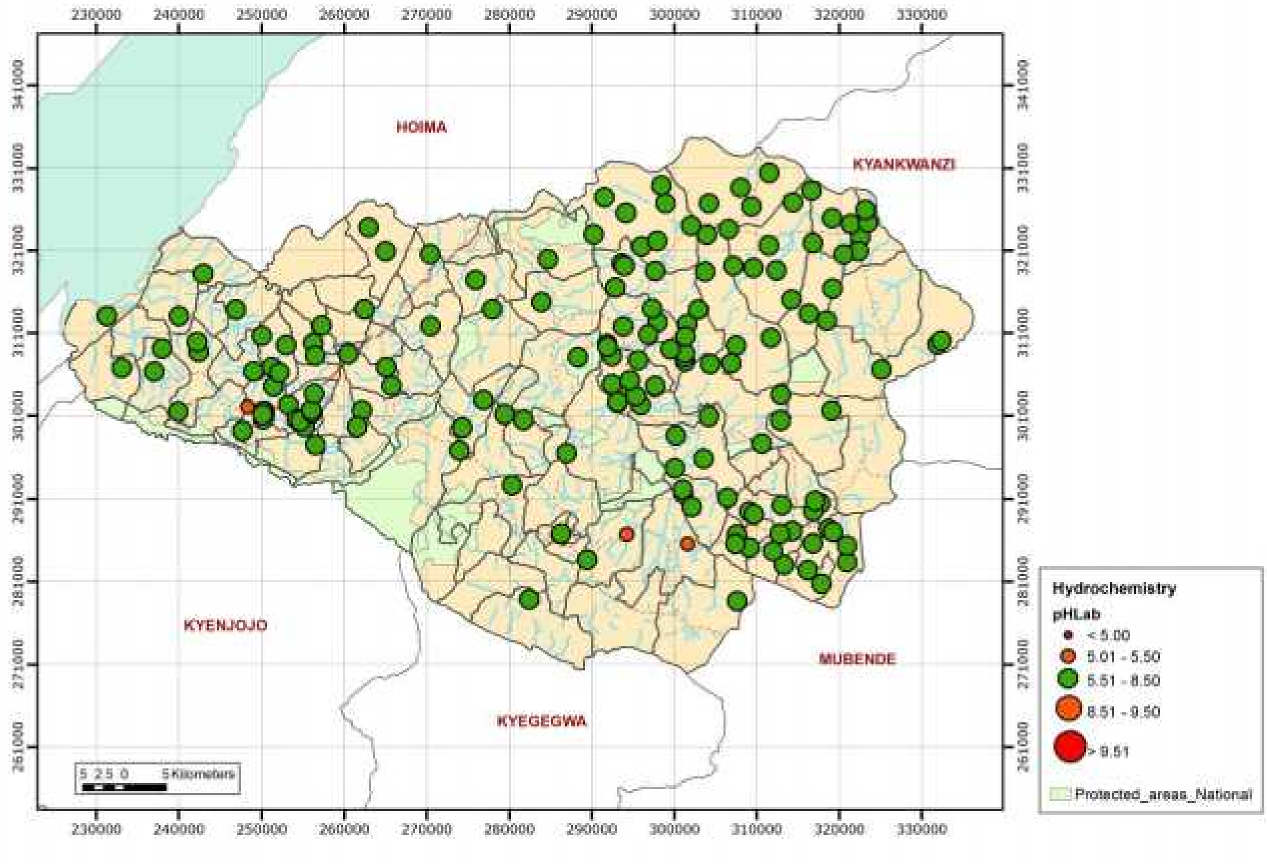
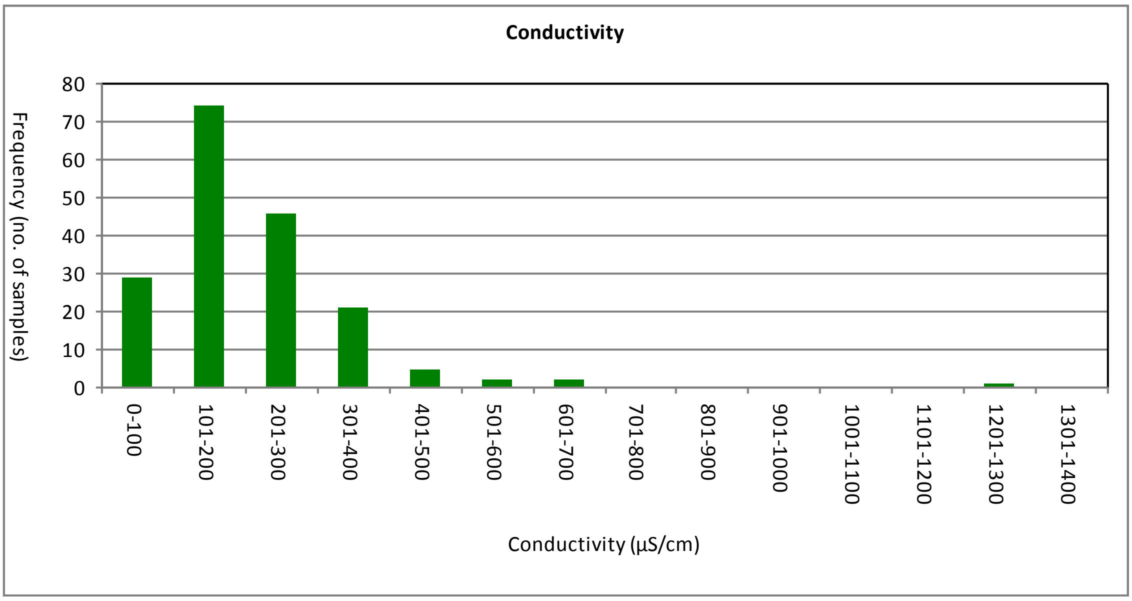


