A Survey of Hydrological Systems in the Great Virunga Landscape:

Water resources assessment and use in and around Mgahinga Gorilla National Park and Echuya Central Forest Reserve, S.W Uganda

A technical report to:

GREATER VIRUNGA TRANSBOUNDARY COLLABORATION

By:

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LISTS OF ABBREVIATIONS

DRC	: Democratic Republic of Congo
ECFR	: Echuya Central Forest Reserve
GIS	: Geographic Information System
GPS	: Global Positioning System
GVL	: Greater Virunga Landscape
GVTC	: Greater Virunga Transboundary Collaboration
ISO	: International Organisation of Standardisation
ITFC	: Institute for Tropical Forest Conservation
MDG	: Millennium Development Goals
MGNP	:Mgahinga Gorilla National Park
MoU	: Memorandum of Understanding
NTU	: Nephelometric Turbidity Units
pH	: Potential of Hydrogen
SRS	: Simple Random Sampling
S.W	: South Western (Uganda)
TDS	: Total Dissolved Solids
TPC	: Total Plate Count
UNDP	: United Nations Development Programme
UNICEF	: United Nations Children's Fund
USGS	: United States Geological Survey
WHO	: World Health organisation

Table of Contents

List of Figures

List of Tables

List of Plates

Acknowledgements

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Executive Summary

The Greater Virunga Landscape (GVL) is an interconnected chain of eleven protected areas that straddle the borders of Uganda, Rwanda and Democratic Republic of Congo. The landscape is famous for its mountain gorillas (*Gorilla beringei beringei*) and other endangered and endemic flora and fauna. Human threats in some of the Protected Areas (PAs) in the GVL include uncontrolled exploitation of forest resources as well as fires and the indirect pressures of demand for land. This is exacerbated by the insufficient water supply in communities that border with most of the PAs. Mgahinga Gorilla National Park and Echuya Central Forest Reserve are part of the GVL and were the focus for this study.

This report summarizes findings of a hydrological assessment study, conducted during December 2013 up to December 2014 in Mgahinga and Echuya forests. To understand the water use/need and quality used by the local people, this study carried out a socioeconomic survey of households around the two forests. A GIS modeling of floods/soil erosion hazard areas was also carried out to identify the high-risk areas in terms of water quantity and quality; mapping out and inventorying the main water sources in the two forests was also carried out. Furthermore, a hydrological assessment of the water sources was also carried out to understand the physical, chemical and biological compositions of the water regimes (water quality). Last but no least, an MS database of the water quantity and quality was made for the Mgahinga and Echuya landscape to be used for future monitoring purposes of the hydrological systems in the GVL.

Socioeconomic survey results show that communities around Mgahinga and Echuya forests were vulnerable to water access and supply (quantity and quality). Areas around Mgahinga have fewer water sources and points than those around Echuya. The few water sources in Mgahinga may be because of the porous nature of the soils and probably exacerbated by climate change effects due to swamp drainages and forest clearances there. It was reported by the local people that there is insufficient water supply from the major water sources in Kisoro district such as Chuho whose water levels have substantively reduced over years. Local communities around Echuya have

reported that water quality for domestic use is getting poor due to high levels of soil erosion and seasonal flooding. The major use of water by households was for domestic chores while livestock and irrigation use of water was the least. Average household water use per day was very low and this was calculated at a minimum of 20 litres and a maximum 60 litres for domestic chores use. Most households do not treat or boil water for drinking and other domestic chore use.

The study established that despite water scarcity and poor quality of water for both Mgahinga and Echuya, little efforts have been made to institute rainwater harvest systems. For a relatively small investment, a great deal of water can be collected with a collection vessel fed by gutters lining the roofs of churches, schools, or individual homes. Some of the interventions put in place lack a systematic approach of implementation thus leaving a lot to be desired. As a result, most community members sneak into the two Protected Areas to collect surface water and therefore may end up carrying out illegal activities such as poaching. Some of the possible underlying factors that may account for the relative success of the water interventions that have been put in place and other areas of interventions that could be explored have been pointed out in this report.

Hydrological modeling results show that surface water runoffs were comparably low for all the parishes around the Echuya landscape, with Chibumba parish having slightly higher values than other parishes. The low runoff values indicate that there is sufficient ground water recharge around the Echuya landscape. This means that the groundwater intersects with the streambed leading to the creation of perennial stream flow and therefore households around the Echuya landscape are less prone to drought. Compared to Echuya, in Mgahinga, there are high surface water runoffs. This was indicated by the high runoff values in the model outputs around Mgahinga landscape that show low infiltration rates, which could be reducing groundwater recharge affecting water availability to the communities. The porous nature of the soils could be the reason why Mgahinga landscape has low water infiltration rates. Results from the water source survey, suggest that the water table in the area is low, as there were no perennial rivers observed during this study period. Most households around the Mgahinga landscape depend on rain fed tanks for their water needs, which means they are likely to face water scarcity if there is a change in rainfall regimes.

Local community parishes around Echuya and Mgahinga Landscapes were evaluated for soil erosion risk. Percentages of the areas affected by soil erosion per parish were computed for the Echuya and Mgahinga landscape. In Echuya, some parishes such as Kagezi, Chibumba, Muhindura and Karengyere experience soil erosions above the acceptable tolerance limit. While others such as Ikamiro, Kacherere, Kashasha and Kishanje the soil loss was below the tolerance limits suggesting that these parishes were practicing soil conservation practices. For Mgahinga, the model output suggests that high proportions of soil loss are experienced mostly inside the park. This could be due to the high elevation and slope (>30) in the park than outside the park. For all the parishes, areas outside the Mgahinga Park, soil loss is at low levels perhaps contributed by lower elevation in those local community areas than areas in the parks that are at high elevations.

Hydrological assessment results indicate that water sources varied within and among parishes of Echuya and Mgahinga. Areas around Mgahinga National Park have the least number of water sources than those around Echuya. In Mgahinga the only water sources found were composed of perched aquifers, high altitude wetland sources inside the park and gravity flow schemes originating from inside the park. Because of water source scarcity in the communities around Mgahinga, rainwater-harvesting tanks are quite common both at household and at communal levels. In parishes around Echuya, Karengyere and Muhindura parishes had the least number of water sources and thus were the most water stressed. Other parishes such as Kashasha, Ikamiro, and Chibumba had a variety of water sources and these included protected/unprotected water springs, wells, ponds, streams, rivers and gravity flow schemes.

Mean pH values across the sampled water sources in region were generally acidic but within the recommended standard range from 6.5 to 8.5. Turbidity was also generally low in all the rainwater sources and protected spring sources sampled. Turbidity was very high in agriculturally impacted water sources such as headwater sources and the streams and rivers they drain into. Water conductivity in all the sampled water sources was below the maximum permissible value of 1000 µS/cm. The conductivity values tended to increase with the intensity of human activities such as cultivation on steep slopes and removal of vegetation around water sources. Total suspended solids were above national standards in most water sources. This implies that most water sources inputs from terrestrial sources such as agricultural and road runoff that add the suspended materials to the receiving water sources. Phosphates values were generally low across the sampled water sources but with very low values in rainwater sources and protected spring sources Phosphorous and nitrate pollution is not yet a problem in the landscape because of the low or no application of fertilizers. Fluorides in sampled water sources were below the maximum permissible standard for portable water implying that the water in the area does not pose a health risk to the communities. Total coliforms and E.coli in all sampled sources had mean values above the standard value of 0. Low values of total coliforms were common in rainwater sources, protected spring sources, and water sources located inside the protected areas. The high levels of coliforms in water sources located in communities are an indication of poor sanitation facilities such as open defecation that contaminate the water with fecal material.

Based on these findings, some local community areas need urgent intervention in terms of establishing water-provisioning facilities such as rainwater harvesting facilities and construction of water gravity flow schemes where clean water sources are inaccessible. Failure to do this will lead to local communities invading the protected areas looking for water for livelihood use and this could exacerbate conflicts. There is a need to regularly maintain these structures for regular supply water provision to the local communities. Areas affected by soil erosion and floods need urgent interventions with reforestations and soil conservation measures. Local government structures and entire local leadership ought to function in order to redeem their people from water related challenges. There is need to continually monitor the water quality in the study area for ensuring water safety.

1. Introduction

Hydrological systems contribute significantly to the richness of biodiversity systems as well as socioeconomic wellbeing of people living in such systems (USAID, 2006). In order to maintain environmental integrity, society requires a more complete understanding of the interactions between social conditions, ecosystem services, and external drivers so that it can respond to environmental feedback and change (Folke *et al.,* 2005), the socio-ecological systems and relationships ought to be understood. Gurrieri *et al.,* (2008), (quoted in Ostrom (2007) argues that such an understanding implies the ability to diagnose the problems and potentialities of social-ecological systems and established a nested, multi-tier framework. It is important to note that, the Virunga Landscape is immensely rich in endemic and threatened species. Plumptre *et al.,* (2003) notes that the Great Virunga landscape (GVL) is presumed as one of biodiversity hotspot regions of planet earth. This was substantiated by the 2006 USAID report which assessed the Ugandan part of the GVL: *"Uganda Biodiversity and Tropical Forest Assessment" it was stated that southwest Uganda is a key component of the Albertine Rift, and constitutes one of the richest areas of biodiversity in the world*". This means that the environmental integrity of this area largely depend on socio-ecological interactions that may have adverse effects if not well understood.

Biggs *et al*., (2012) have argued that fostering an understanding of social-ecological systems as complex adaptive systems should represent one of the key principles for managing ecosystem services. One of the key elements of achieving this integrity sustainably would be to ensure a reliable water access through safe water supplies to a population that surrounds these protected areas. The World Health Organisation (WHO) observes that water is an essential natural resource that shapes regional landscapes and is further seen as a vital for ecosystem functioning and human wellbeing (Postel, 2000). In addressing watershed management and water supply development, the true regional and global importance and its full range of environmental, social and economic values of the Great Virunga landscape ought to be better understood.

It is predicted that human use of fresh water will triple in the next two decades (Postel, 2000; Jackson *et al*., 2001). The Millennium Development Goal Number 7 looks at providing sustainable safe water to half of the world population by 2015. Human demands on water resources have strong effects on the integrity of freshwater ecosystems (Naiman *et al*., 1995; Postel, 2000). Serious water shortages have been predicted to exacerbate with climate change (Jackson *et al*., 2001), attracting the need for improved water management (Postel, 2000; Jackson *et al*., 2000). Anecdotal evidence from natural resource management agencies such as forestry and wildlife bodies reveal that the water levels of the existing water sources in the Great Virunga, both in and around the protected areas, in all three countries of Uganda, Rwanda and DR Congo have been steadily dropping in the recent past.

1.1 Context of the report

Communities in the GVL in the three countries continue to face water scarcity yet the afro-montane forests of the Virunga Massif and Echuya are major watersheds in the landscape. Previous reports such as Gurrieri *et al.,* (2005 and 2008) attribute this to the high rates of infiltration of the volcanic soils and rocks of the area that lead to a scarcity of surface water sources in the dry lava zone where the communities live. There are limited visible water collection points in communities bordering Virunga and Echuya despite the fact that there are many streams that emanate from these forested protected areas. Natural springs are scarce because the rain that falls on these high altitude forests seeps into the soil and re-emerges largely through regional flow system springs at lower altitudes, leaving high altitude areas on the hill and mountain sides devoid of spring water. People living near the two protected areas are therefore forced to trek long distances looking for water. As a result of limited surface water sources, community members end up collecting water from springs, streams, lakes and swamps in the protected areas. More often than not, some people use the opportunity of being in the protected area to also illegally extract resources such as honey, bush meat, firewood and medicinal plants.

Much as government is supposed to take care of water supply and sanitation, several interventions by IGCP, URP, GVTC, EEEGL and other organizations and institutions like churches have made an attempt to alleviate the water scarcity in the GVL. EEEGL, in consultation with front-line communities of Volcanoes National Park, Rwanda, and Mgahinga Gorilla National Park, Uganda, prioritized demand for water above all other problems. Previous studies (ITFC, 1998; USDA, 2005; EEEGL, 2011) show that a sizeable proportion of the people in the GVL relied, both illegally and legally, on the water that collected in surface streams within the parks. Collecting water within parks is not ideal for either the people or the parks. People, especially women and children, walk far looking for water and risk encounters with dangerous wildlife or with park staff. In the process, the protected areas are degraded; there are increased likelihood of mountain gorillas contracting human diseases due to increased chance of contact; and people using the opportunity of being in the protected areas to extract other resource extraction such as setting illegal snares or collecting firewood (EEEGL, 2011). Therefore, understanding the status and use of existing water regimes provides a basis for addressing community water needs and wellbeing as well as maintaining and restoring the ecological integrity of the Great Virunga landscape.

1.2 Goal and objectives of study

The study aimed at making an inventory and mapping water sources in the Ugandan part of the GVL to enhance effective water quality and quantity, sustainable water resources management, livelihood development and environmental integrity.

The specific objectives were to:

i. determine water demand and constraints by local populations located in each water regime;
ii. inventory the existing natural water-regimes (wetlands, streams, lakes, reservoirs, and springs) and level of protection and the underlying causes of the level of protection;
iii. determine the quantity and quality of water supplied by the natural water regimes;
iv. geo-reference the potential water resources and their attributes and map out flood/soil erosion hazard areas in the region;
v. establish a database of water quantity/quality regimes and related disaster areas; and
vi. make recommendations for sustainable water resource management in the region.

From the set objectives, five main themes were earmarked for the chronological flow of the hydrological assessment. These included among others land use, water sources and access; water demand and supply; perceptions on water quality and quantity; water management, challenges and effects; and locally generated solutions and recommendations.

2. Study area description

The Great Virunga Landscape (GVL) is an interconnected chain of eleven protected areas that straddle the borders of Uganda, Rwanda and Democratic Republic of Congo (DRC) as part of the northern

Albertine rift region (Plumptre *et al*., 2007). The GVL is famous for its mountain gorillas (*Gorilla beringei beringei*) and other endangered and endemic flora and fauna. With its large gradient in elevation, the GVL supports a wide variety of habitats conducive for many terrestrial vertebrates, some endemic and threatened, than any other site in Africa. In Uganda, the study took place around Mgahinga Gorilla National Park and Echuya Central Forest Reserve.

2.1 Mgahinga Gorilla National Park (MGNP)

Mgahinga is located in Kisoro District, Uganda but boarders Rwanda and DRC (Figure 1). Mgahinga natural forest facilitates the collection, infiltration, and storage of large amounts of water. However, communities surrounding these forests find it hard to access water. The problem stems from the spatial distribution of ground water discharge points relative to the population that surround the two forests.

It has also been documented that the main sources of fresh groundwater are the large contact springs that discharge from the terminus of lava flows. In cases where the permeable lava flows containing ground water extend to the valley bottom and pinch out over low permeability Precambrian rocks, large volumes of water are forced to the surface. This can be manifested in Cyuho and Jinya wetlands in Kisoro district (Gurrieri *et al.*, 2008).

The low gradient of the ground surface in the saddles between the volcanoes of MGNP favor the accumulation of rainfall, surface flow, and groundwater seepage into swamps. The high rates of infiltration of the volcanic soils and rocks of the Virunga volcanoes lead to a scarcity of surface water sources in the dry lava zone where the communities closest to the parks live. There is serious water scarcity in the communities surrounding Mgahinga due to lack of access to reliable water sources and points. This usually forces the local people to encroach on the parks in search of water. This has continued to facilitate other illegal activities yet there are endemic and threatened species in the two ecosystems (Plumptre *et al.*, 2003). In a study that was done by USDA Forest Service in 2005, three options were suggested to transport water from the sources to populations in need: 1) gravity flow from a source to down gradient users, 2) pumped from a source to up gradient users, and 3) extracted from wells near the location where water is needed. However, this study found out that feasibility studies are pertinent in order to recommend a viable option.

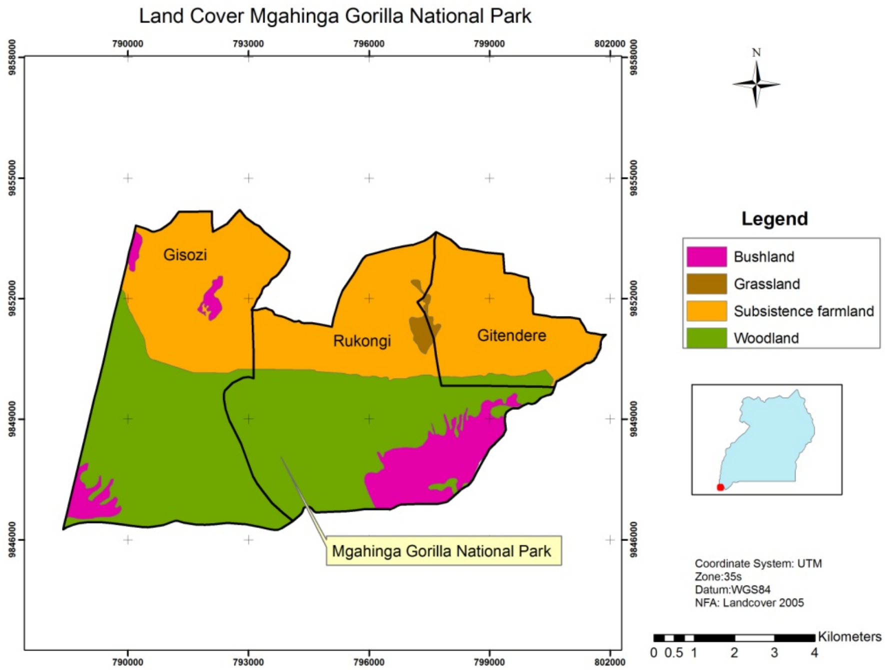


Figure 1. Mgahinga Gorilla National Park and the surrounding parishes

2.2 Echuya Central Forest Reserve (EFCR)

Echuya Central Forest Reserve is one of the rich biodiversity forests located in Bufumbira county of Kisoro District and Rubanda county of Kabale District (Figure 2). Echuya is therefore shared by the districts of Kisoro and Kabale. The forest lies between 1°14' - 1°21' S and 29°47' - 29°52'E, covers an area of 34 km, and has an altitude range of 2,270 – 2,570 m. It is situated on the high altitude range running between Lake Bunyonyi, 5kms to the East, and Mgahinga Gorilla National Park, 13 km to the south west. It is 11 km east of Kisoro town and 15 km west of Kabale town. The southern end runs along the north-eastern border of Rwanda. The main Kabale-Kisoro road passes through the northern end.