(b) Spatial Distribution

Figure 17 pH



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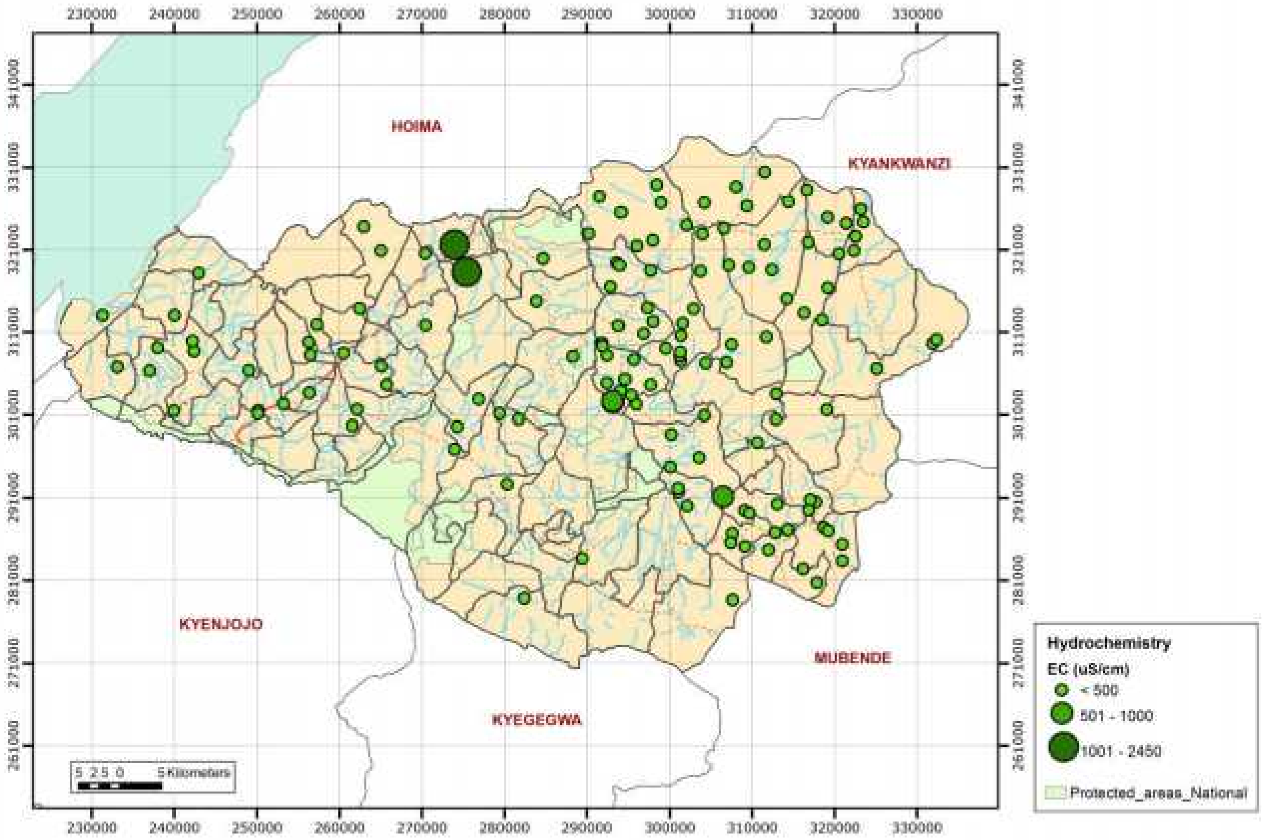
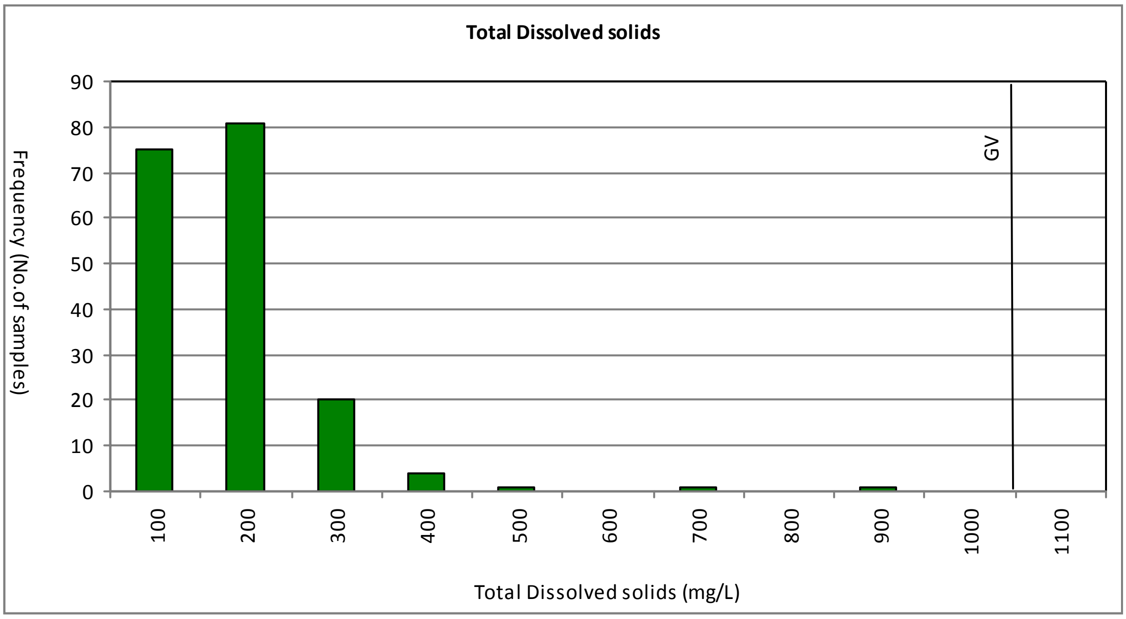