The forest lies at the heart of the biodiversity rich Albertine rift eco-region and is a site of global biodiversity importance and hence is categorised by BirdLife as an important Bird Area because of the high diversity of bird species, some of which are globally threatened and endemic. Echuya is particularly known for its high quality bamboo, *Yushania alpina*. There are also areas of broad-leaved forest, particularly along the Eastern side and higher altitude northern end of the

Kabale-Kisoro road. The forest cover is approximately 80% mature *Macaranga kilimandscharia* and *Hagenia abyssinica* forest and 20% mountain bamboo *Yushania alpina*.

As a water source, Echuya contains the large Muchuya swamp which runs north south along the reserve and drains it to the south. The forest is surrounded by areas with very high population density that depends entirely on natural resources and forest products for their basic livelihood needs such as firewood, bamboo for construction and medicinal plants. Most of the landscape around Echuya has been deforested, leaving the Echuya as the only local source of forest products. The surrounding communities have been using forest products unsustainably due to lack of alternative sources of livelihoods. Other conservation organizations including Uganda Wildlife Authority (UWA) have also come up with sustainable programmes such as gorilla tracking birding and community walks that are geared towards improving the livelihoods of the surrounding communities.

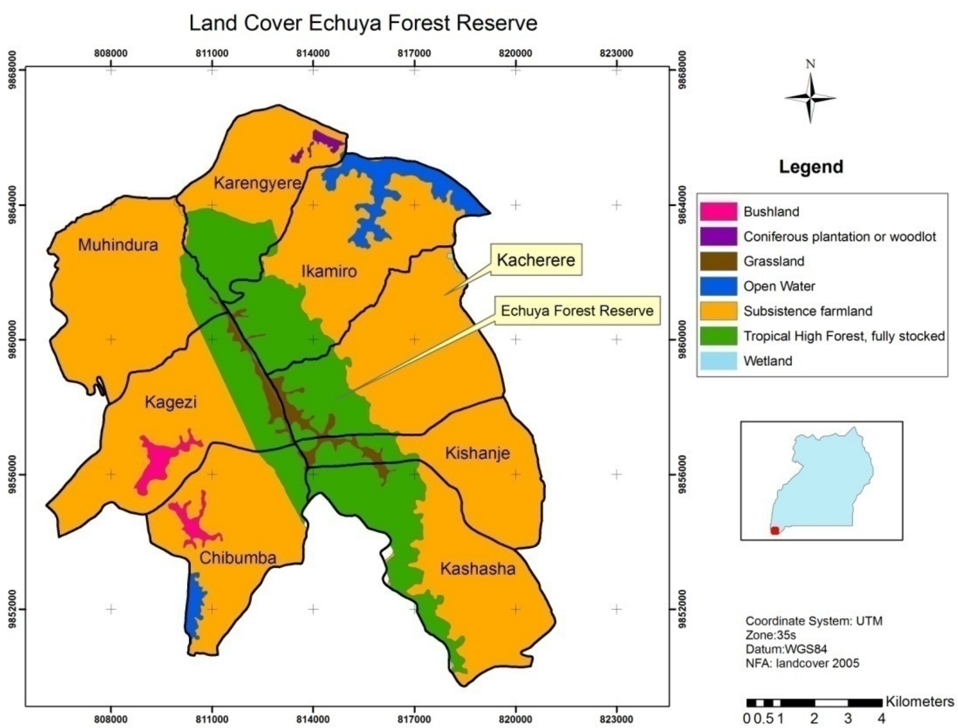


Figure 2. Echuya Central Forest Reserve and the surrounding parishes

Both Mgahinga and Echuya watersheds have highly porous volcanic rocks which favor storage of this water in the subsurface rather than in streams. All of the developed and undeveloped water supply sources are located at ground water discharge points. It was noted by USDA (2005) that certain geologic and hydrologic characteristics of the Virunga landscape favor the occurrence and retention of freshwater in underground aquifers although the geologic and hydrologic characteristics of the aquifers vary widely. Surface water is sparse across the landscape due to the high permeability of the volcanic rocks.

3. Study design and methods

3.1 Socioeconomic Surveys

3.1.1 Procedure of data collection

In order to establish the water access needs and constraints that local communities surrounding Mgahinga and Echuya have and encounter, a combination of quantitative and qualitative survey techniques were used. The combination of both qualitative and quantitative methods aimed at substantiating views that would be generated from various sections of the respondents. We first generated contextual data from previous reports (ITFC, 1998; USDA, 2005, 2008; EEEGL, 2011) and existing literature to determine the sampling frame and guide primary data collection. The existing literature highlighted key issues surrounding water access and demand around the great Virunga landscape. A mixed methodology was then adopted to triangulate views generated from a range of respondents. Primary methods included; Household Surveys (HSs), Focus Group Discussions (FGDs), Key Informant Interviews (KIIs) and Observation methods.

We then designed the tools which included a questionnaire, interview guide, FGD guide and an observation checklist. The tools were peer reviewed at the Institute of Tropical Forest Conservation (ITFC). After the review, we trained Research Assistants (RAs) in the methodology and data collection. The tools were pretested in Rwesanziro village, Katooma parish, Ruhija subcounty, Kabale district. This village boarders Bwindi Impenetrable National Park (BINP) and has some water sources that originate from the park. We chose Rwesanziro since it has some characteristics of water flows from the BINP as with ECFR. After the pilot study, we generated lists of residents of Local Council ones (LC1s) in the first parishes that surround MGNP and ECFR. This was intended to facilitate the procedure of stratified random sampling.. We then formally informed the chairpersons LC3s and made appointments with the

LC1s to inform the sampled respondents in the respective villages. Household interviews, FGDs and direct observation were then conducted.

3.1.2 Methods of data collection

3.1.2.1 Household Surveys

Semi-structured household interviews were conducted to document data on household water use and demand from community members who are directly affected by limited water access in both Mgahinga and Echuya. Household surveys are justified because they collect information in an organized and methodical manner about characteristics of interest from some or all units of a population using well-defined concepts, methods and procedures, and compile such information into a useful summary form (MoI Canada, 2003). Interviews were held with twenty community household members randomly selected from the parishes that boarder with both MGNP (N=03) and ECFR (N=08). The random sampling technique was intended to ensure that members from both frontier and non-frontier villages in surrounding ECFR and MGNP were interviewed and comparisons made in terms of water needs, access, quality and quantity, challenges and local solutions. The random sampling also helped capture data from representative sample of local people regarding their water needs, conditions, demands, and constraints and solutions to improving them.

3.1.2.2 Focus Group Discussions

Focus Group Discussion (FGDs) techniques were used principally in the extraction of qualitative data from a range of various community leaders. As observed by Wilkinson (1998:182), the Focus Group method is 'distinctive not for its mode of analysis, but rather for its data-collection procedures, and for the nature of the data so collected'. The study included key leaders in the FGDs who included members of Local Councils (LCs), stretcher groups and community water project leaders and resource user groups. Community leaders were interviewed basically because they implement most of the government and civil society programs. They are always involved in the implementation processes to gain support from the community members for the success of most water projects. This was important in understanding their views on the successfulness of the existing water projects and the challenges befalling the projects. The implementation project staff provided technical views on water project evaluation. We used maps of protected areas as water source diagrams. We also used FGDs because it generates collective views on pertinent issues such as water access, quality and availability and constraints in water management. By skillfully managing the group dynamic, it is possible to cultivate ‘natural’ conversation and discussion (through ‘synergy, snowballing, stimulation and spontaneity’) as a focus of investigation in its own right (Catterall and MacClaran, 1997; Jovchelovitch, 2000; Linell, 2001).

We conducted two (N=02) FGDs in each parish selected. One FGD (n=01) was conducted in the frontier village and another FGD (n=01) in a non-frontier village. Frontier villages referred to those villages that boarder with the PAs. These community discussions were composed of both men and women who are vital in water resource management and activity implementation. This was done to ensure gender disaggregation of the data collected. An FGD guide was designed prior to the discussions and entailed guiding themes that aided in the assessment and determination of water resource availability and quality. Themes discussed included among others; water supply in the selected areas and community views on both water quantity and quality of the potential water sources, the existing demand for water for instance for animals, farming and energy; benefits and challenges of the existing water projects (Appendix ii). Preference and matrix rankings as well as scoring were done during the FGD exercises.

3.1.2.3 Direct Observations

Direct observations were used to get information on some of the water projects already implemented and also the interactions on various water sources and points. This process was guided by an observation checklist, where key areas of focus were highlighted. This was done in order to enable new insights into the study and also to enrich the already collected data from the field. As Sarankatos justifies the use of direct observation, “Observation entails gathering data through vision as its main source” (Sarankatos, 2005:221). This process allowed us to obtain first hand information on water sources in their natural setting. The focus of the observations was also to capture the non-verbal communication behaviors of the local residents towards the existing water projects.

3.1.2.4 Key Informant Interviews (KIIs)

KIIs were used to solicit qualitative data from a number of natural resource management agencies. A focused use of key informants is intermediate in nature because it assumes broad general knowledge of the area, but precedes the ability to choose the relevant alternatives incorporated in a well-designed sample survey (Tremblay, 1957:7). Key agencies included

UWA, Uplift the Rural Poor, BMCT and water projects' technical staff in the districts' engineering departments. Natural resource managers were interviewed basically because they implement most of the government and civil society programs. They were found to be involved in the implementation processes of most water projects. This was important in understanding their views on the success of the existing water projects and the challenges befalling such projects. The implementation project staff provided technical views on water project evaluation. Because information comes directly from knowledgeable people, KII often provide data and insight that cannot be obtained with other methods (Kumar, 1989:3).

3.1.3 Sampling techniques

A total of 614 respondents were contacted for this research study (Table 1). These included: 330 respondents from 115 villages that participated in individual household interviews/survey (Figure 3 and 4), 264 respondents that participated in FGDs and 20 who were purposively sampled as key informants from key organizations that are involved in hydrological systems management. These organizations included the district engineering department (n=05), conservation and community organizations (e.g., URP, BMCT and IGCP n=09), management agencies (NFA n=03 and UWA n=03).

We used purposive and Simple Random Sampling (SRS) techniques. Parishes surrounding both Echuya and Mgahinga were derived from ITFC GIS database and validated with records from National Forest Authority and Uganda Wildlife Authority for Echuya and Mgahinga respectively. The only parishes included in the study were the frontier parishes bordering the two protected areas. These were purposively selected since they border with MGNP and ECFR. ECFR borders with eight parishes (N=08) as shown in Figure 2. These include; Ikamiro, Karengyere, Muhindura, Kagezi, Chibumba, Kashasha (Bufundi), Kishanje and Kacerere. For this study, all the 08 parishes were purposively included. Mgahinga GNP boarders with three parishes (N=03) and all were purposively selected basing on their drainage pattern from the park. The parishes included Gitendere, Rukongi and Gisozi. Both frontier and non-frontier villages within the parishes were selected. The inclusion of frontier and non-frontier villages was intended to make comparisons of water flows from Echuya and Mgahinga and understand the levels of water demand, access, quantity and quality. In the selection of parishes and villages, simple random sampling was employed in order to give parishes and villages equal chances of being selected and to avoid bias.

Table 1: Summary of the study population and sampling framework

Area of Study	**Data collection Method**	**Sampling Technique**	**Study Population**	**Respondents per parish/area**	**No. of respondents**
Echuya parishes	Household surveys	Stratified and simple Random Sampling	Local residents	30	240
	Focus Group Discussions	Purposive Sampling	Local Council officials	06	48
			Stretcher group leaders	06	48
			Resource user groups	06	48
			Local water project leaders	06	48
Mgahinga parishes	Household surveys	Stratified and simple Random Sampling	Local residents	30	90
	FGDs	Purposive Sampling	Local Council leaders	06	18
			Stretcher group leaders	06	18
			Resource user groups	06	18
			Local water project leaders	06	18
Echuya and Mgahinga	Key Informant Interviews	Purposive sampling	District engineering department	05	05
			Conservatio n NGOs	09	09
			NFA	03	03
			UWA	03	03
Total Respondents					**614**

Residents around Echuya and Mgahinga to whom household interviews were administered were randomly selected whereas key informants that took part in FGDs were purposively selected basing on their knowledge and level of involvement in water related activities. The use of random generator for semi-structured household surveys gave all sections of residents who are affected by hydrological processes equal chances of being selected to get all round views. SRS is a one step selection method that ensures that every possible sample of size *n* has an equal chance of being selected. As a consequence, each unit in the sample has the same inclusion probability. This probability, π, is equal to n/N, where N is the number of units in the population (MoI Canada, 2003:93). The use of purposive sampling included sections of the population who directly deal with water resource management and activity implementation.

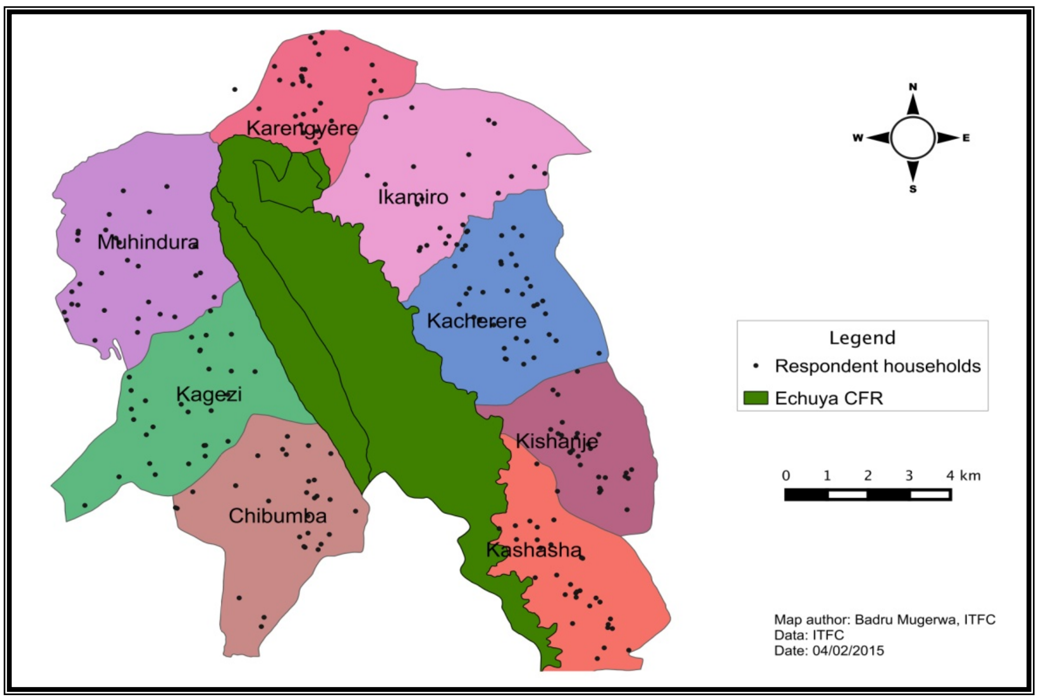


Figure 3. The distribution of respondents across parishes around Echuya CFR, Uganda

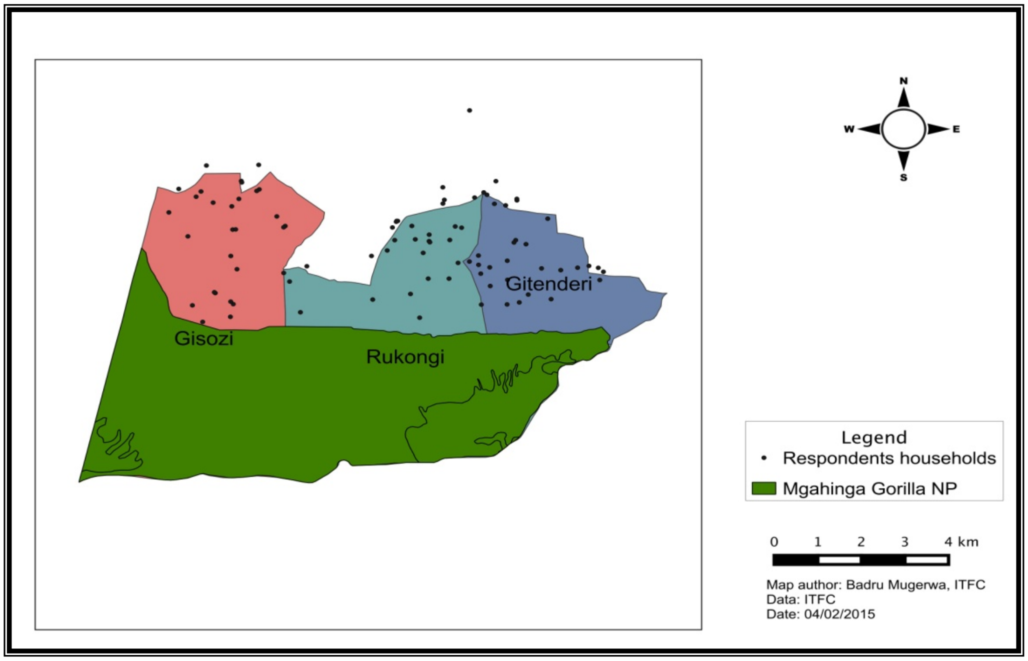


Figure 4. The distribution of respondents across parishes around Mgahinga NP, Uganda

3.1.5 Data analysis

Socioeconomic data was mainly analysed using thematic analysis. Descriptive statistics were applied to generate tables, charts and graphs. Thematic analysis or sometimes referred to as content analysis is a technique of making inferences by systematically and objectively identifying special characteristics of the messages (Holsti, 1968: 608). Berelson (1952) argued that content analysis should be systematic, objective and quantitative. It has been argued that thematic analysis helps researchers move their analysis from a broad reading of the data towards discovering patterns and developing themes. Thematic analysis differs from other analytic methods that seek to describe patterns across qualitative data – such as, thematic discourse analysis, thematic decomposition analysis, IPA and grounded theory (Boyatzis, 1998). The method focuses on identifying and describing both implicit and explicit ideas within the data, that is, themes. Codes are then typically developed to represent the identified themes and applied or linked to raw data as summary markers for later analysis (Denzin and Lincoln, 2005). This study arranged data according to key themes that were provided in the Terms of Reference (ToRs). Analysis was then run theme by theme to in-depth to understand both implicit and explicit ideas within the data for proper interpretation. Table 2 shows the analysis process that we undertook for this study.