(b) Spatial distribution

Figure 18 Electrical Conductivity



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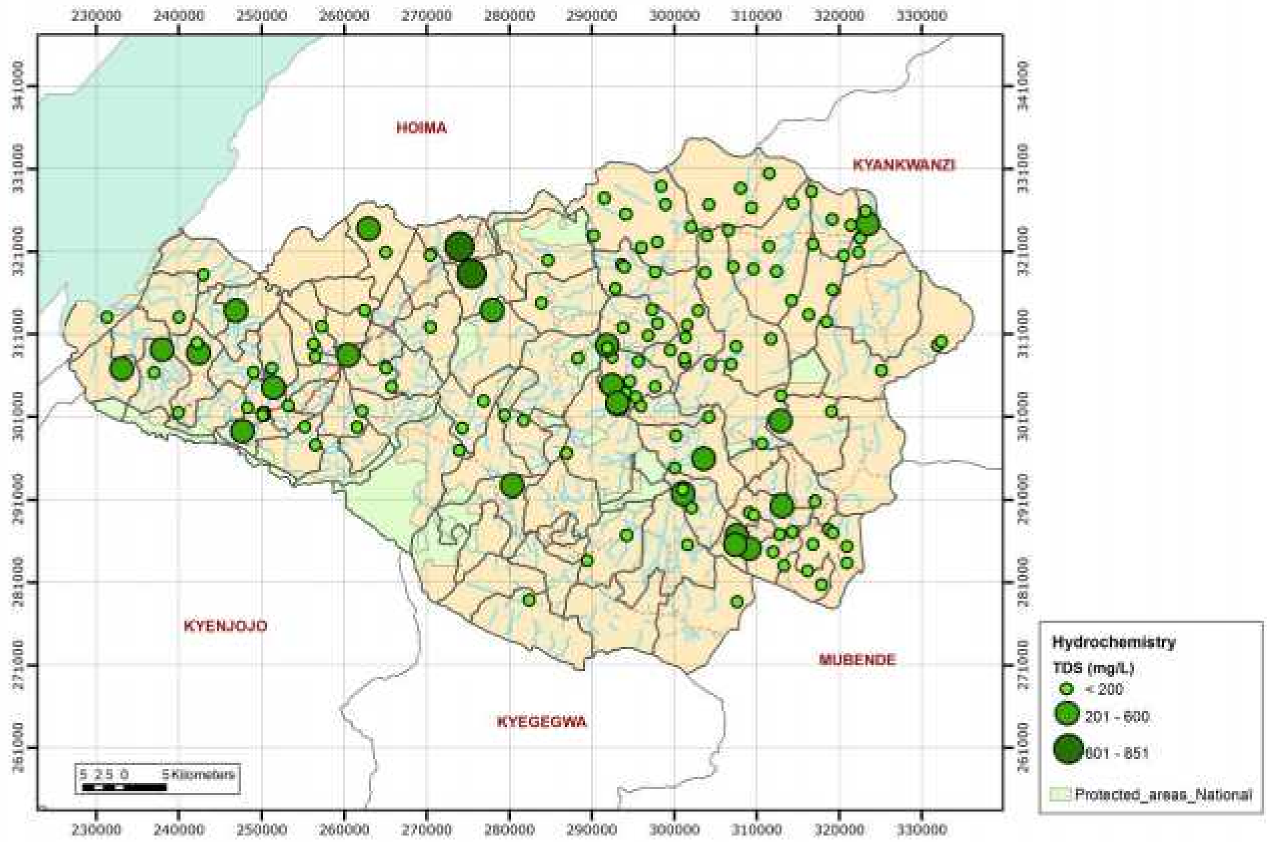
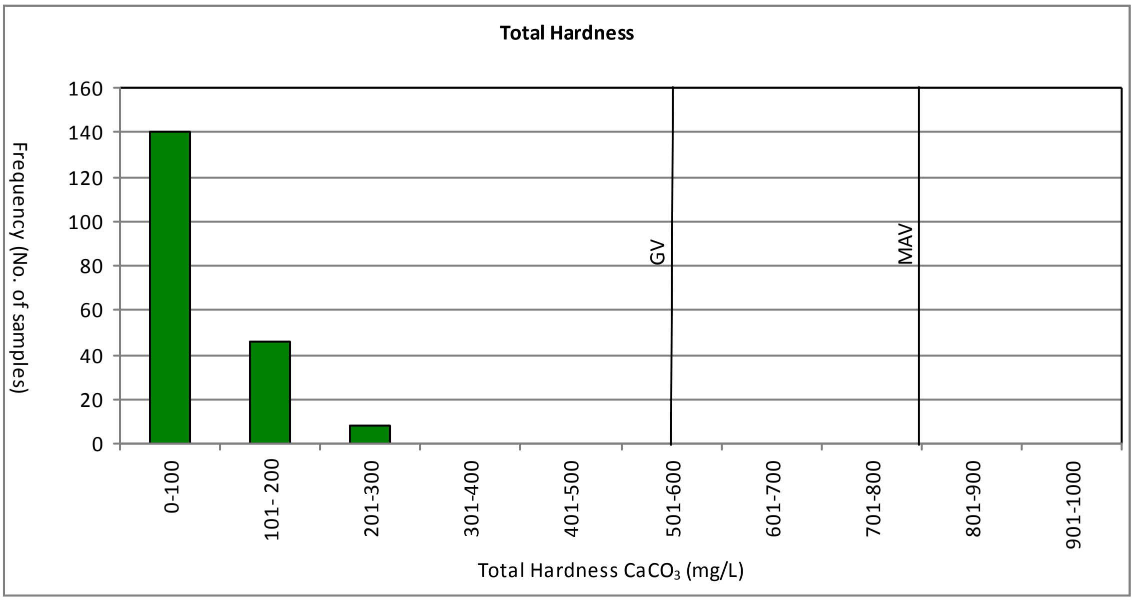