3.1.5.1 Social-demographic profiles of the respondents

Social and demographic characteristics of respondents create linkages that explain the relationships between such variables and the problem under investigation (Boyatzis, 1998). This study established the linkages between; category of respondents, age differences, ethnicity, marital status and level of education. Other variables looked at included; responsibility and position one had in society, the time respondents had stayed in their communities and respondents' main source of livelihood. The socioeconomic variables were disaggregated according to the parishes in order to create an in-depth analysis of the differences that exist between and among parishes and protected areas.

Table 2. Data analysis process

Step	**Description of the Process**
1. Familiarizing with collected data	We transcribed, read and reread the data, noting down initial ideas that emerged from the field.
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking in the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic map of the analysis.
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

Source: Braun and Clarke, 2006

3.2 GIS Hydrological modelling

3.2.1 Watersheds and stream network delineation

Hydrological modeling involves delineation of watersheds and rivers/streams. Sub-watersheds and rivers/streams were delineated from a 30m resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Digital Elevation Model (DEM). Terrain pre-processing for the DEM to delineate watersheds and streams was carried out by using Geographical Information System (GIS) and Arc Hydro Tools.

The threshold for river definition was taken to represent 1% of the maximum flow accumulation. Maximum flow accumulation in the study area = 4032106 cells; 1% of flow accumulation = 4032 cells; drainage area to delineate rivers $4032 \text{ x } 0.03 \text{ x } 0.03 = 3.63 \text{ km}^2$; streams were delineated basing on drainage area of 1.8 km^2. The catchments were defined basing on the cells from which the water drains to the pour point. A total of 24 sub watersheds were delineated in and around the study area (http://web.ics.purdue.edu/~vmerwade/education/terrain_processing.pdf). The outputs from the analysis (flow accumulation, flow direction, sub-watersheds, stream network, pour points, watershed characteristics) were used as input files for modeling the runoff and soil loss (Figure 5 and Figure 6)

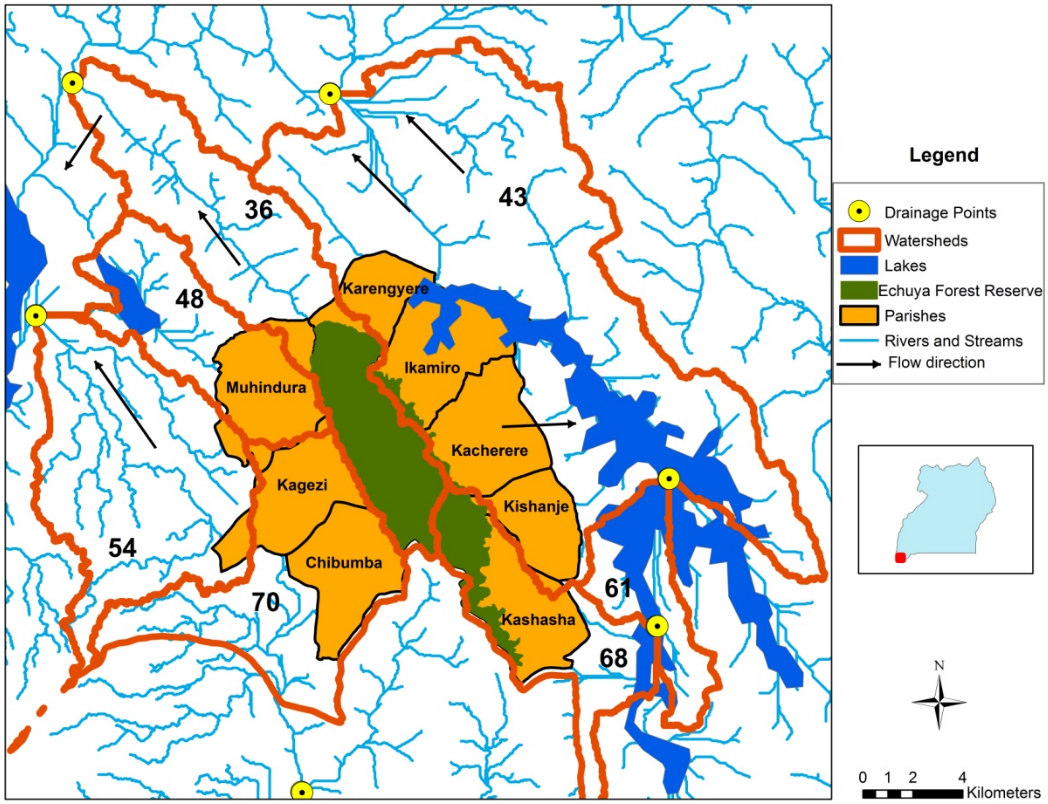


Figure 5. Delineated sub watersheds, rivers and streams around Echuya Central Forest Reserve

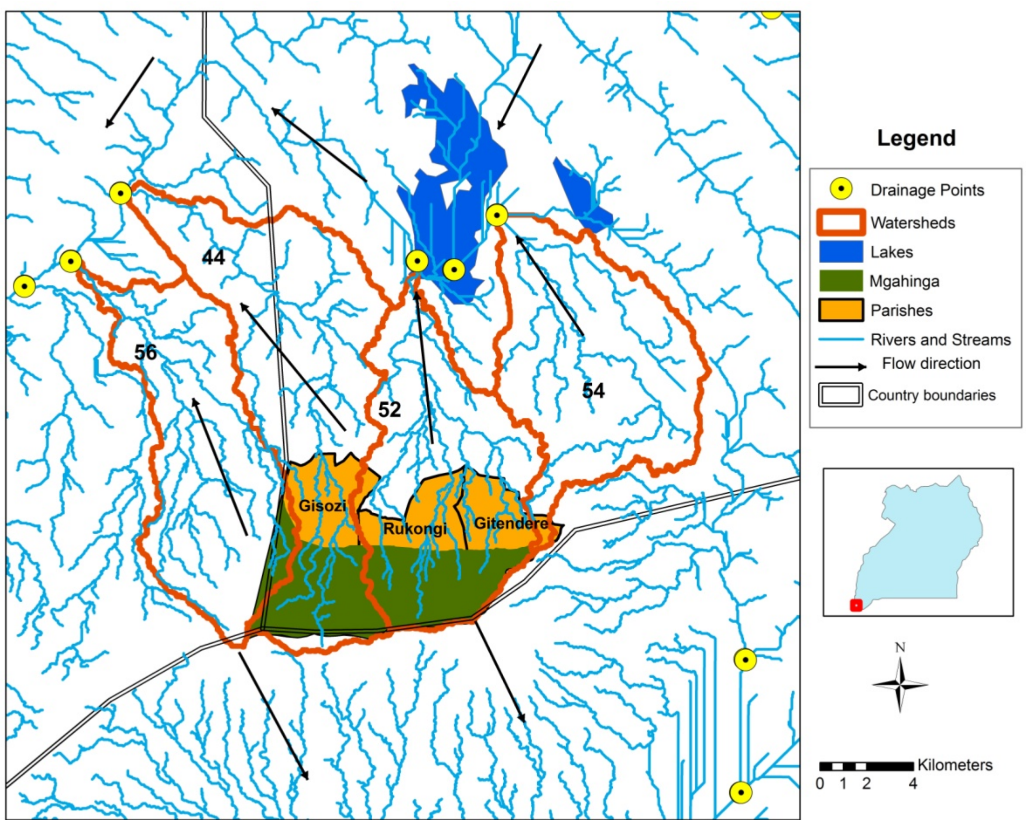


Figure 6. Delineated sub watersheds, rivers and streams around Mgahinga Gorilla National Park

3.2.2 Surface runoff

Surface runoff is composed of storm flow and base flow. Storm flow occurs when part of rain water flows overland and subsequently reaches rivers and streams leading to an increase in discharge while base flow is sustained by groundwater. The curve number (CN) method developed by the Soil Conservation Science (Natural Resources Conservation Service) was used to estimate the potential for storm water runoff within the drainage basins (Weng, 2001; USDoA, 1986). CN is characterized by the hydrological properties of the soil and is a quantitative description of land cover and soil conditions that affect the runoff process.

The CN equation for estimating storm runoff depth is mathematically expressed as:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{Equation 1}$$

$$Q = 0 \qquad when \qquad P \geq 0.2S; P \leq 0.2S$$

where Q is the direct runoff depth (inches), P is the event rainfall depth (inches), and S is potential maximum storage. With the above variables in inches, S is transformed to the dimensionless expression:

$$S = \frac{1000}{CN} - 10 \quad or\ S = \frac{2500}{CN} - 254\ (if\ precipitation\ is\ in\ mm);$$

CN represents runoff curve number of hydrologic soil group–land cover overlay.

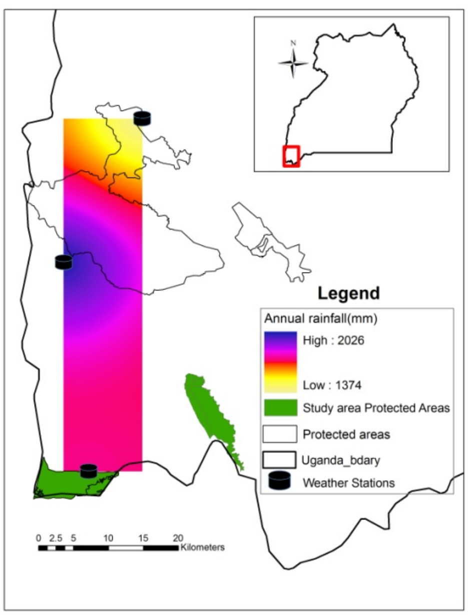
CN is a transformation of storage factor (S) taken to be a measure of watershed response to a rainstorm and it varies from 0 (no runoff) to 100 (all rain becomes runoff; zero retention). The 0.2 and 0.8 in Equation [1] is the "initial abstraction", or Ia, that represents all losses before the runoff begins at the onset of the storm. Geographic Information Systems and Arc Hydro Tool were used in the compilation of runoff for this study using the following steps:

i. Watershed delineation for which curve number(s) were calculated
ii. Mapping soil types and land use for the drainage basin
iii. Converting the soil groups to four (A, B, C, D) hydrologic soil groups based on their drainage properties
iv. Intersecting land use and hydrologic groups maps
v. Assigning curve numbers to each polygon based on the standard Soil Conservation Science curve number table
vi. Overlaying the drainage basin map on the land use-soil group polygons
vii. Deriving CNs for each drainage basin by area weighting the land use-soil group polygons within the drainage basin boundaries

Using the above equations, the storage factor (S) was derived from the area weighted CN for the drainage basins and runoff were computed from the storage factor and annual precipitation using the raster calculator in ArcGIS 9.3. All layers were re-sampled to 30 arc-seconds (~1 km). Precipitation data was obtained from 3 rain gauge stations located at (Nkuringo, Rushaga, Ntebeko) for the study area. The data was for year's 2001 to 2014, however due to the spatial location of the 3 rain gauge stations relative to the study area, the interpolation method did not fully capture the area of interest (Figure 7). The annual precipitation from Worldclim that was produced by interpolation of average monthly climate data obtained from various databases/

weather stations (1960 to 2000) on a 30 arc-second resolution grid was used in the analysis (Hijmans *et al.*, 2005; http://www.worldclim.org) (Figure 8). The mean annual precipitation from the 3 weather stations for years (2001 to 2006) ranges from 1300mm to 2030mm while the Worldclim data ranges between 1000mm to 1933mm.

The land cover (2005) from the National Forest Authority was used in the analysis of this study (Figure 9). Other sources of land cover that were considered include the GlobCover 2009 and FAO SPOT2000 land cover maps, however they were not used in the analysis as they did not describe the land use in the study area in detail. The land cover in the study area is dominated by subsistence farmland. The FAO world Soils data base (Harmonized World Soil Database) was used in the definition of soil classes for the study area (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009) (Figures 10 and 11). Buffers of 200m were also delineated along the rivers and streams of Echuya (Figure 12) and Mgahinga (Figure 13) landscapes.



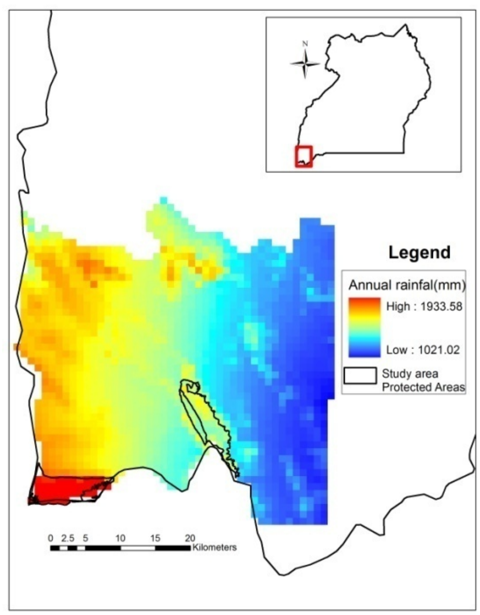


Figure 7. Interpolated precipitation data

Figure 8: Annual precipitation (Worldclim)

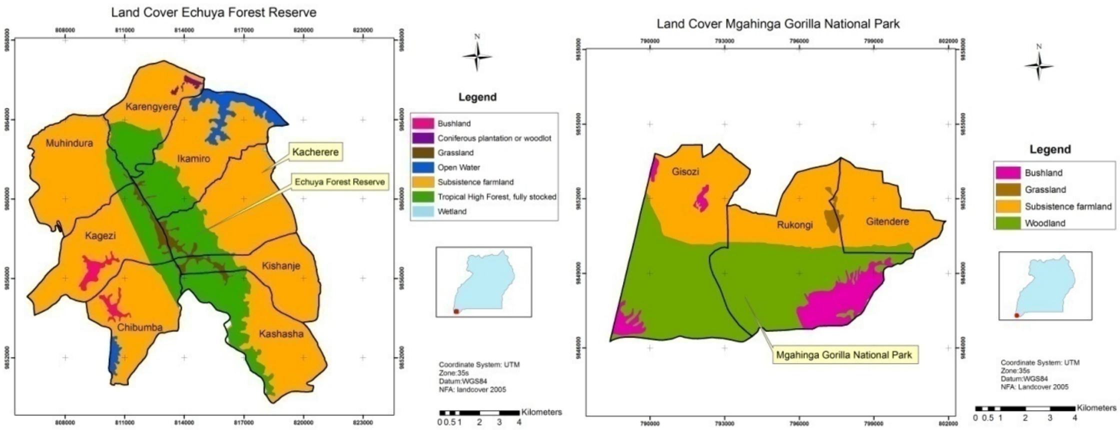


Figure 9. Land cover map of the Echuya and Mgahinga landscapes

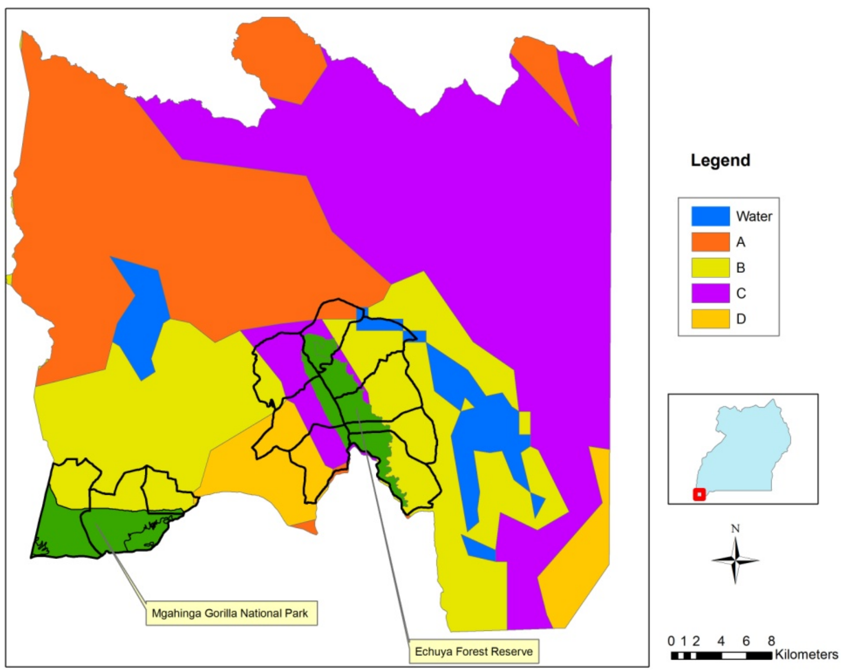


Figure 10. Hydrologic soil classes for the Uganda study area

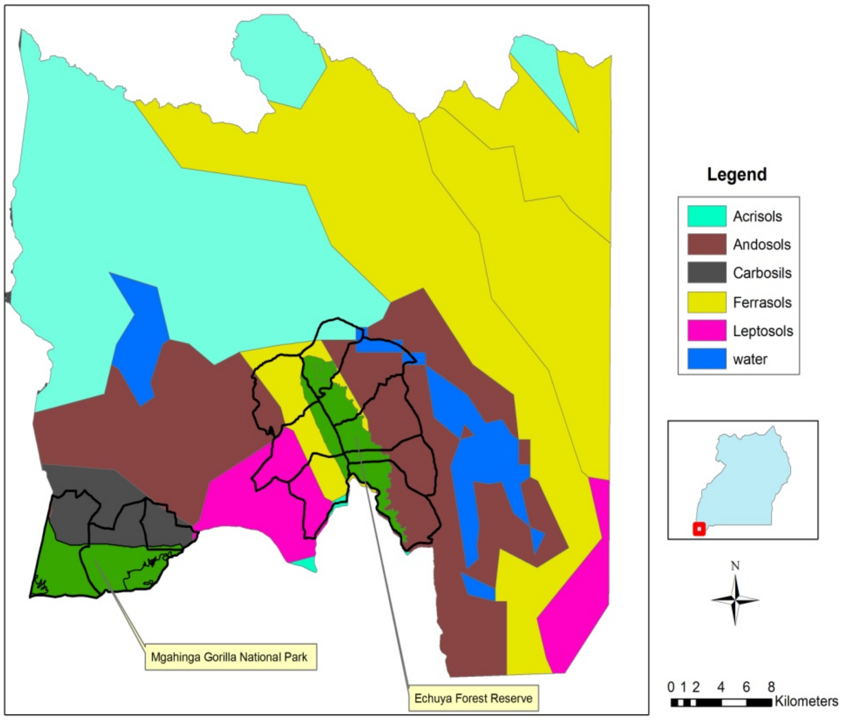


Figure 11. Soil classes for the Uganda study area

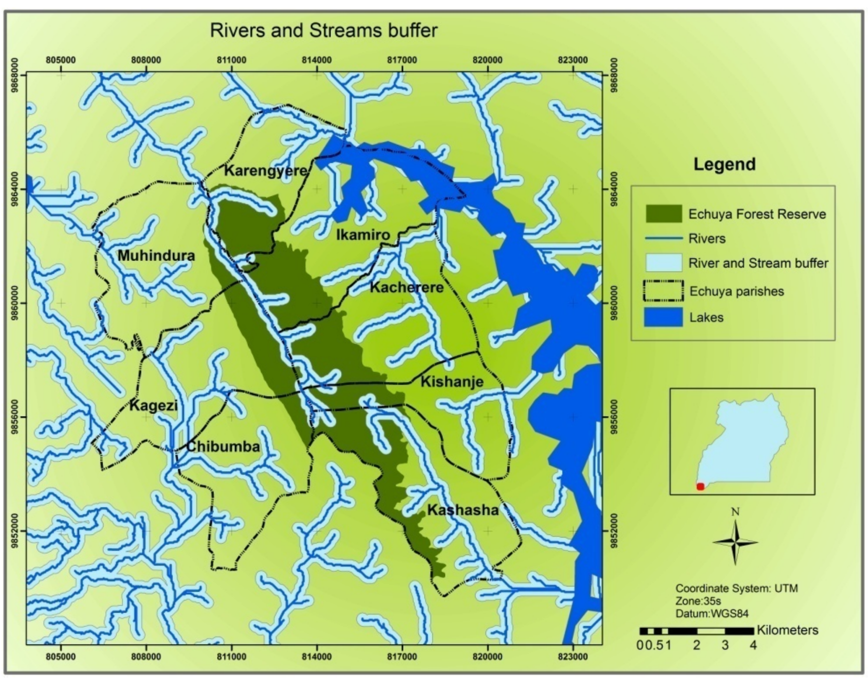


Figure 12. 200m buffers around delineated rivers and streams around Echuya landscape, Uganda