(b) Spatial Distribution

Figure 19 Total Dissolved Solids



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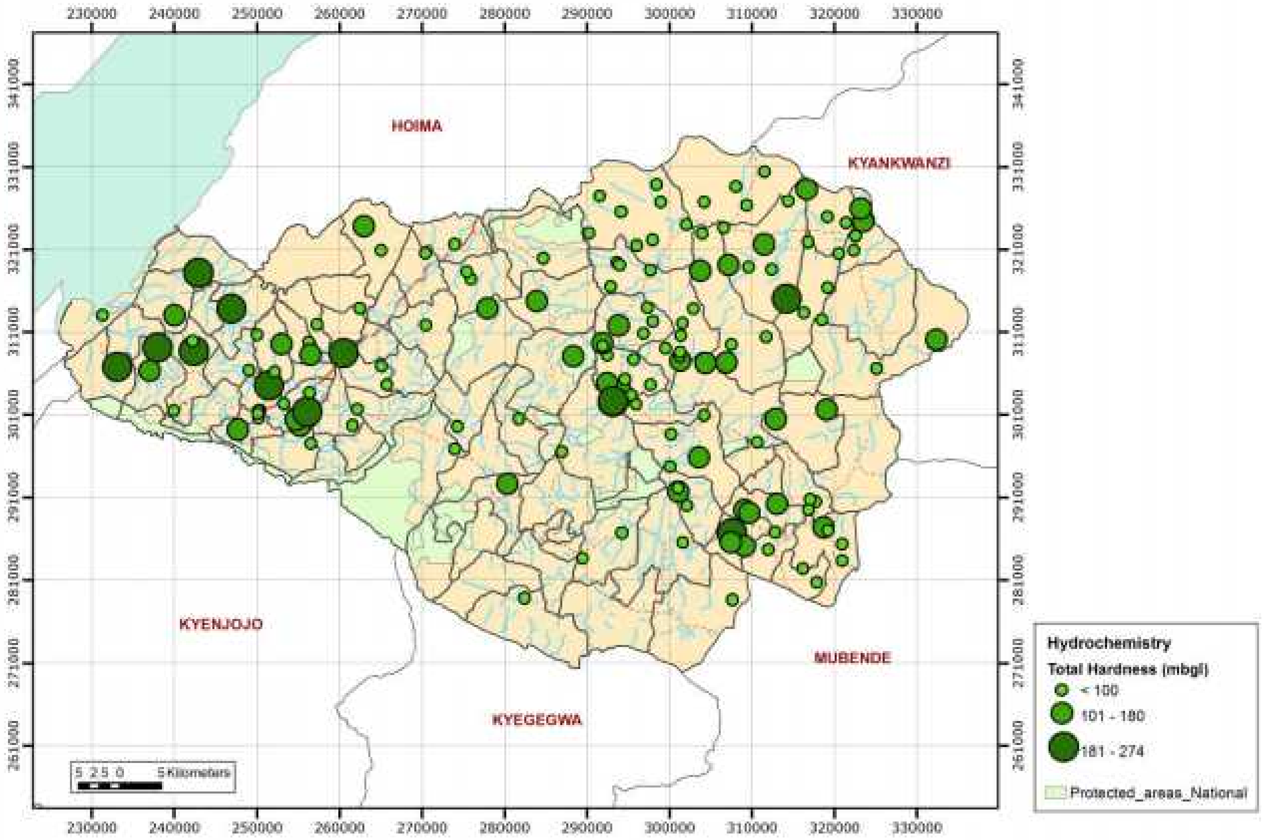
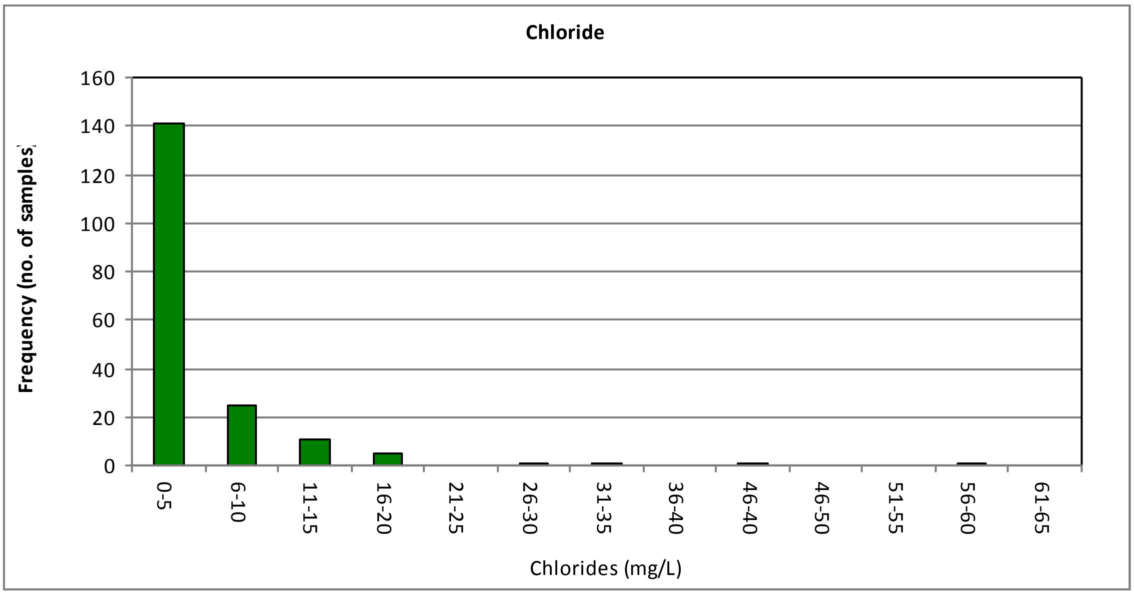