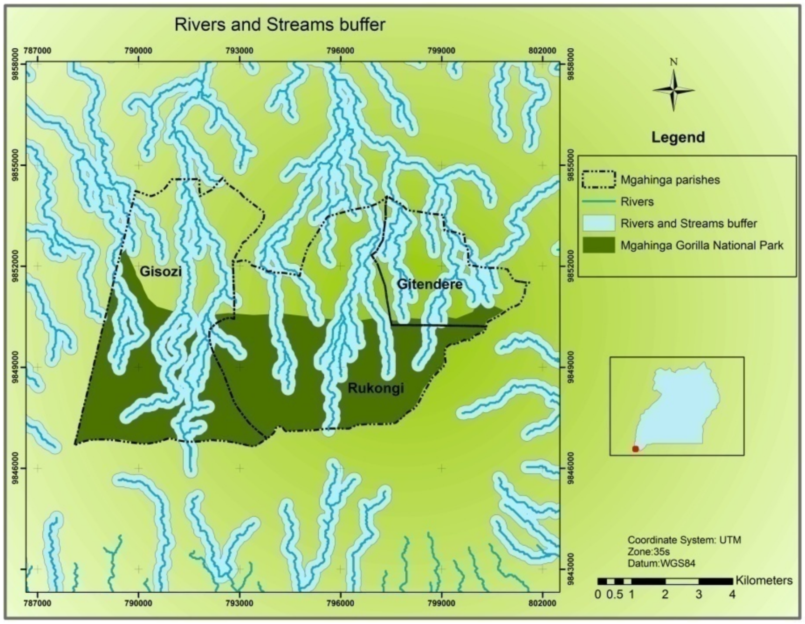


Figure 13. 200m buffers around delineated rivers and streams around Mgahinga landscape

3.2.3 Soil erosion modeling and risk assessment

The Universal Soil Loss Equation (USLE) which is the most widely used estimator for assessment of soil erosion was used to estimate the average annual soil loss in the study area. The soil loss prediction procedure was developed by Wischmeier and Smith (1965) based on about 10,000 plot years of runoff and soil loss data from research stations throughout the Eastern USA spanning a period of more than 20 years (Wischmeier and Smith, 1965).The USLE predicts the average annual rate of soil erosion based on the crop system, land management practices that are linked to a specified soil type, rainfall pattern, and topography. The USLE has been superseded by the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.,* 1997). The Revised Universal Soil Loss Equation (RUSLE) has been adopted for predicting soil erosion as it provides improved means of computing soil erosion factors (Renard *et al.*, 1997). The RUSLE retains the basis of the USLE while incorporating new and better data to evaluate soil erosion factors.

The RUSLE equation:

$$A = R \,.\, K \,.\, L \,.\, S \,.\, C \,.\, P$$

Where:

(A) - Computed spatial average soil loss and temporal average soil loss per unit of area (t/ha/yr), (R) = Rainfall- runoff erosivity factor (MJ.mm/ha/hr/year), (K) = Soil erodibility factor (t. ha. h/ ha/MJ/ mm), (L) = Slope length factor, (S) = Slope steepness factor, (C) = Cover management factor, (P) = Support practice factor. L, S, C and P factors are dimensionless parameters.

The RUSLE parameters in the study area were derived using the raster calculator in ArcGIS 9.3.

3.2.4 Rainfall erosivity map layer

The rainfall erosivity factor (MJ mm/ha/ hr/year) represents potential of a rainfall event to cause soil erosion (Wischmeier and Smith, 1978); Renard *et al*., 1997). The rainfall erosivity factor (R factor) is computed as an average annual total of the storm EI values for a particular locality (Wischmeier and Smith (1978). EI is an abbreviation for energy-times-intensity. EI for a particular rain storm, is a product of total storm energy (E) times the maximum rainfall intensity in 30 minutes (I_{30}). To account for the apparent cyclical rainfall patterns, the computation of rainfall erosion index requires long-term rainfall records which are rarely available. For this analysis, the erosivity map layer was computed using the raster calculator in ArcGIS 9.3, based on the relationship from linear regressions of ($KE_{15} > 25$) on mean annual rainfall on rainfall erosivity in East Africa (Moore, 1979, Lufafa, *et al.,* 2003).

The regression equation is represented by:

R = 0.029(16.58P – 6963) 26 Where R = erosivity parameter (joules per m^{-2}), P = annual precipitation(mm)

3.2.5 Soil erodibility map layer (K)

The soil erodibility factor describes the susceptibility of soil particles to water erosion based on soil properties. Soil map classes of the study area were used to determine the erodibility values following the soil erodibility equation by Wischmeier & Smith (1978) and applied in South Africa (Mhangara *et al.*, 2011) . The K factor values illustrate the susceptibility and vulnerability of the different soil types to water erosion. The FAO world Soils data base (Harmonized World Soil Database) was used to compute the K factor (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). The equation is as follows:

$$K = [2 \times 10^{-4} \times M^{1.14} \times (12 - OM) + 3.25(S - 2) + 2.5(P - 3)]/7.59\times 100$$

where K = soil erodibility factor (ton h $MJ^{-1}\ mm^{-1}$), OM is soil organic matter content, M is product of the primary particle size fractions, M = (%silt + %very fine sand) x (100 - %clay), S is soil structure code, P is permeability class. T_texture and Drainage in the FAO Soil database represent S and P in the equation. The FAO world Soils data base (Harmonized World Soil Database) do not have organic matter in their attributes, however they do have organic carbon. A conversion factor of 1.72414, which assumes that organic matter contains 58% carbon was applied (Nampindo, 2013). Organic Matter (%) = Organic Carbon (%) x 1.72414)

3.2.6 Slope length and steepness factor (LS)

The effect of topography on soil erosion in the RUSLE, is captured by the LS factor which is a combination of slope length factor (L) and a slope steepness factor (S). The LS factor was computed by applying a Grid based algorithm (Arc Macro Language) program proposed by Hickey (2000) using Digital Elevation Model as an input from an ArcInfo Workstation ArcGIS 9.3 (http://www.onlinegeographer.com/slope/slope.html) (Van Remortel, *et al.*, 2004)

3.2.7 Cover management factor(C)

The Cover factor represents the combined effect of cropping and management practices on erosion rates (Renard *et al.*, 1997). The Normalized Difference Vegetation Index which represents vegetation vigor and health is an important estimator of the C factor. NDVI is derived from satellite imagery using the following formula:

$$\text{NDVI} = \frac{rNIR - rRed}{rNIR + rRed}$$

where *rNIR* is the near-infrared band; *rRed* is the visible red band.

The C- factor was estimated by applying the following provisional formula developed by Van der Knijff *et al.,* (2000)

$$C = Exp\ (-\ \alpha\ \frac{NDVI}{\beta - NDVI})$$

Where:

C is the cover management factor; NDVI is the vegetation index, and α, β are parameters that determine the shape of the NDVI-C curve. An α-value of 2 and a β-value of 1 have been suggested to produce reasonable results (Van der Knijff *et al*., 2000). A 10-day maximum-value composite NDVI images at 250m spatial resolution (for the month of March 2014) from the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) were used to compute the C factor (http://earlywarning.usgs.gov/fews/africa/index.php)

3.2.8 Support Practice factor (P)

The Support Practice factor (P) represents the impact of soil conservation practices on the soil erosion rates (Renard *et al*., 1997). The range of P factor ranges from 0 to 1 (the lower the value, the more effective the soil conservation practices are). However, due to lack of data on the conservation practices in the study area, the P factor was considered to be 1.

3.2.9 Combining layers

After all the layers were computed for predicting the average annual soil loss, they were combined in the raster calculator in ArcGIS 9.3 **(**Figure 14), to produce a soil erosion risk map of the study area.

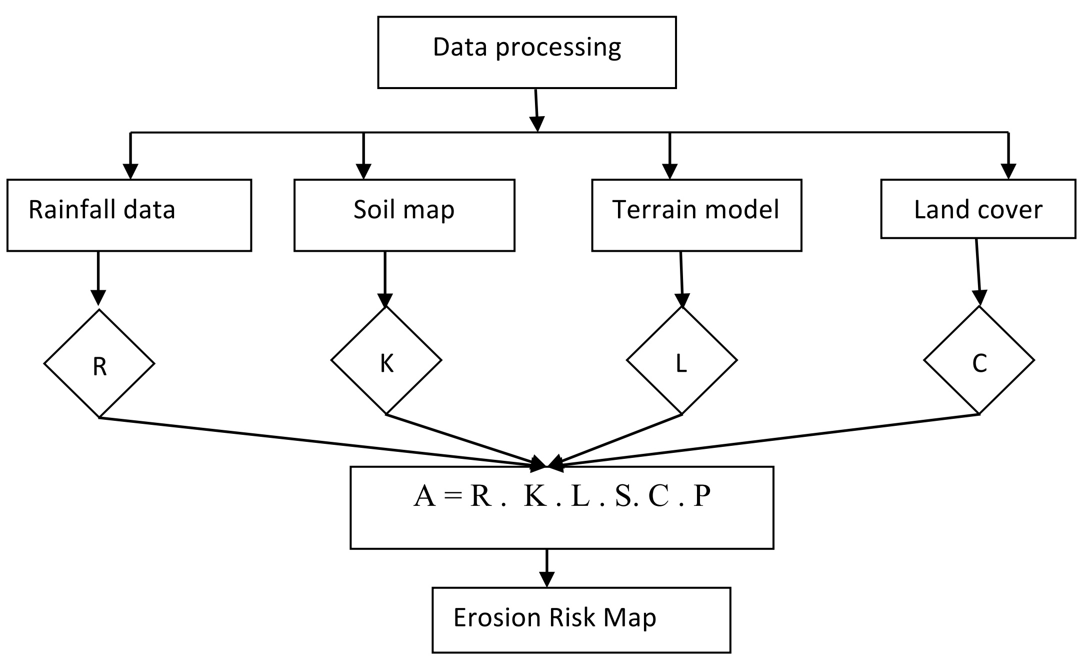


Figure 14. Flow chart for soil erosion mapping and risk assessment

3.3 Hydrological assessments

3.3.1 Study area description

Water quality and quantity measurements were carried at eight frontier parishes of Echuya CFR and three of Mgahinga Gorilla NP. The study sites are characterized by a volcanic history and therefore, the soils are porous leading loss of water to underground sources after precipitation. This result in a limited number of stream networks, more especially around Mgahinga Gorilla NP.

The study parishes are described in detail:

i. *Karengyere*: very hilly, many valleys and with few water sources and water points; with few protected springs and one gravity water scheme that serves a small area; soil erosion cases were observed and no fallowing; the water sources of Chumbiriza and Kajenje can be considered for gravity water flow schemes though they are down in the valley;

ii. *Ikamiro*: is very hilly and characterized by poor methods of farming. There are several streams and the parish boarders Lake Bunyonyi. The parish has two gravity water schemes that serve majority of the population. But people leaving next to the forest depend on ponds for water;

iii. *Kacerere*: not all the villages are hilly but the water sources are not many as there is only one main stream draining to Lake Bunyonyi. Poor methods of farming and a lot of soil erosion is evident in the landscape. There is only one gravity water flow scheme that does serve all the villages in the parish; the 5 villages that are hilly use only one protected spring of Kayungwe. Of the 5 villages, 3 belong to Kashanje parish;

iv. *Kishanje:* small parish with hilly villages and one large valley. Water sources are limited and the gravity water flow scheme of Ngasire is nonfunctional. Soil erosion cases were not many but observed in some high altitude locations;

v. *Kashasha:* this parish has a good number of streams and springs from the Echuya forest and the gravity scheme of Byakashera is nonfunctional. Soils are degraded as the villages are hilly with one big valley drained by Kashasha stream. During the dry season, cows graze in Echuya forest and in the process they are watered from the source of river Kashasha where the water quality is very poor;

The following are frontier parishes of Echuya forest located in Kisoro district:

vi. *Muhindura*: this is the largest parish with a lot of soil degradation; very hilly, poor methods of farming, limited water sources and water points. Some villages do not have any water source and depend on a few water tanks; the gravity flow scheme of Mivumu is in need of urgent repairs as water flows freely out of the source but not in the laid pipes and the Gatongo aquifer needs to be considered for development if resources permit;

vii. *Kagezi*: partly hilly with several water sources (springs) and many streams. The area is characterized by poor methods of farming, Kagezi swamp has been converted for agricultural purposes thus affecting the quality of water from the wetland;

viii. *Chibumba*: is partly hilly with many water sources including Lake Kayumbu. Cases of soil erosion were seen in the upper parts characterized by poor methods of farming on the hillslopes. The gravity flow scheme of Rugeshi needs repairs at the main source as the pipes rusted and water was gushing out at some sites;

Below are the frontier parishes of Mgahinga Gorilla National Park:

ix. *Gitendere*: The parish does not have any known water sources in the community. The people depend on only one big gravity tank that has a line from the Kabiranyuma swamp (gravity source). People depend on the rain water harvesting tanks which are also not many. More tanks are needed and the gravity pipes to be repaired and extended in the parish.

x. *Rukongi*: this parish is also like Gitendere as they have a gravity water flow scheme that has a connection to the Kabiranyuma. They also depend on the rain water harvesting tanks.

xi. *Gisozi*: this parish has 2 main water sources; Mbuga and Ijinya. During the rainy season, the Ntebeko seasonal stream supplies them with water in addition to the rain water harvesting tanks, and they have Nyakagezi gravity scheme that supplies the community but the pipes at the source are often trampled and broken by elephants and buffaloes as they wallow in the wetland.

3.3.2 Site selection

The study sites were selected based on the nature and intensity of the stream network following an initial mapping of water sources within the study area. During the socio-economic survey component of this assessment, most water sources and points located within the study area were identified and geo-referenced. Sites for water quality and quantity were sub-sampled from the geo-referenced water sources.

3.3.3 Onsite field measurements

Physicochemical variables that were measured in the field included water temperature, dissolved oxygen, pH, turbidity, electrical conductivity, total dissolved solids, water transparency, flow velocity.

3.3.4 Electrical conductivity (µS/cm)

This is a measure of the ability of water to conduct electricity. It varies with level of human activities in the watershed and the nature of the underlying geology. It also varies with season being lower in the wet season and higher during the dry seasons. We will use the YSI 30 conductivity meter.

3.3.5 Surface water temperature (°C)

Water temperature is extremely important for all freshwater ecosystems. This was measured onsite using digital equipment such as conductivity and dissolved oxygen meters. With the threat of global climate change, stream water temperature is predicted to rise with negative consequences for biota and water quality.

3.3.6 Dissolved oxygen (mg/l)

The dissolved oxygen is a crucial requirement of all life in water. It is normally saturated in fast flowing rivers. It is however expected to drop with a reduction in river discharge and an increase in water temperature. Other human impacts such as pollution may alter the concentration of oxygen. This was onsite using a digital meter YSI 55 model.

3.3.7 Water pH

pH is a standard measure of the hydrogen ion concentration of the water and is represented using a logarithmic scale. A digital pH meter was used for measuring the water pH. A robust model such as PHEP 5 TESTR by HANNA instruments will also be used.

3.3.8 Water transparency/clarity (cm)

This was indexed from a transparency tube fitted with a miniature secchi disc at the bottom. This is also a measure of turbidity and is expected to increase with an improvement watershed condition. Furthermore, total dissolved solids/total suspended solids wasmeasured using digital meters onsite. These measure the amount of sediment and other substances getting into a water source mainly as a result of unsustainable landuse practices in the watershed e.g. erosion and runoff from agricultural fields.