(b) Spatial Distribution

Figure 20 Hardness



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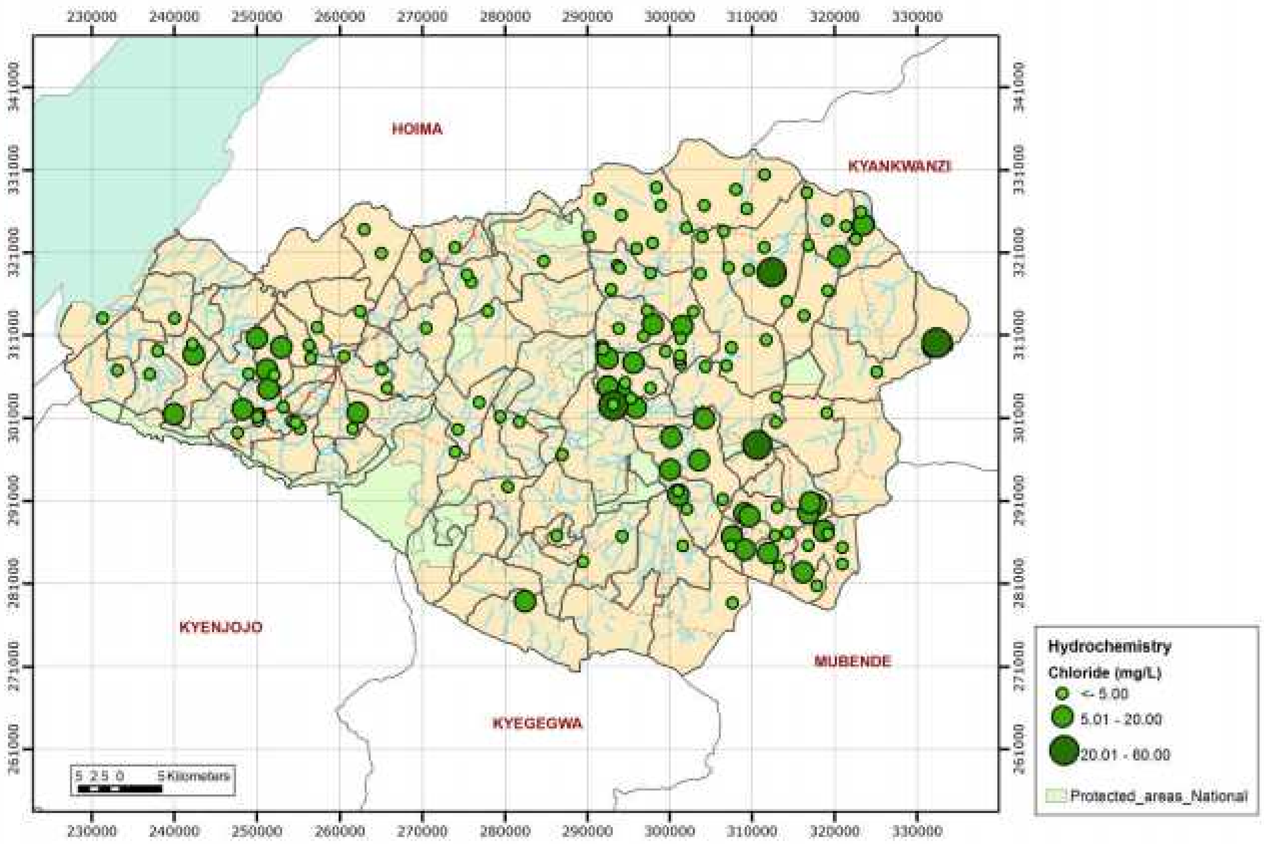
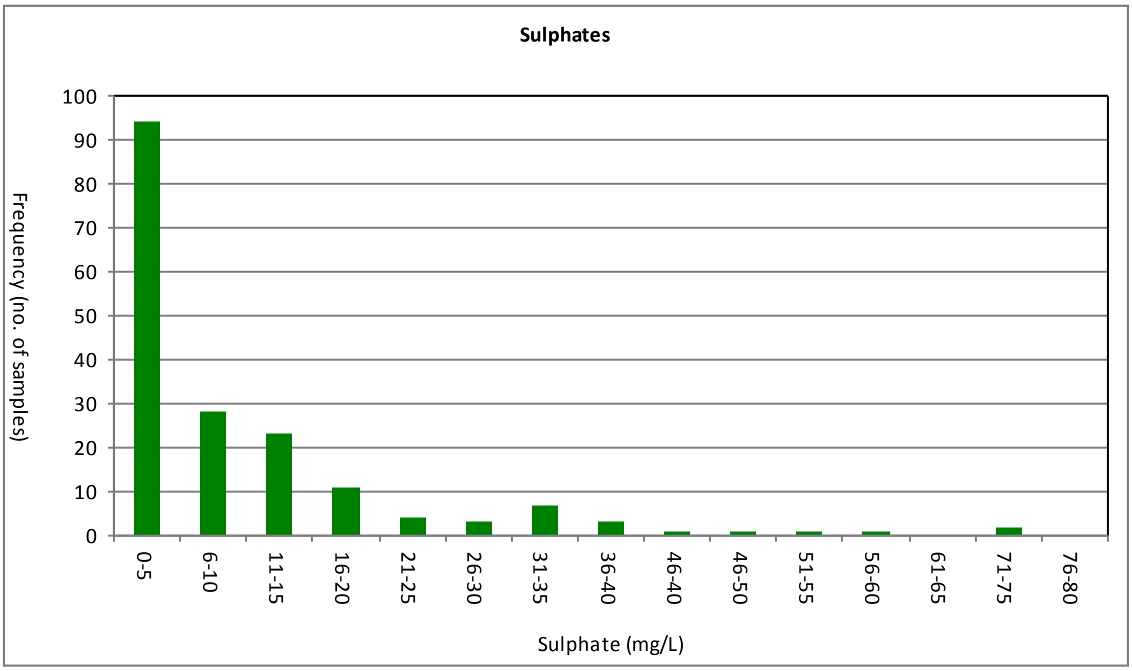