3.3.9 Turbidity (NTU)

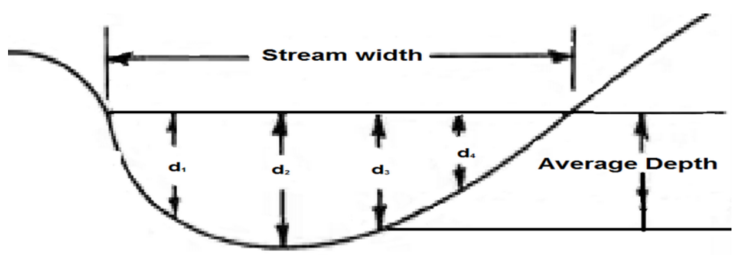
Turbidity in water is caused by suspended particles or colloidal matter that abstarcts light transmission through water. It may be caused by organic or inorganic matter or a combination of both. This was measured in the field using a digital meter.

3.3.10 Total Dissolved Solids (TDS)

The term "solids" is widely used for the majority of compounds which arepresent in natural waters and remain in a solid state after evaporation (some organic compounds will remain in a liquid state after the water has evaporated). Total suspended solids (TSS) and total dissolved solids (TDS) correspond to non-filterable and filterable residue, respectively.This was measured in the field using a portable meter.

3.3.11 Discharge/flow measurements

Stream/River discharge (Q) is the volume of water passing a cross-section per unit of time and is generally expressed as cubic meters per second (m^3/s). Discharge is velocity times cross-sectional area ($Q = VA$). Measurement of the area is determined by measuring the width and depth of the stream as illustrated in figure 1 below.



3.3.12 Water chemistry

Other water chemistry variables such as nutrients and inorganic ions were analysed from the National water and Sewerage Corporation (NWSC) laboratoryin Uganda. Some of the ions tested for included Alkalinity,Calcium, Fluoride, Magnesium, Phosphorous as phopshates, Total suspended solids, Alkalinity total, Hardness total, and Nitrates. Sample handling and preservation closely followed guidelines in Bartram and Balance (1996). Water samples for water chemistry analysis were collected from representative water sources of different types within the landscape and delivered to the laboratory for analysis.

3.3.13 Microbiological assessment

The E. coli tests and total coliform were carried out on water samples taken from the sites to assess the level of feacal contamination in the different water sources. The Coliscan Water Monitoring kit was used to carry out the tests.

Both water chemistry and microbiological analyses followed standard operating procedures and techniques following APHA (1992).

3.3.14 Inventory and geo-referencing of major water resources

Water resources surrounding and inside the two protected areas were surveyed. Field visits were made to developed and undeveloped water sources in the parishes surrounding the two PAs. Locations for water sources were geo-referenced using a hand held GPS unit (Garmin model 60CSx). At each water resource location, land use cover, distance to main roads, trading centers, homesteads and land use types were recorded.

3.3.15 Sampling design

i. *Sampling of streams and rivers*

Rivers were sampled following a longitudinal gradient from upstream to downstream but also taking into consideration the land use types along the river. For example, for a river that originates from a protected area, sampling was done inside the protected area, at the boundary and in community land where communities access the source.

ii. Sampling of wetlands/lakes

Wetland water sources are mostly standing or lentic sources. For wetlands with inflows and outflows, measurement was done at the inflow, middle, and outflow of the wetland.

iii. Sampling point sources

Point sources include protected and unprotected springs, boreholes, wells and ponds. For these types of water sources, measurements were done at representative water sources. We aimed to assess water quality from at least 30% of the water sources in a given parish.

3.3.16 Data analysis

The water quality of sources located inside protected was compared to that of sources located in community land. All water quality variables were compared to the National Portable water standards for Uganda to detect pollution and suitability for different uses. Charts and graphs were used to compare water quality variables from different water sources. Kriging interpolation was used to explore the spatial variation of the measured water quality variables. In order to assess seasonal variation in the measured water quality variables, a paired t-test was carried to test significance.

3.4 Hydrological systems assessment database

The main objective of the assignment was to design an Ms Access database to capture data from the survey on hydrological systems in the Great Virunga Landscape while minimizing data redundancy and improving consistency and integrity of the data.

3.4.1 Approach and methodology

The process of designing and building the database generally entailed the following tasks:

a) Reviewing project documents and methods outlines above
b) Creating an inventory of the variables that need to be tracked for subsequent analysis and information sharing
c) Unifying variables in categories and sections
d) Developing an entity-relationship model and schema for the database
e) Designing queries
f) Building the database
g) Training ITFC staff on the aspects of data entry, data editing, data query of the MS Access database

3.4.1.1 Review of Study documents

Relevant documents such as reports, presentations, checklists and questionnaire were reviewed in order to create an inventory of variables/data items for storage by the database.

3.4.1.2 Analysing Variables

Each data item was analysed carefully to determine its purpose, the type of data it stores (textual, numerical, or categorical), range of possible values, whether it is required or optional, whether it is an identification or informational variable, the scale at which it is to be measured (nominal, ordinal, interval, or ratio), among other things.

3.4.1 3 Organizing variables

Given the enormous kinds of data items that have been captured as shown in the methods above, the data was decomposed and organized into entities and their attributes. Relationships between data entities were also analyzed and modelled by identifying keys (primary and foreign) that were used to bridge the data entities.

3.4.1. 4 Developing database schema and entity-relationship diagram

The structure and organization of the database was formally presented by generating a database schema comprising of entities, their attributes, and relationships between entities. *An entity relationship diagram exists from the relationship icon.*

3.4.1.5 Designing system queries & reports

The database was designed to support running of relevant queries as will be deemed necessary in order to facilitate retrieval & mining of specific data sets for subsequent analysis and reporting on pertinent information requirements the client might require of the database. This can be accessed from the queries and reports icon on the database.

3.4.1.6 Building the database

The database was developed, programmed, and hosted using Microsoft Access Database Management System. The Structured Query Language (SQL) was used to generate Tables and Queries whereas the Visual Basic Access Programming Language to automate some database processes such as generating of queries.The database has a main dashboard and a series of tables and their relationships for data storage. In order to facilitate the data entry process, respective questionnaires, data entry forms/sheets were created each with various sections to capture different categories of data feeding into the tables. The database was created using the following questionnaires/datasheets as shown below:

a) Socioeconomic household surveys

The household survey forms included the following sections:

- Location/Background information
- Biographic data
- Water sources and access
- Water use, demand and supply
- Household and community water quality
- Water source management and governance systems
- Challenges in ensuring water quality/quantity
- Effects of poor quality and limited quantity of water
- Recommendations and strategies for sustainable water resource management

b) Water quantity/quality assessment form

This water quantity/quality survey forms included the following sections

- Background/location Information [parish, LC1, name of location
- Water source info [water-source name, type, eastings, northings, seasonality i.e seasonal or permanent, whether flowing, discharge, width, depth]
- Water quality [physical - color, turbidity, pH, taste, odor, conductivity; inorganical contaminants – arsenic (As), cadmium (Cd2+), Lead (Pb2+), copper (cu2+), etc; and microbiological variables]
- Quantity (cross-sectional area, volume stored, Precipitation, Surface-inflow, ground-inflow, evapotranspiration, surface-outflow, groundwater-outflow)

c) Field data observations Form

This forms included the following sections

- Location information
- Water management
- Observations on water demand
- Water sources in the location

A detailed user guide for the database has been attached to this report in the appendix

4. Results

4.1 Socioeconomic surveys

The socioeconomic survey results are presented in the context of key thematic areas that were investigated. This section presents data on demographic characteristics of the respondents, land use patterns around Mgahinga and Echuya as well as water sources and drainage systems in and around the two PAs. The section also presents local people's perceptions on water supply and demand, perceptions on water quality used by households and challenges of accessing water for household use.

4.1.1 Population and settlement patterns in S.W Uganda (Echuya and Mgahinga landscape)

Population density in this report refers to a group of people living in an area per square kilometer. It has been visualized to further describe the settlement patterns in the landscape. According to Uganda National Census (2014) findings showed that Kabale has a total population of 534,160 and Kisoro 287,179 people. This reveals that the two districts are densely populated compared to many other districts in Uganda. Mgahinga and Echuya are found in Kabale and Kisoro districts. The population around these two protected areas was indicated at the sub-county level. Murora and Muramba are densely populated compared to other Sub Counties around

Echuya and Mgahinga respectively. The population density around Mgahinga and Echuya increased from 123 persons per square kilometer in 2002 to to 174 persons per square kilometer (UBOS 2014). Parishes with the highest population density were Gitenderi around Mgahinga and Kacherere around Echuya (Figure 15 & Table 3).

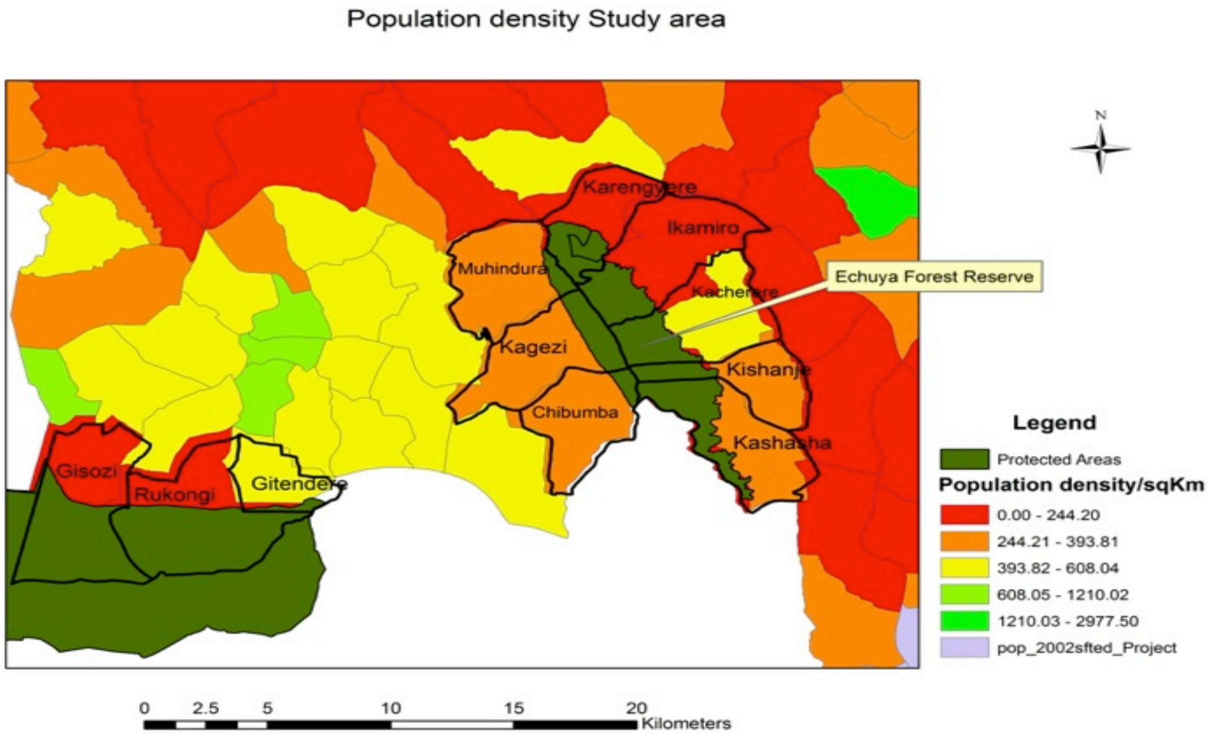


Figure 15. Population density distribution in and around Mgahinga and Echuya Forests-Uganda

Table 3: Population Density per parish (at 3.4% growth rate per annum)-Echuya and Mghahinga

District	Sub County	Parish	Population density (2002)	Current no. of households/ Parish	2014 average population/ household	Total population per parish
Kisoro	Kanaba	Kagezi	244.21 - 393.81	1273	4.7	5983
		Muhindura	244.21 - 393.81	1601	4.7	7524
	Murora	Chibumba	244.21 - 393.81	1741	4.6	8008
	Nyarusiza	Gitendere	**393.82-608.04**	2600	4.4	11440
	Muramba	Rukongi	0.00 -244.20	1574	4.3	6768
		Gisozi	0.00 -244.20	1739	4.3	7478

Kabale	Bufundi	Kashasha	244.21- 393.81	1376	4.5	6192
		Kishanje	244.21 -393.81	1012	4.5	4554
		Kacerere	**393.82- 608.04**	1394	4.5	6273
	Muko	Ikamiro	0.00 -244.20	1195	4.5	5378
		Karengyere	0.00 -244.20	1101	4.5	4955

Source: UBOS, 2002; 2014 and Local Council records, 2014

4.1.2 Demographic characteristics of respondents

4.1.1.1 Category of respondents

Four categories of individuals that constitute a household were identified during household surveys. A typical household in the study area constitutes of a husband (usually household head), a wife, children (child) and a household helper. The distribution of households heads interviewed in the study area is shown in Figure 16. From the figure, majority of interviewed household heads were men (husbands) who overall constituted 52% of respondents while the household helpers were the least and constituted of only 1%. A significant number of respondents were women and these constituted 42%. The interviewed women were either representing their husbands while away or were household heads themselves and/or were either widows or were not living with their husbands. The children/household helpers were the few individuals found at home during interviews when the household heads were away. The married men who were not at home during the interviews were said to have gone to look for jobs to distant places such as Kampala, Mubende, and Kibaale among other areas.

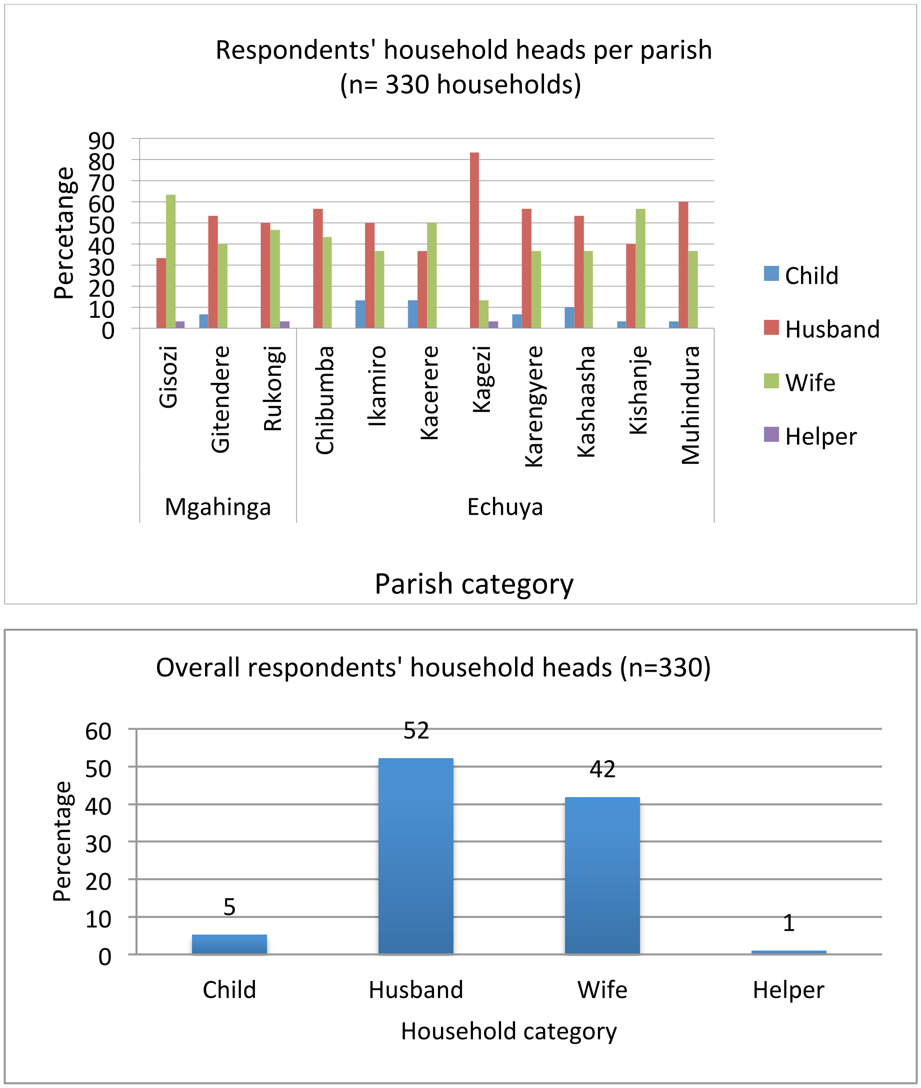
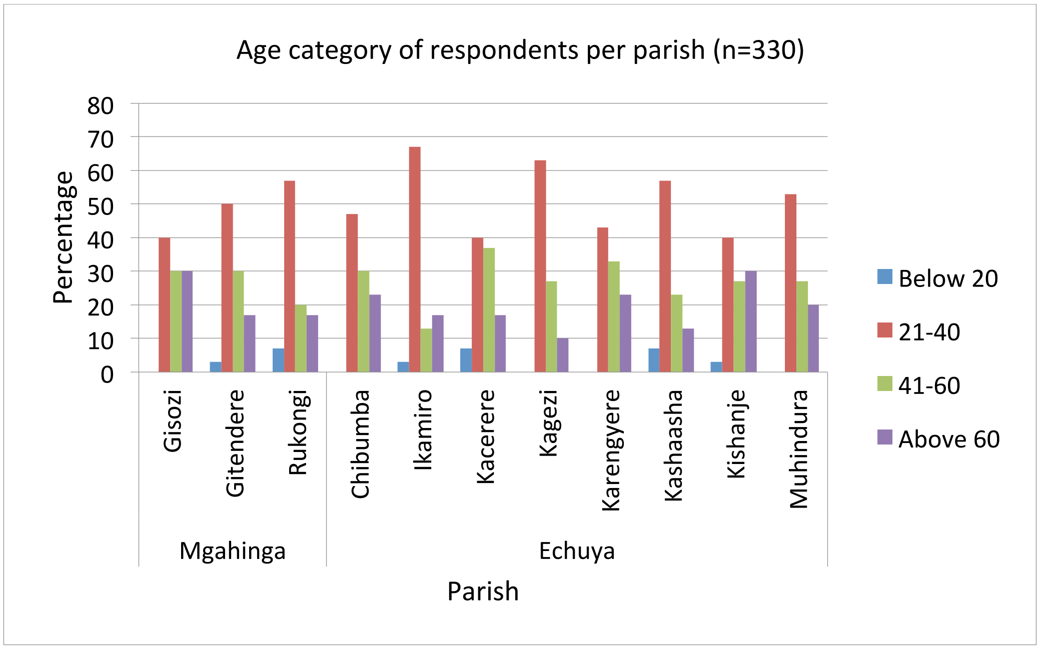


Figure 16. Categories of interviewed household respondents in the study area

4.1.1.2 Age group of respondents

Figure 17 illustrates age differences and distribution of the 330 respondents that were interviewed. Age is an important variable that informs the kind of responses one generates from respondents (Kumar, 1989). Age differences also impact on the way certain activities are done and the level of knowlege about the phenomenon under investigation. Respondents in the age category of 21-40 years old were the majority and these constituted of 51%; this is the category that is most active with household chores such as fetching water and farming. The least category of respondents was that of 20 years and below and constituted of 3%.



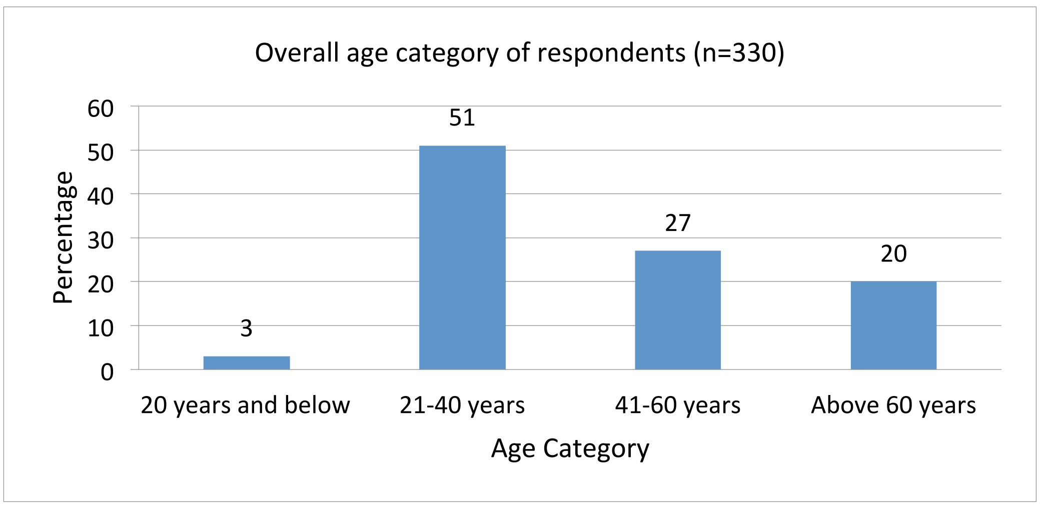


Figure 17. Age category of the respondents in the study area

4.1.1.3 Marital status of the respondents

The study related marital status of the respondents to water access and demand. This was premised on the assumption that, married people had big families compared to respondents that were not married (single) and this would therefore influence their level of demand for water. This also applied to widows or the divorced and that have limited labor for water collection since they will be involved in other livelihoods to maintain a home. Figure 18 shows that majority of the respondents were married and these constituted of 78% and the least were the cohabiting and single categories that constituted of 1% and 5% respectively.

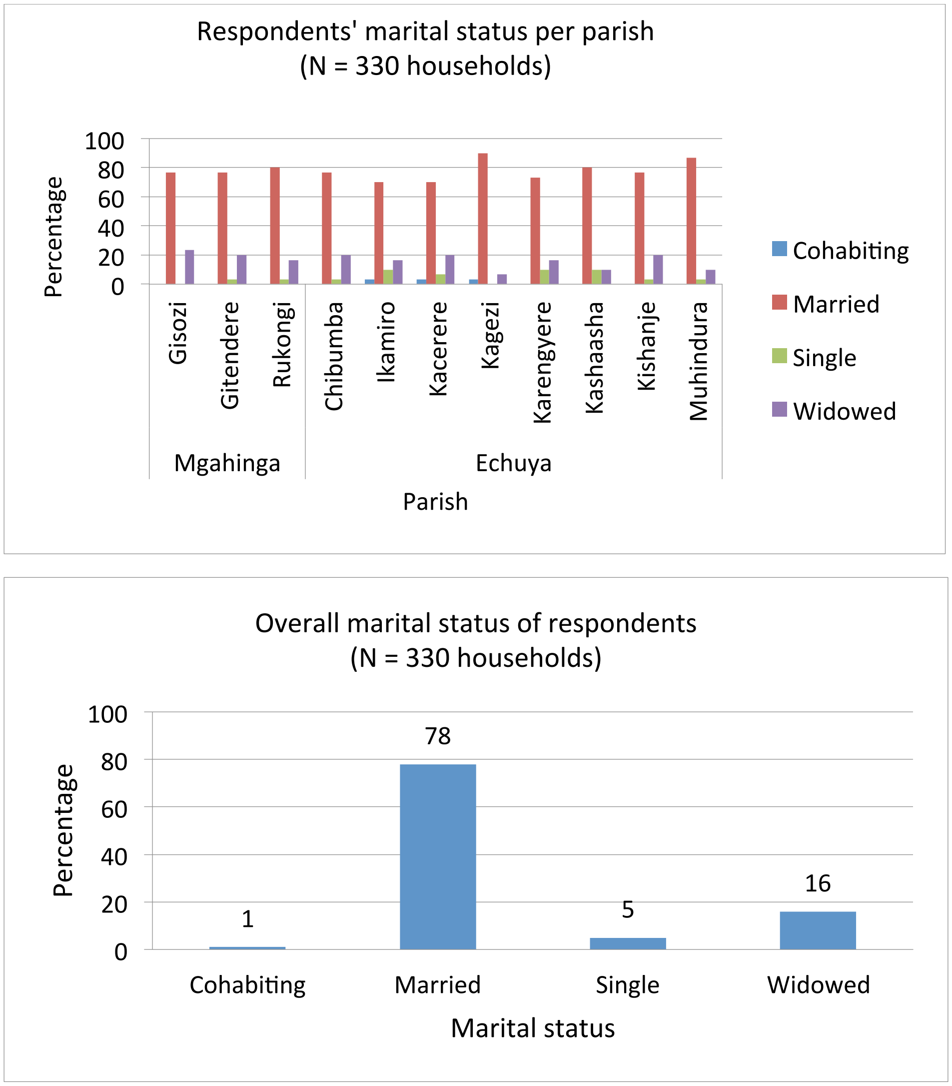


Figure 18. Marital status of respondents in the study area

4.1.1.4 Education level of respondents

Majority of the respondents (about 84%) had limited education (no formal education or had only primary education) as shown in Figure 19. Of these, only 49% had attended primary school and the rest had no formal education. Only fifteen percent of the respondents had attained secondary school education and no respondent had attained tertiary institution level of education. There were however differences in education levels among the study parishes. Mgahinga parishes' respondents had high illiteracy levels compared to those of Echuya. In Echuya, majority of respondents indicated that they had attained primary education compared to majority of the respondents around Mgahinga who had no formal education.

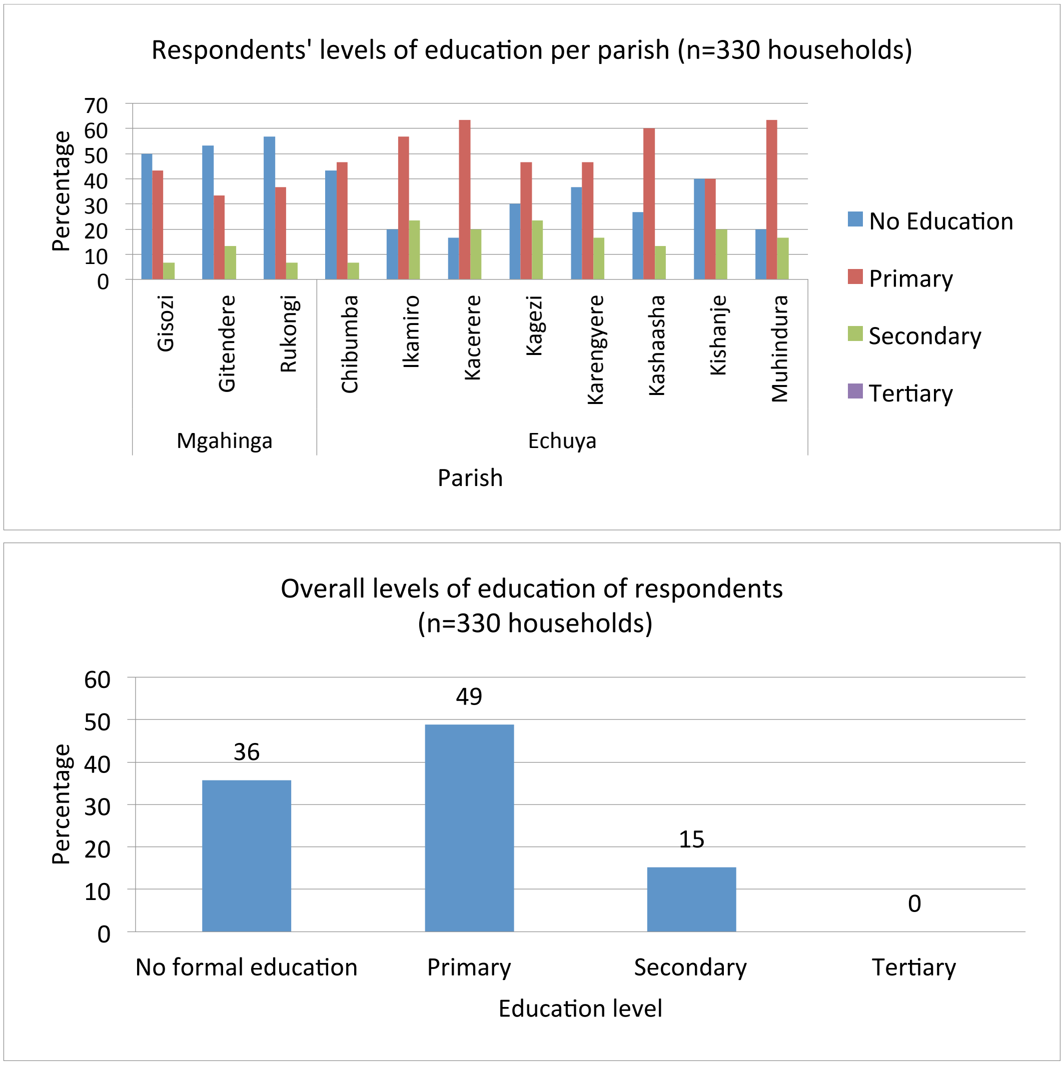
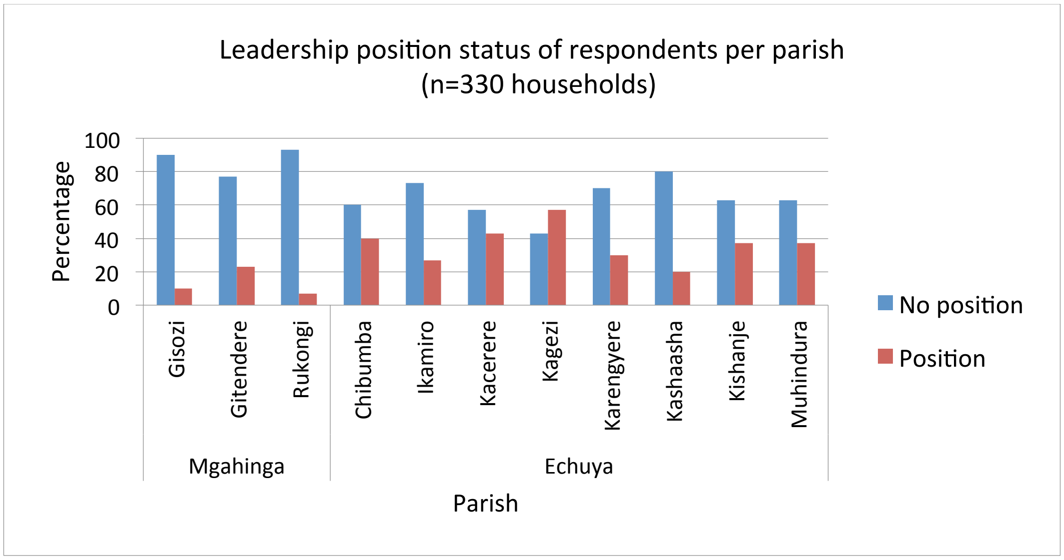


Figure 19. Levels of education of the respondents in study area

4.1.1.5 Leadership position of respondents

Responsibility and leadership position in society of respondents reflects a degree of influence one has on local community members. This is because responsibility opens gates for negotiations at both local and national levels. Categories of respondents'/responsibility and position in society included leaders of: stretcher groups (*engozi*), farmer groups, saving and credit society groups and Local Council governing members. Other responsibilities mentioned included being church leaders, project leaders and community opinion leaders. Figure 20 shows the distribution of respondents' leadership positions in society. From the figure, 30% of the respondents mentioned that they were in leadership positions among their societies. The 30% members of local community in leadership positions are adequate enough to influence policies and issues of water in the society. The local people in leadership positions were found to live in places that are easily accessible to water points and water sources compared to those without any status. These will also likely influence the water quality issues in society. It was not clear whether the status in community influences accessibility to water sources or those who are able and have a good social economic status in society are likely to be elected as leaders.



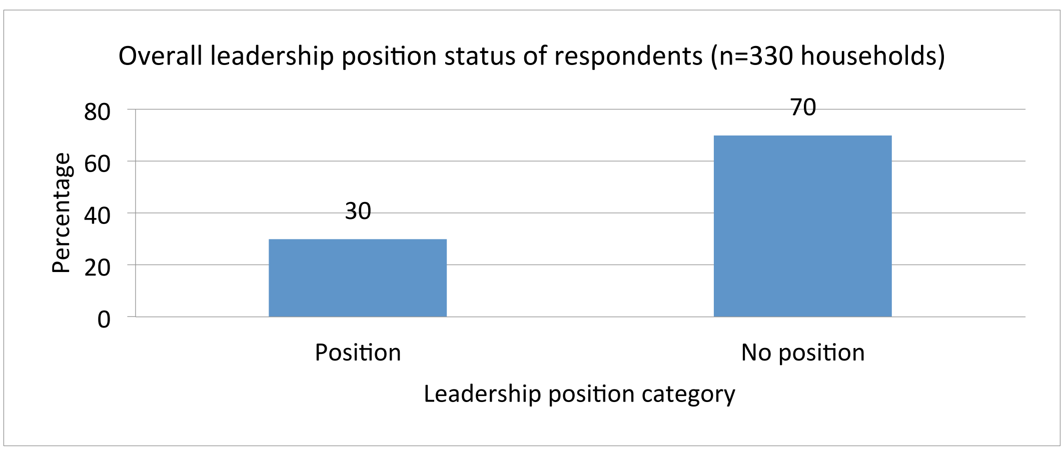
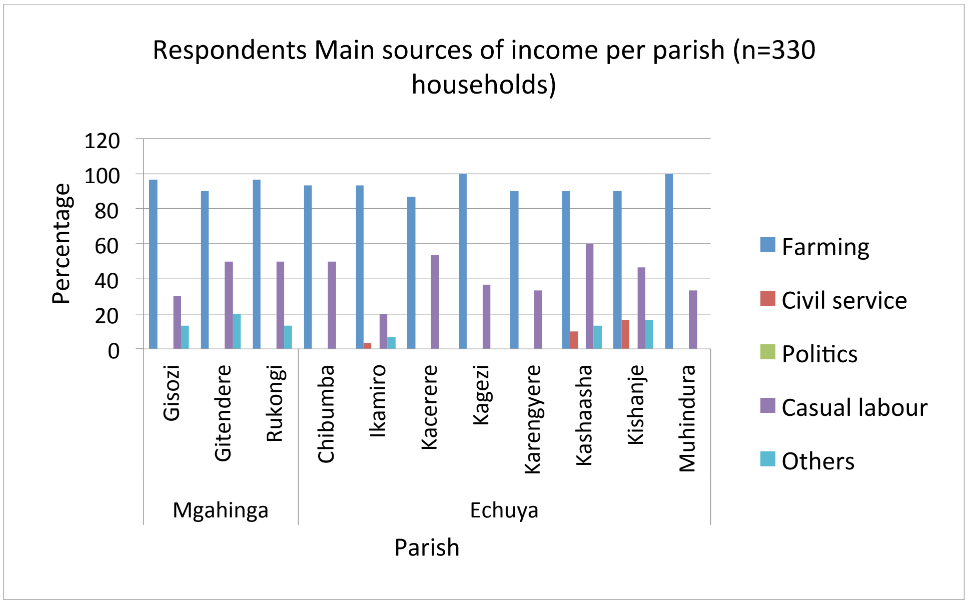


Figure 20. Leadership position status of respondents in the study area

4.1.1.6 Source of income of respondents

Various categories of income sources of respondents were predetermined prior to interviews through pilot surveys. These categories were: farmers, casual laborers, civil servants and politicians. The farmers were either subsistence or commercial farmers and carried out either/or both crop and livestock farming. Ninenty three percent (93%) of the respondents were farmers who depended largely on subsistance farming (Figure 21). The 8 parishes (Gisozi, Gitendere, Rukongi, Chibumba, Kacerere, Karengyere and Muhindura, did not have any civil servant among the respondents. A few civil servants were reported in Ikamiro, Kashasha and Kishanje parishes (Figure 21).