(b) Spatial distribution

Figure 21 Chloride



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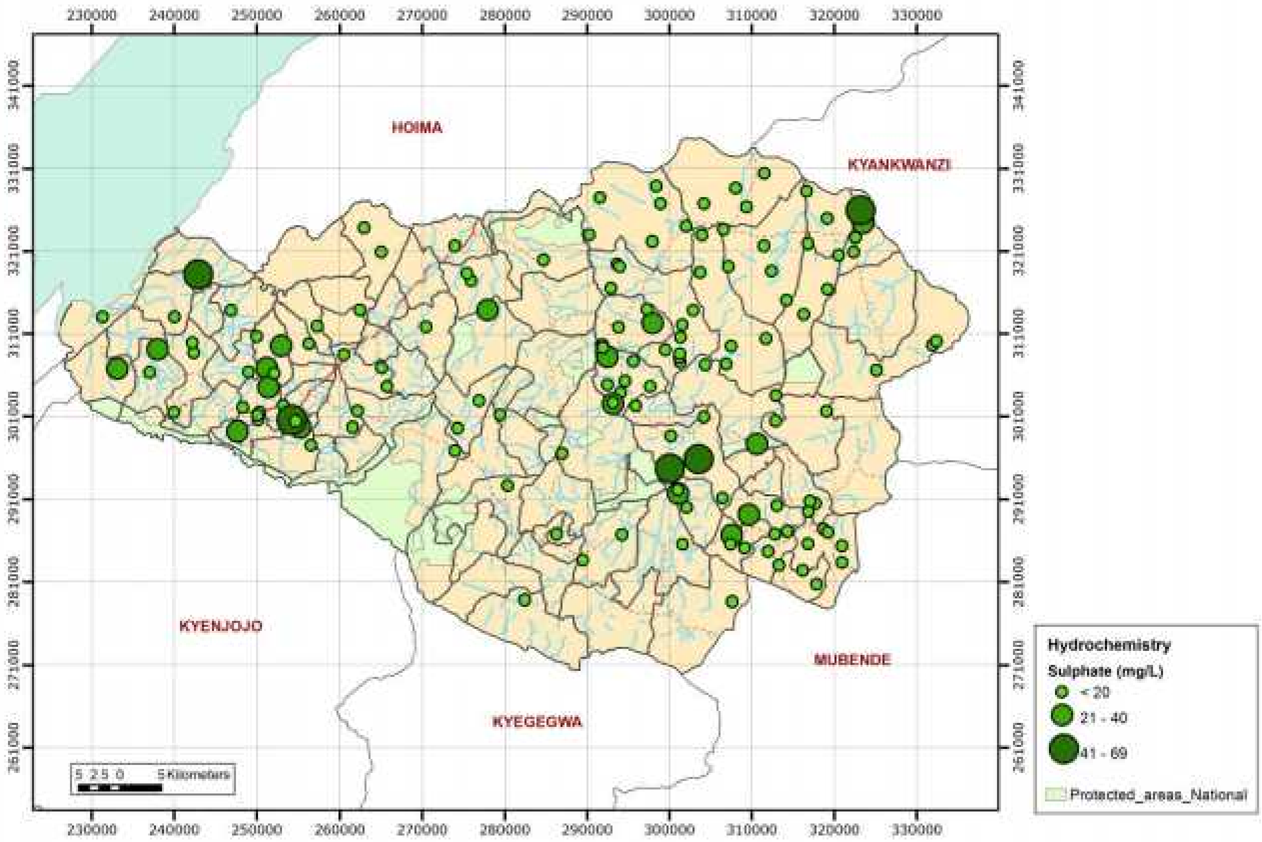
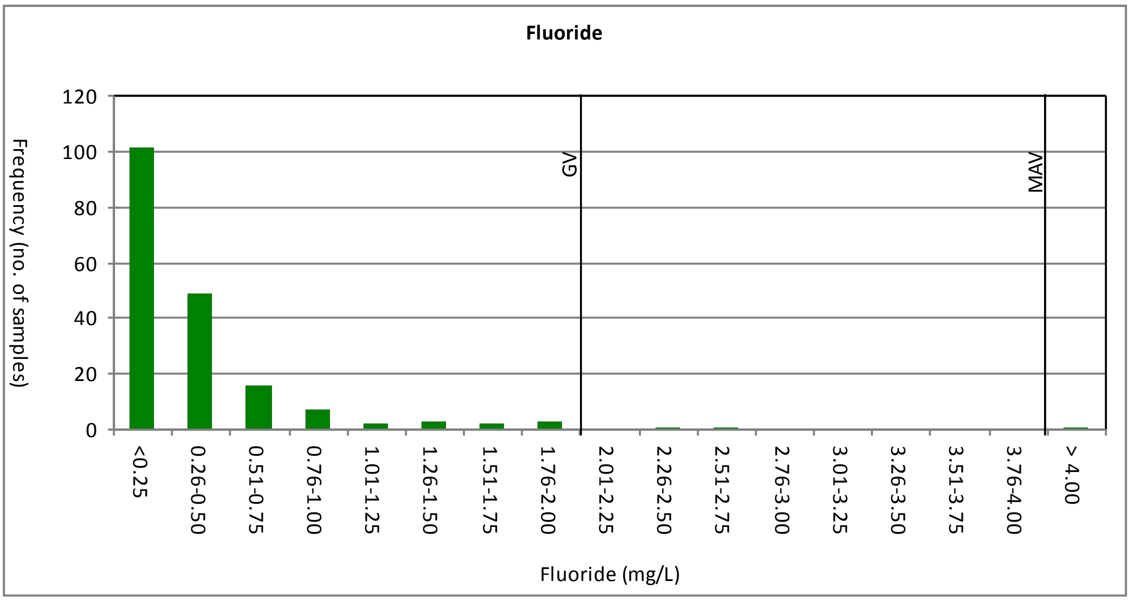