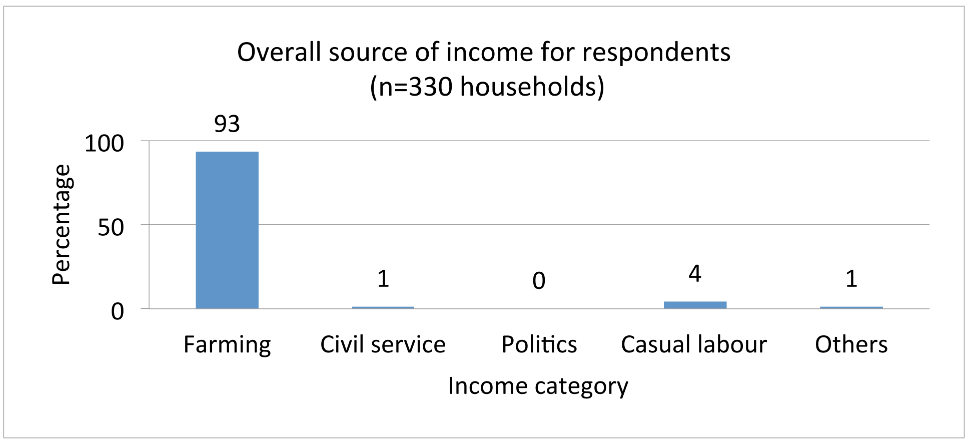


Figure 21. Sources of income and livelihood for respondents

4.1.2 Land use patterns and water access by the local people

Land use around Echuya and Mgahinga is responsible for the rate of soil erosion and flooding. In areas where farming methods are poor, there were elements of high surface run-offs and soil erosions. This was ascertained by establishing the most common and widespread land use patterns in the parishes neighboring the two Protected Areas. Figure 22 shows the type of land use practiced in the study area and the frequency the respondents mentioned them across the eleven parishes. From the figure, the most common type of land use as reported by respondents was arable farming and this was mentioned by 86% of respondents. Arable farming, livestock keeping and woodlot are three most prevalent land use patterns practiced around Echuya and

Mgahinga as Figure 22 shows. Agricultural practices around both Mgahinga and Echuya have changed over years. Most people have discarded the traditional land use practices that involved terracing, bush fallowing and planting of hedge crops. Most of the arable farms that we observed did not have provisions for soil erosion prevention. There was evidence of sheet and rill erosion as well as the deep gullies as a result of sediment run-off during the wet season periods. Local residents revealed that when it rains, crops are washed away due to poor land use practices. The poor agricultural practices are responsible for the current soil erosions observed on the steep slopes in the study area. The soil erosions have led to flooding of valleys and rivers and therefore contributed to poor quality water for domestic use as reported by most respondents. This was very common in Mgahinga parishes of Gitendere and Rukongi. It was also mostly reported in the steep areas of Chibumba and Karengyere parishes around Echuya in Kisoro district.

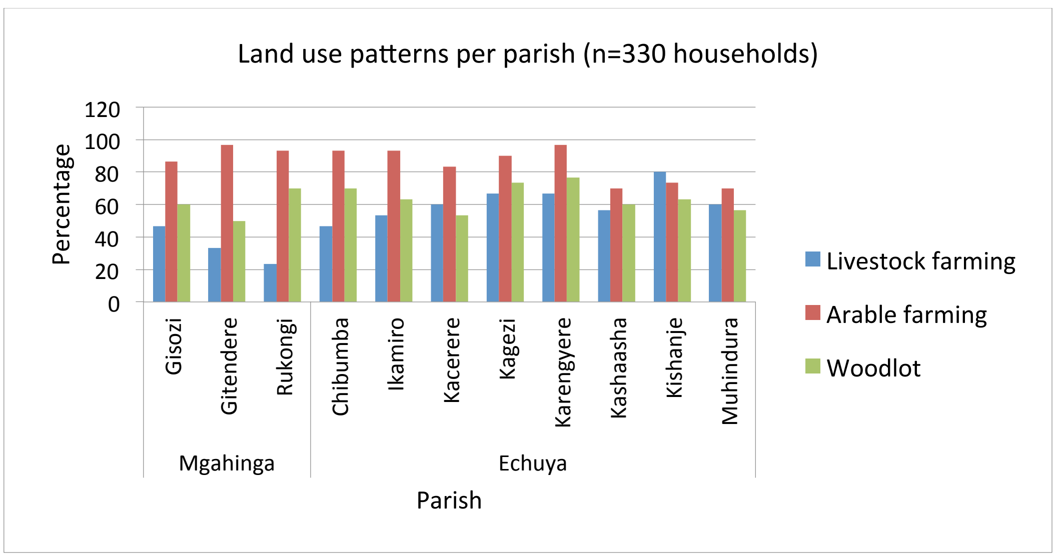
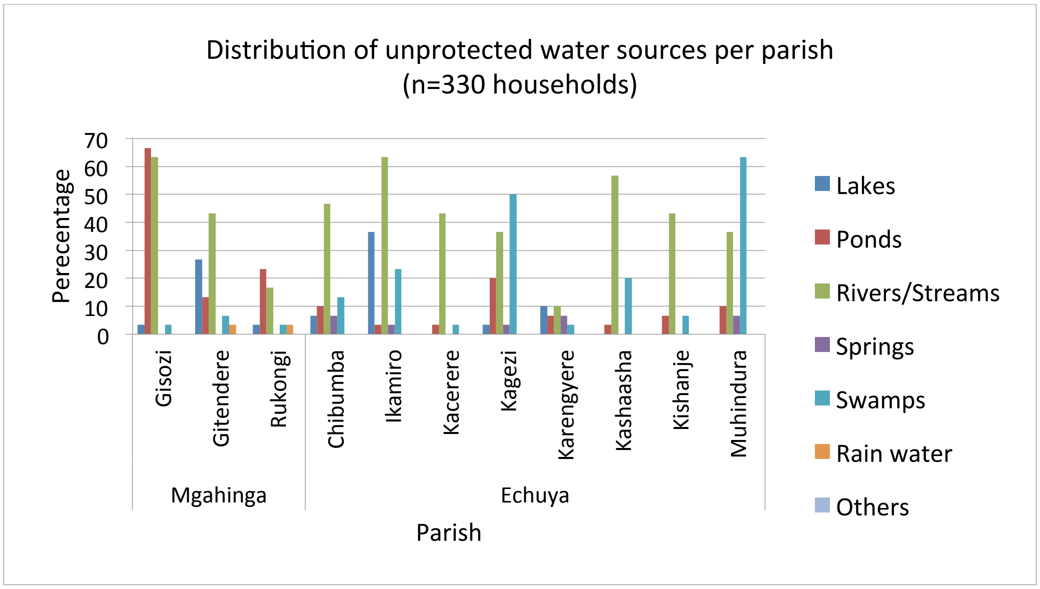


Figure 22. Land use patterns as reported by respondents in the study parishes

4.1.2.1 Source of water for household use

Respondents mentioned water sources for household use and these were grouped into unprotected and protected water sources. Results show that the unprotected water sources were the main sources of water for the local people around the study area. These sources were; permanent and seasonal rivers, ponds, swamps, lakes and dams. There were other water sources that included other water channels such as reservoirs. Figure 23 shows how respondents ranked the unprotected water sources that are important to them. Majority of the respondents collected water from rivers (42%) followed by swamps (18%) and ponds (15%). These were mainly respondents neighbouring Echuya forest. In Mgahinga, the unprotected water sources such as rivers, lakes and ponds were not common. In Echuya, the rivers were reported to be the main water sources in the parishes of Ikamiro, Kashaasha, Chibumba, Kishanje. This was also true for Gitenderi Parish in Mgahinga (Figure 23). In parishes of Muhindura, Kagezi of Echuya, the main water sources were the swamps whereas Gisozi and Rukongi of Mgahinga the main water sources were ponds. Karengyere parish of Echuya reported lakes as the main unprotected water source.



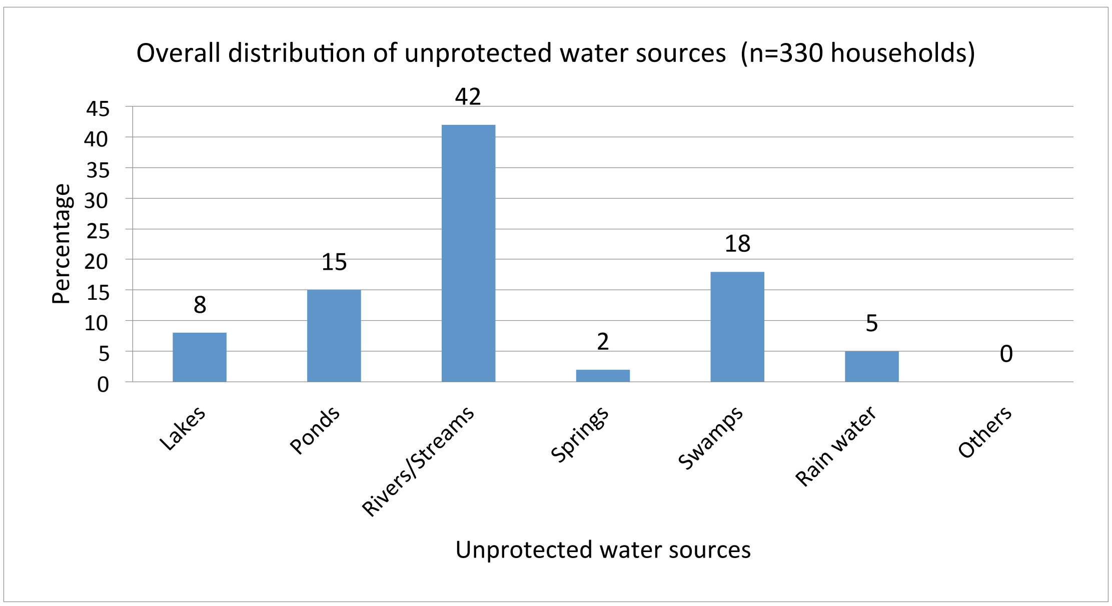
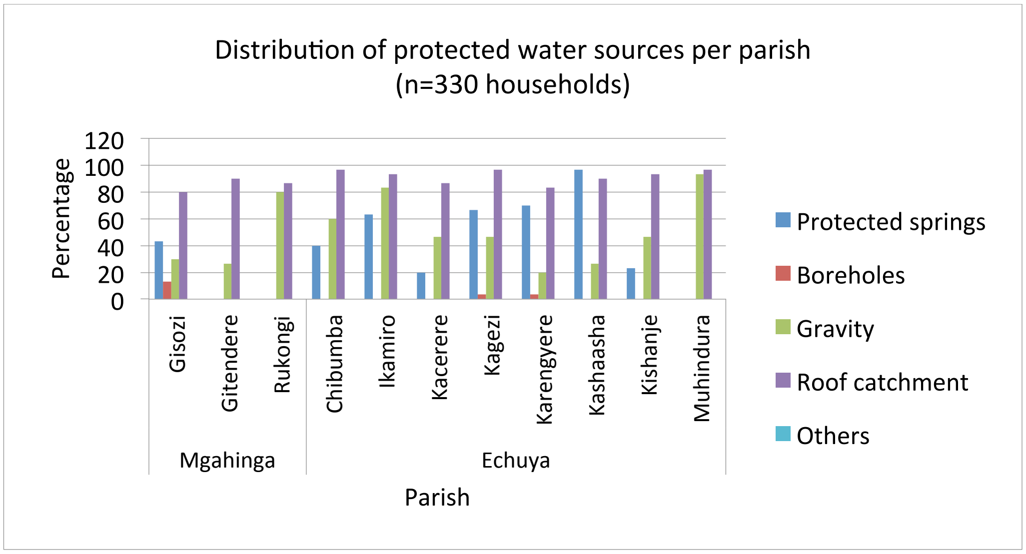


Figure 23. Distribution of unprotected water sources in Mgahinga and Echuya.

The protected water sources mentioned by the local people included water springs, gravity water schemes, boreholes, and rain water roof catchments as shown in Figure 24. The major sources of domestic water from protected sources used by the local people were the rain water roof catchments (50%), gravity schemes (28%) and protected springs (21%). In Mgahinga parishes (apart from Rukongi and Gitendere), the main souce of water for domestic use were from protected water sources. Most respondents from Mgahinga parishes depend on protected water sources that have been installed by government and other development organisations and these included gravity water schemes and rain water roof catchments. The rain water roof catchments included community tanks, household tanks, water jars and protected taplines. The use of protected water sources in Mgahinga more than in Echuya is attributed to a few available permanent water sources and the seasonality of other water sources in the landscape. In Echuya, apart from Kashaasha parish which reported protected springs as the main water source, other parishes across both landscapes reported roof catchments.

Gravity water flow schemes are not well distributed within the parishes. Much as efforts have been made to extend gravity water flow schemes to all parishes around Mgahinga and Echuya, some villages do not have gravity water schemes. Some gravity water schemes were found to be dysfunctional. This was attributed to poor management. The most covered parishes with gravity water flow schemes were: Muhindura, Kishanje, Ikamiro, Rukongi and some communities in Chibumba, Kagezi, Kacerere and Kishanje. Only a few sites in Gitendere, Karengyere, Kashaasha, and Gisozi are supplied with water from gravity water flow schemes. There were limited boreholes observed and reported in Gisozi, Kagezi and Karengyere. Lastly, no protected water springs were reported in Gitendere, Rukongi and Muhindura.



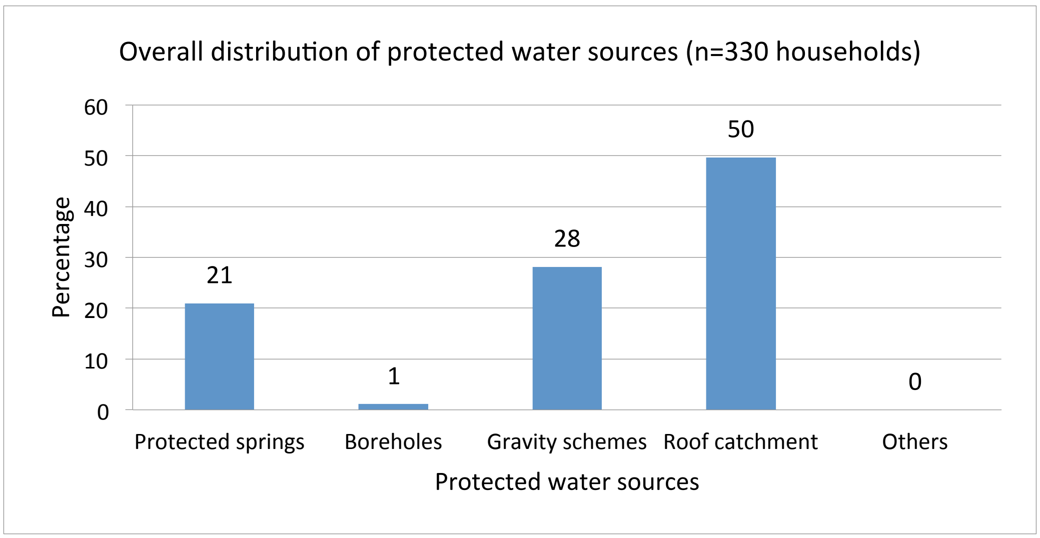


Figure 24. Distribution of protected water sources in Mgahinga and Echuya

4.1.2.2 Water use, demand and supply

All respondents reported the major use of water in households was for majorly domestic use (house chores, cooking, drinking, washing and bathing). Other reported water uses were for watering livestock and irrigation of crops. The use of water for irrigation and livestock watering was not reported to be a major water activity in the households. This was attributed to limited water supply especially and limited engagement in commercial farming (both crop and animal farming) by households.

Respondents also estimated the amount of water they use for their household chores. Figure 25 illustrates the estimated usage of water per day by households as reported by respondents. From the figure, majority of the respondent said they used 1-3 jerricans of water per day for their household chores while the least said they used over 10 jerricans of water per day. A jerrican contains about 20 litres of water, this therefore implies that majority of households used a minumum of 20 litres of water per day and a maximum of 60 litres of water per day for their household chores. The few respondents who reported using above 10 jerricans of water per day (200 litres) could be those engaged in arable and livestock farming and therefore used the water for watering animals and crops. Family size, proximity to the water source and water availability also determines the amount of water a household uses. Other probable high uses of water could be for commercial purposes such as brewing local beer for sale. Parishes with households that reported more use of water for domestic purposes (10 jerricans and above) were Gitenderi (Mgahinga), Ikamiro, Kagezi, Karengyere and Kashasha (Echuya). Houseolds around Echuya forest therefore use more water for domestic purposes than those around Mgahinga.

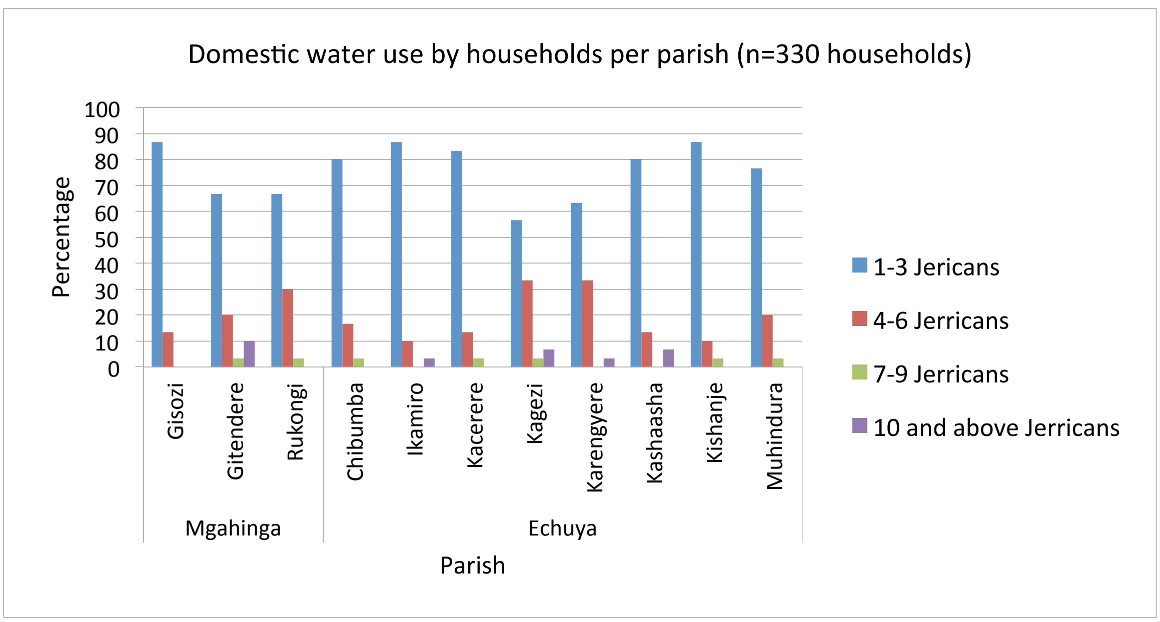


Figure 25. Reported amount of water used by households for domestic use

Few households, reported use of water for livestock watering (14 households) and arable farming (26 households). Of these, most households reported that they used about 1-3 jerricans of water for livestock watering per day (Figure 26). Furthermore, most households reported that they needed about 1 to 6 jerricans of water to irrigate their crops (Figure 27). Therefore water needed by each household in Mgahinga and Echuya to water livestock ranges between 20 to 60 litres while that needed to irrigate crops ranges between 20 to 120 litres. Parishes with households that reported more use water for livestock watering (10 jerricans and above) were Gisozi and Rukongi (Mgahinga), Kagezi and Karengyere (Echuya). In areas where livestock farming is practiced, households rear an average of 3 livestocks across all the mentioned parishes.