(b) Spatial distribution

Figure 22 Sulphate



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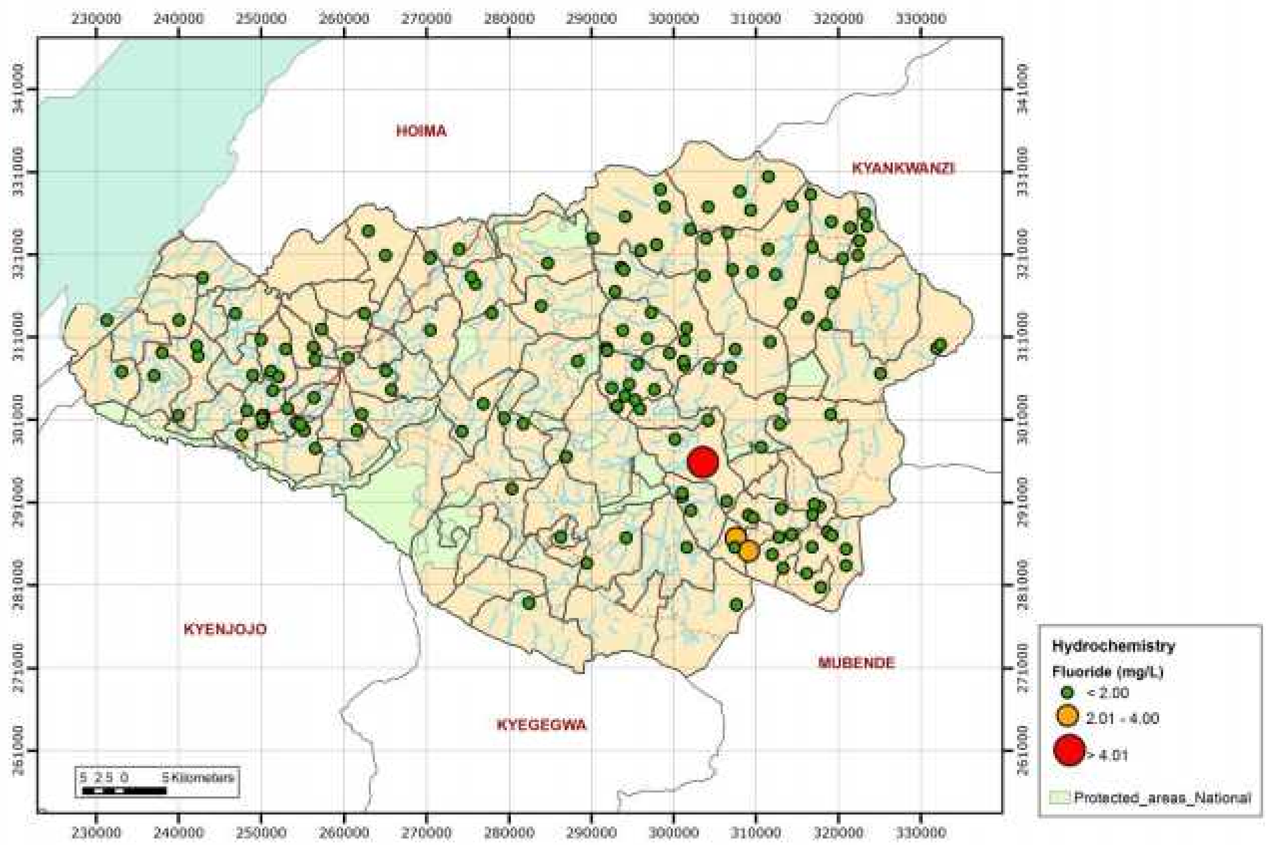
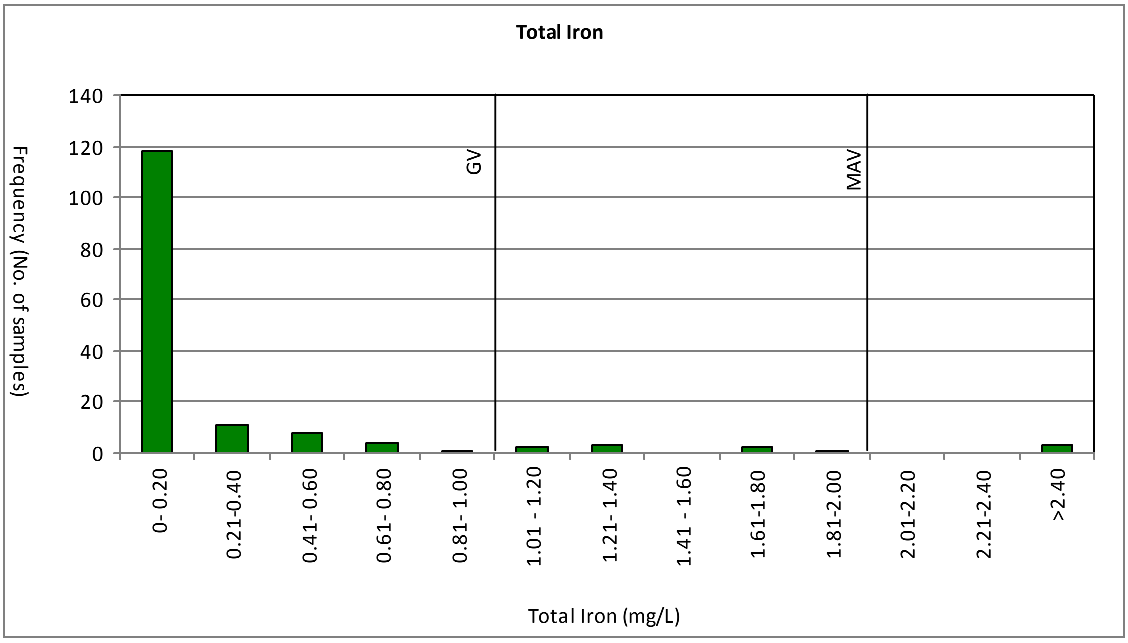
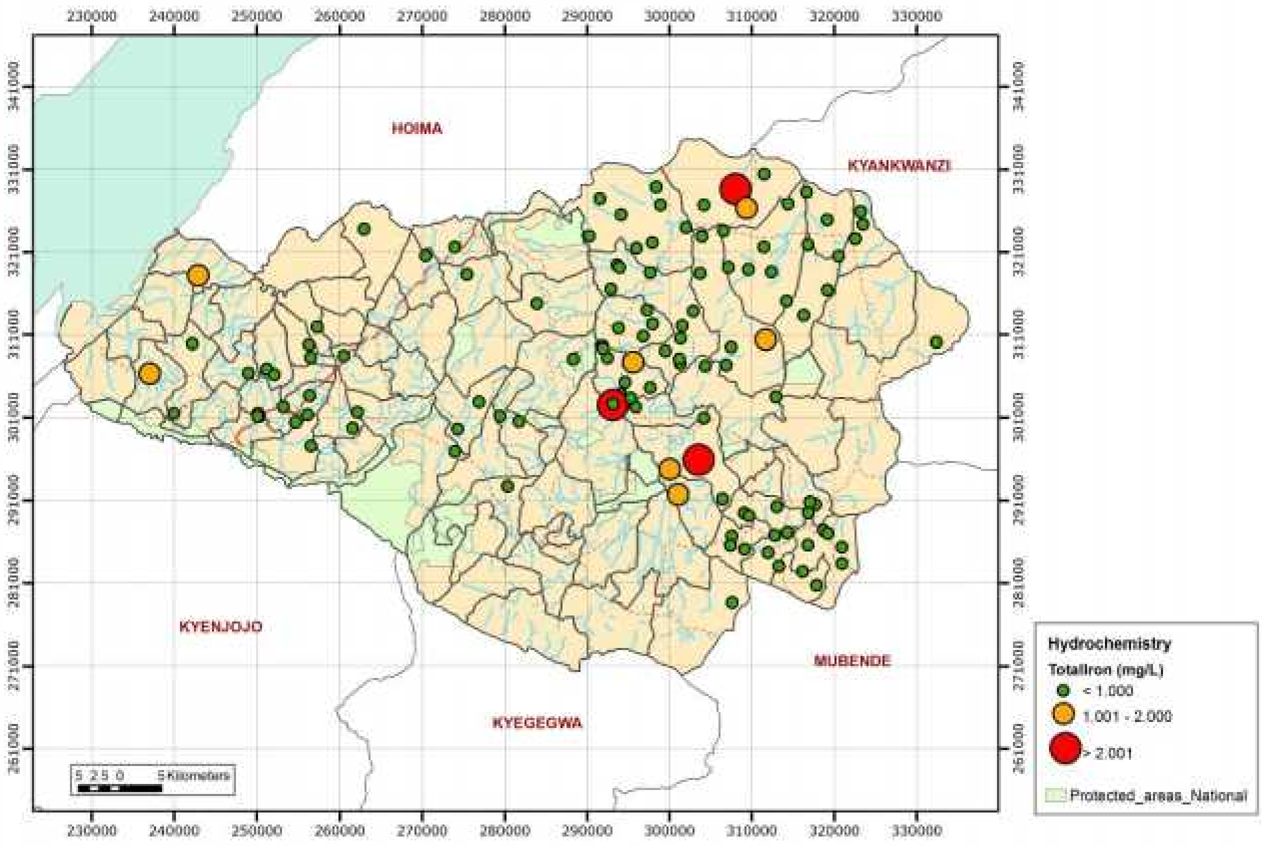


(b) Spatial distribution

Figure 23 Fluoride

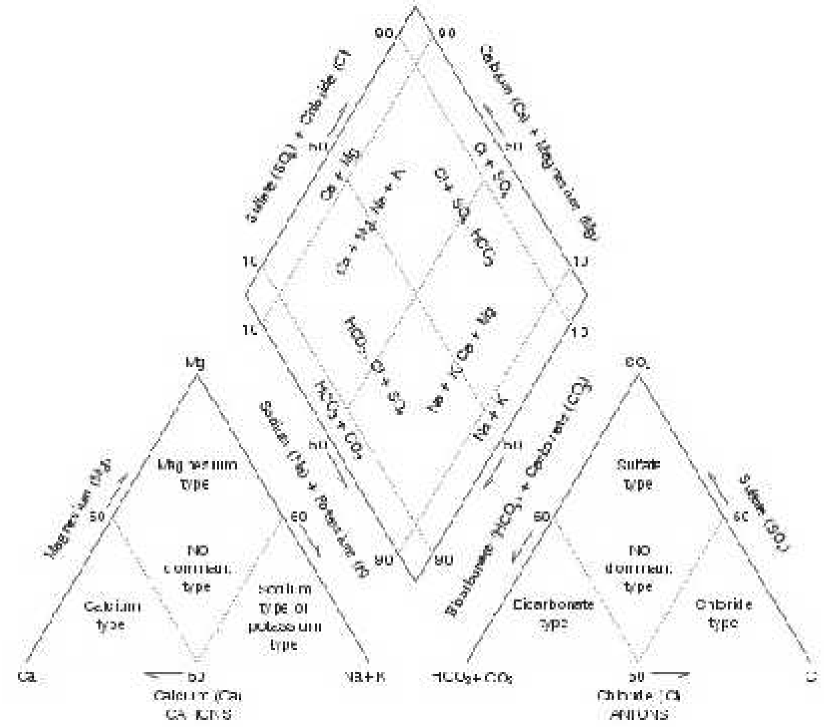


(a) Statistical distribution

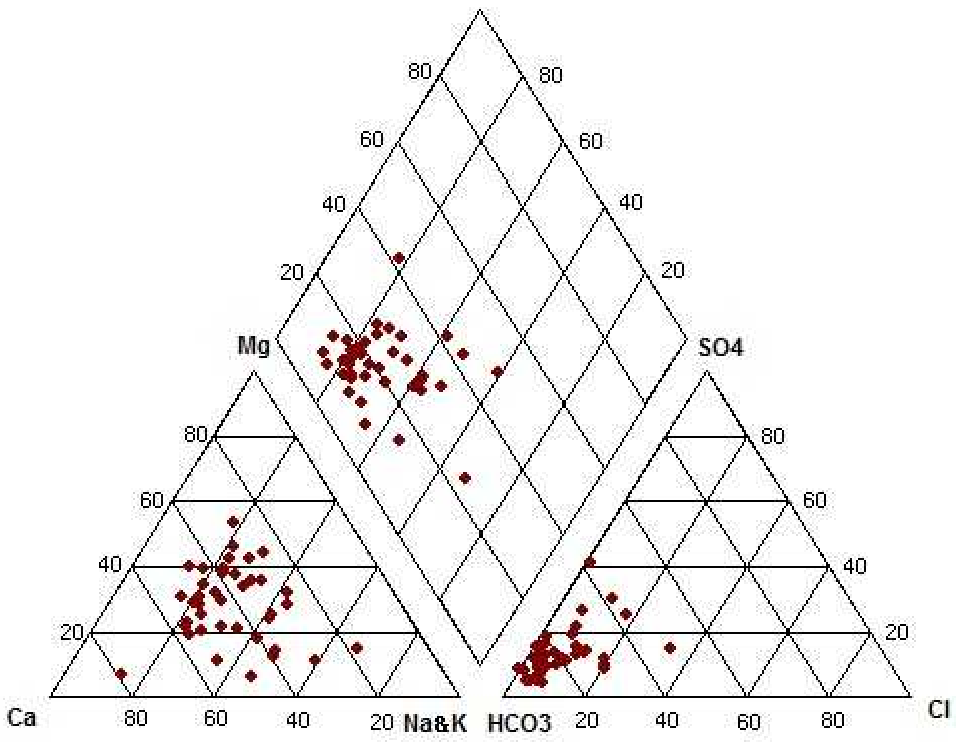


(b) Spatial distribution

Figure 24 Total Iron



(a) Water Types



(b) Data plot for Kibaale

Figure 25 Piper Diagram

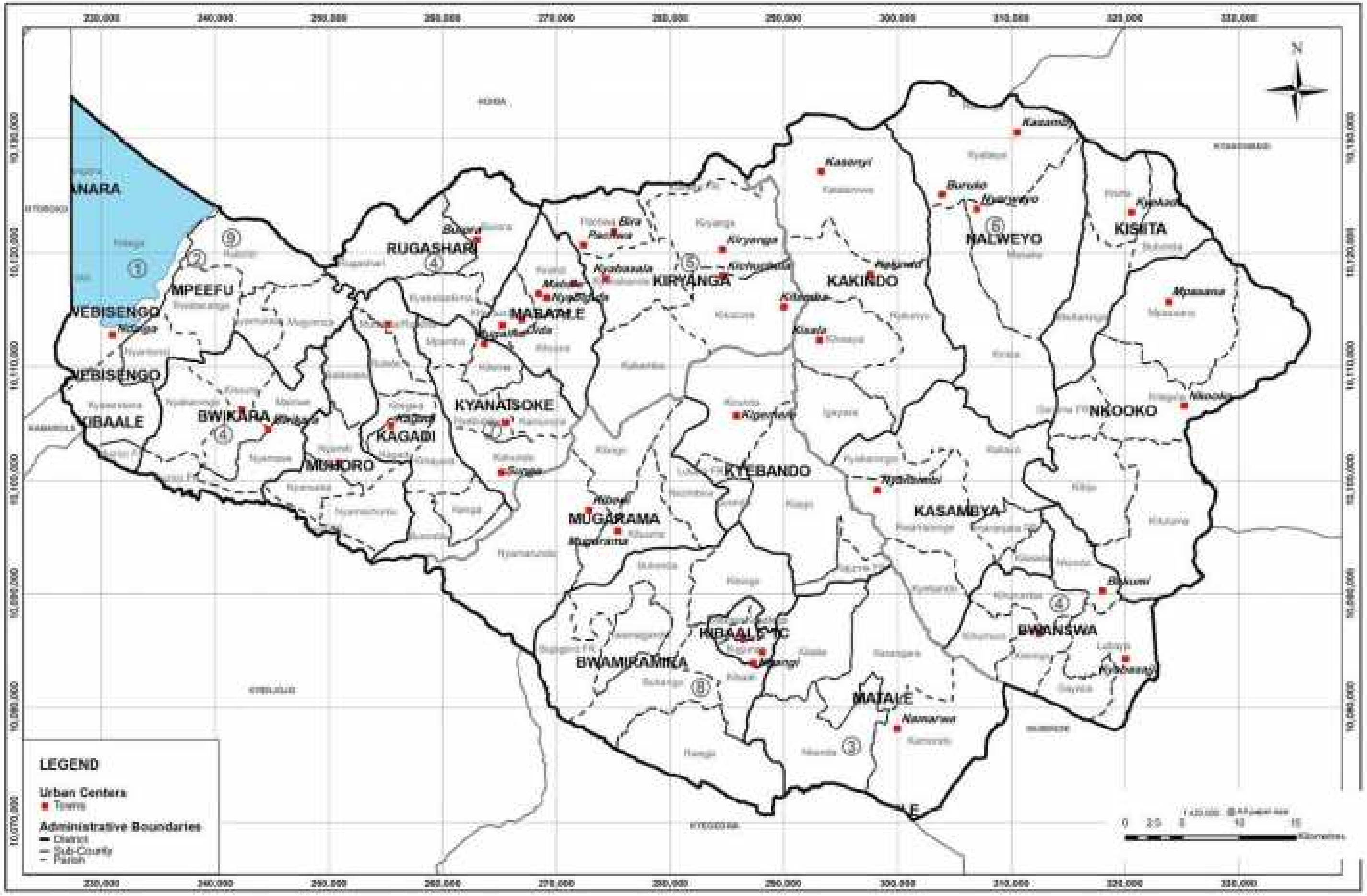


Figure 26 Locations where maps deviate from local knowledge

Annex 1: Groundwater Maps