Overall, the results show that water use in the study area is very minimal (only 1-3 jerrycans per day). This nevertheless does not reflect people's demand for water but what is currently available for household use. Respondents attributed the low use of water to water scarcity and distance to water sources. Water use in the household is always highly regulated due to its scarcity and therefore the reported low volumes consumed by households. Furthermore the water taps in the gravity water schemes are regulated by the water tap committees that open the taps at specific times of the day. This shows that if people had other options of having plenty of water, the amount used would increase in each household. There is also a tendency to observe differences in water usage during the dry and wet seasons. During the wet season, the usage of water for homestead chores is quite high compared to the dry season when it is used sparingly.

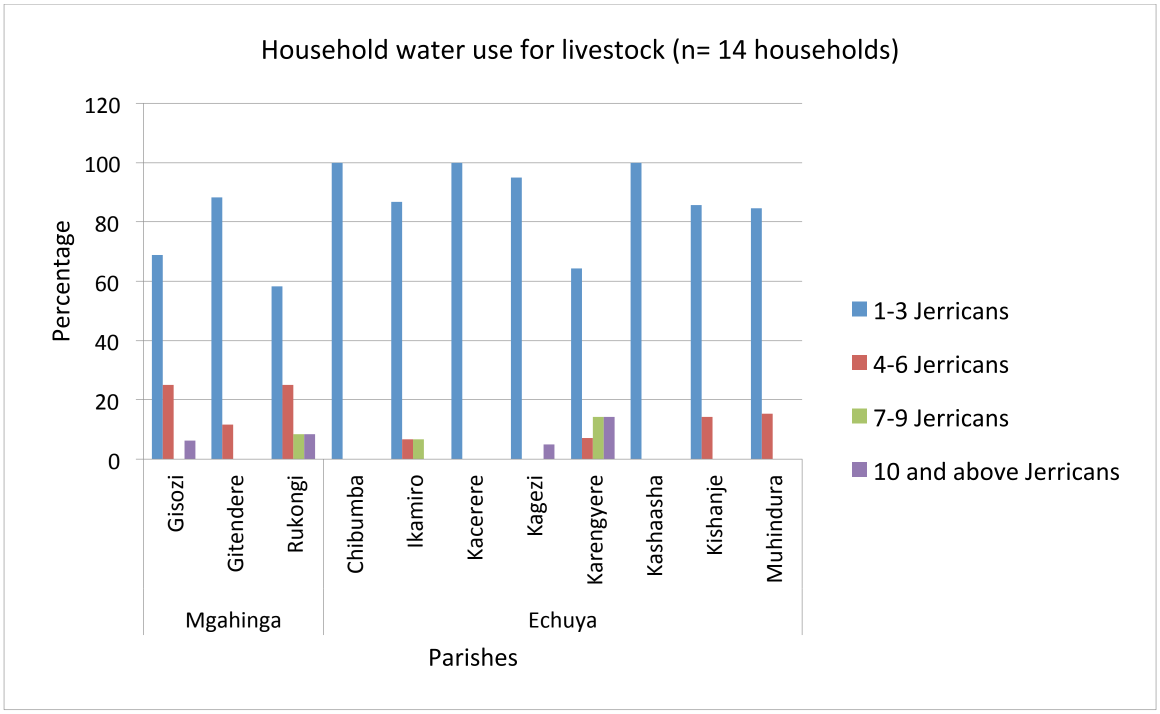


Figure 26. Household water use per parish for livestocks in Echuya and Mgahinga

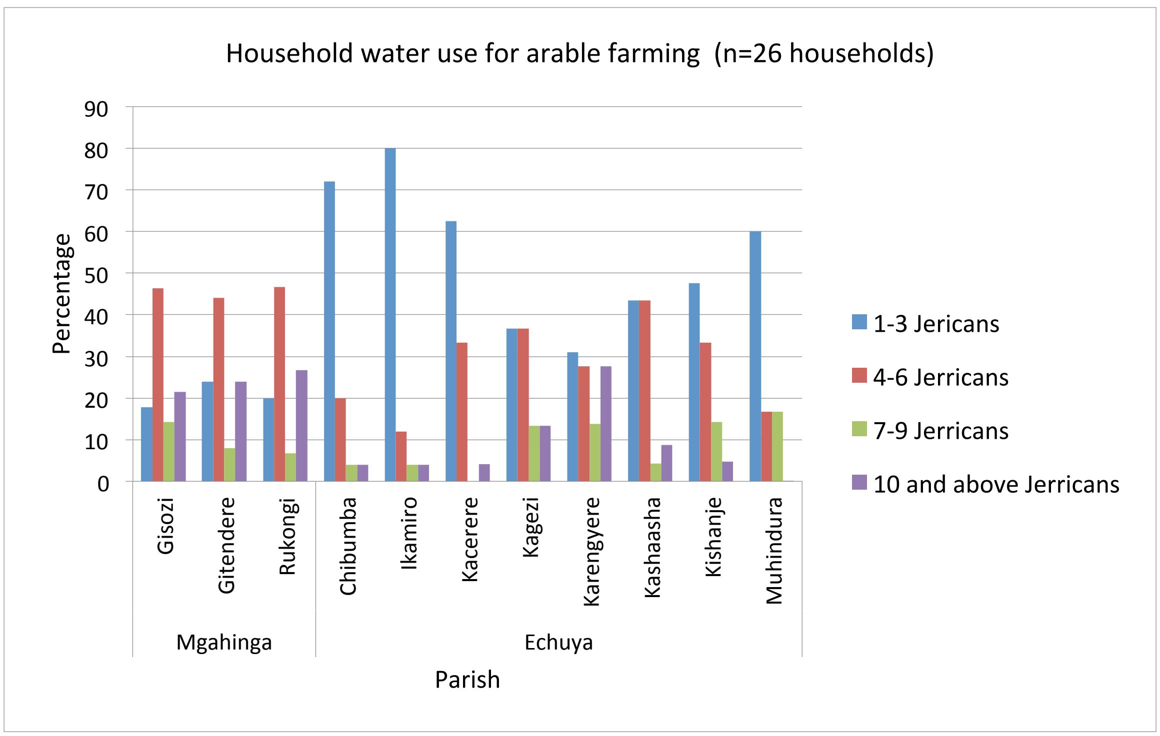


Figure 27. Household water use per parish for arable farming in Echuya and Mgahinga

4.1.2.3 Gender distribution of labour for water collection

This study established the division of labour among household members for accessing water at water sources. The categories identified from the pilot study included children, labourers, men alone, both men and a women, water vendors, women alone, women and children. This was intended to establish the existing gender relations and gaps that may be affecting household water use issues

Figure 28 shows the gender relationships and division of labour by households for fetching water for domestic use. According to the respondents, water for homestead use is mostly collected by children and women and these constituted of over 90% of the respondents. Of these 34% are children alone, 26% women alone and 28% both women and children a small percentage (4%) constitutes of both women and men (Figure 28). Differences however exist in areas where men completely do not participate in water collection. In parishes such as; Gisozi, Gitendere, Kashaasha and Chibumba, men do not participate in water collection at all. Results show that children and women are the main source of domestic labour for water collection. Result therefore reveal gender disparities in terms of water access. This gender gap narrows a bit around Mgahinga where the issue of water buying and selling came up strongly during all the Focus Group Discussions. This was attributed to limited water sources and distance covered to access water. Although the women and children are the major source of labour for water collection, it has has been already noted above, that the men are the ones involved in leadership positions and therefore are responsible for making decisions to do with water usage in a community.

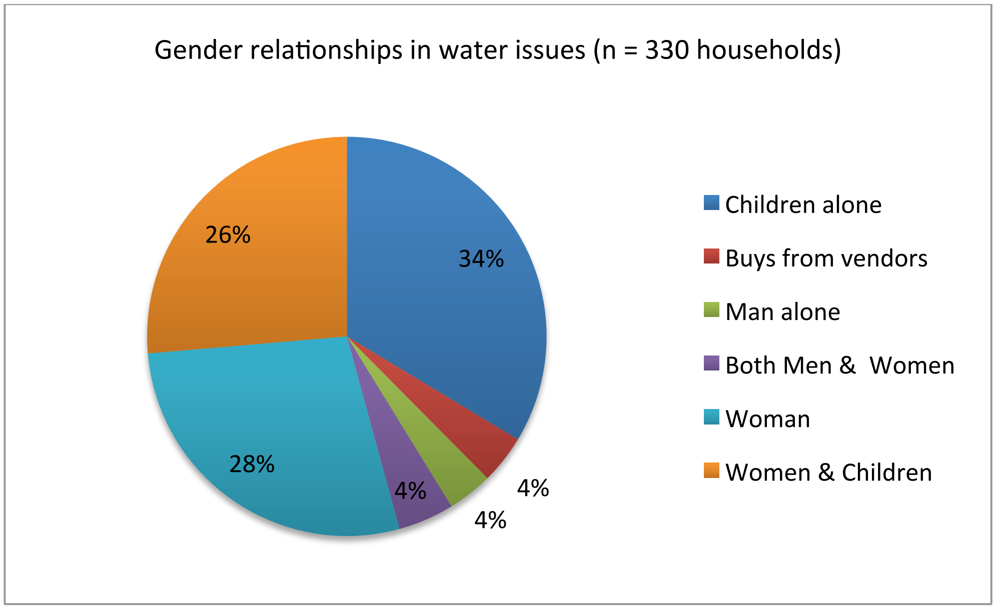


Figure 28. Overall gender relationships and division of labour for water collection in study area

4.1.2.4 Distance travelled to access water source

The distance covered by household members to access water from households was also determined. This was measured in terms of the perceived time it takes for members of the households to fetch water for domestic, livestock and arable farming. However, much attention was given to water used for domestic chores. Figure 29 shows the responses on approximate distances to water sources by household members in both Echuya and Mgahinga. Generally, most respondents indicated that they took over 30 minutes to access water for household use with 37% indicating that it took them over 1 hours to access the water points. This implies that for most households, water access points are located very far away from households. Members of households living adjacent Echuya and Mgahinga landscape therefore cover long distances to access water. Results further indicate that, residents in Mgahinga landscape travel longer distances to fetch water compared to those of Echuya. In order to overcome long distance travels to access water, some residents have opted to go into the nearby Mgahinga National park and Echuya forests to access water in the rivers found there, see plate 1 for such river. However such entry into protected areas often results in illegal activities such as poaching and wild plants collection by the local people.

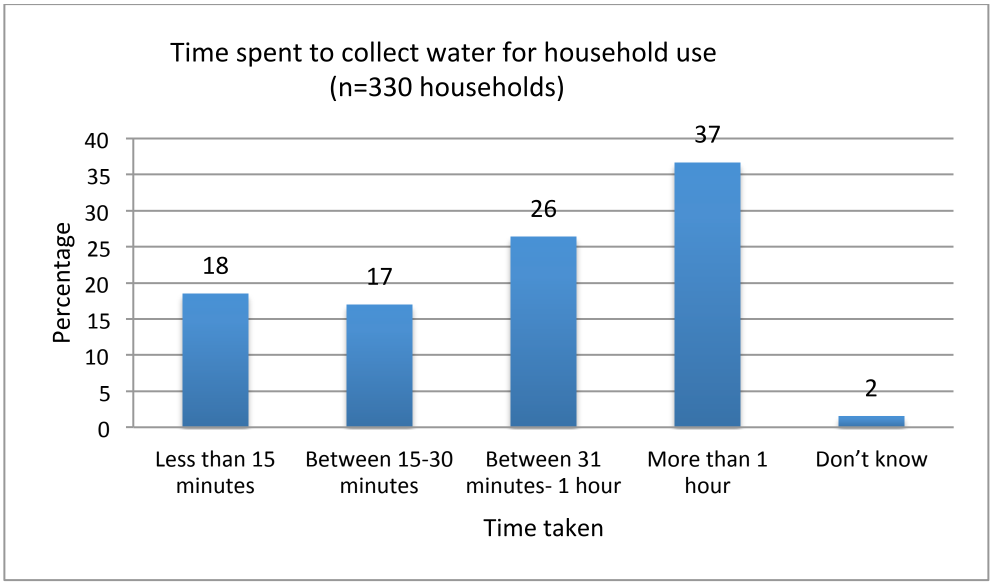


Figure 29. Distance walked by household members to water point sources in the study area

Plate 1: Ntebeko seasonal river water bed inside Mgahinga National Park, such rivers are important water sources for local communities especially during dry season spells

4.1.2.5 Household and Community Perceptions on Water Quality

The perception of respondents on water quality was based on their visual outlook on water color and presence of dirt or suspended particles in the water. Three categories of water quality were identified: clean/safe water, fairly clean water and dirty water. As mentioned previsouly, water for household use was for domestic use (cooking, drinking, bathing and washing), livestock watering and crop irrigation purposes. Figure 30 shows a general perception of local people on water quality used by households adjacent Echuya and Mgahinga forests. Water for domestic use was percieved by the majority (55%) to be generally clean and safe for use while the least (15%) thought the water was dirty and not good for human consumption (Figure 30). On the other hand, water for livestock watering and crop irrigation was percieved by the majority to be dirty and unsafe for human consumption. Only less than 27% of the respondents thought the water was clean and safe for human consumption. Respondents attributed the safe and clean water for domestic use to permanent clean water sources available near households and availability of roof catchments to tap rain water that is considered clean.

Local people's clean water perception was attributed to the permanence of some clean water sources, use of rain water harvest systems and gravity flow schemes in the study area. Households with/near these clean water schemes are likely to perceive water to be clean than those without or far away from the souces. The use of dirty water was attributed to occassional rain water run-offs during the rainy seasons in high altitude areas that also result in floods and soil erosions leading to siltation of rivers and ponds (Plate 2). Most parishes reported using dirty water for crop irrigation and livestock watering during focussed group discussions. Respondents mentioned that arable farming and livestock watering does not need clean water.

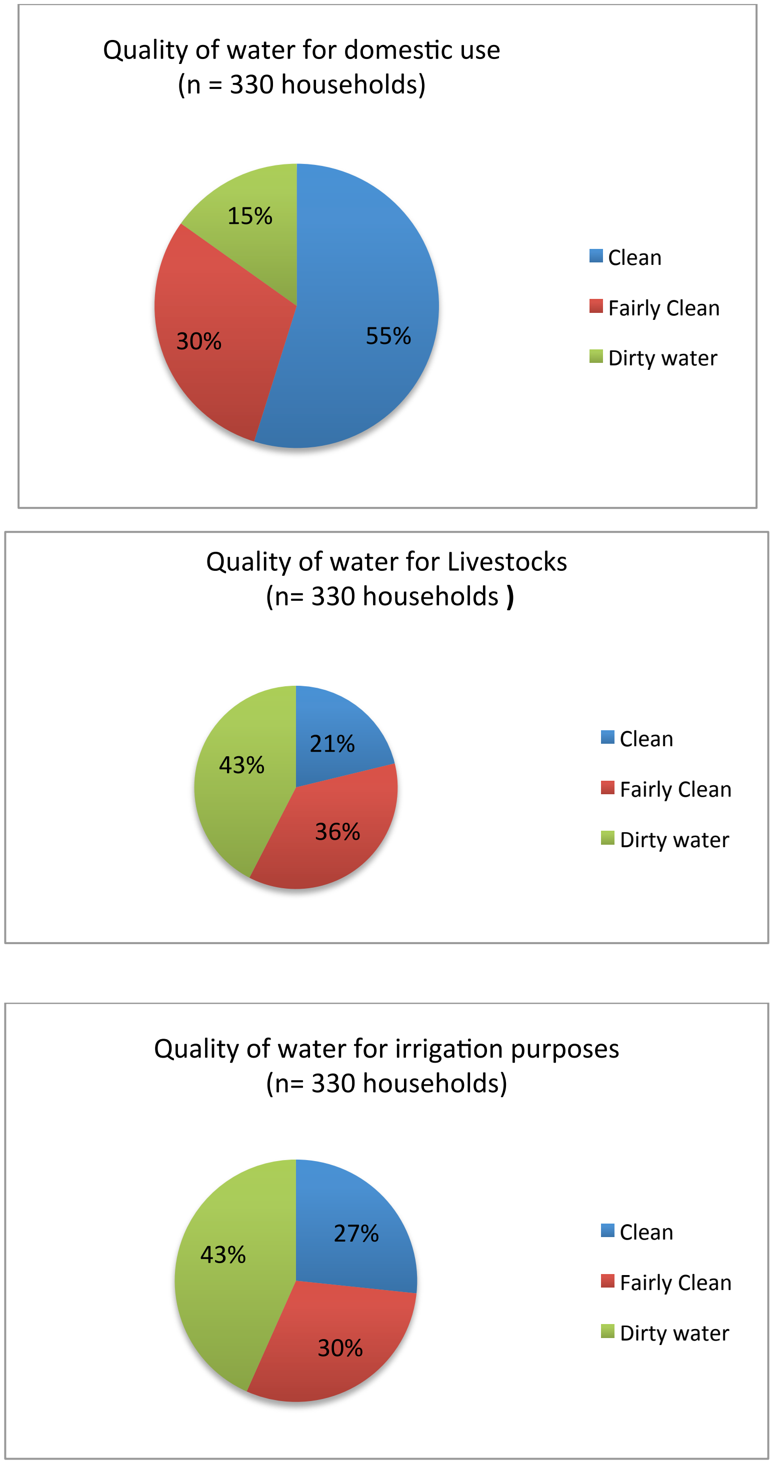


Figure 30. Perceptions of respondents on the quality of water used by households

Plate 2: Water silting as a result of soil erosions and floods around Echuya forest

4.1.2.6 Water treatment for domestic use by households

Majority of respondents (51%) claimed to use water boiling/cooking as the main method for water treament used by household whilst the least (1%) claimed to use sun drying as the main method of water treament (Figure 31). None of the households used the conventional methods such as use of chlorine tablets, use of water filters etc for the treament of water. They claimed that they were not able to afford the convetional water treament methods. The limited methods of water treatment were attributed to limited sensitisation and awareness and lack of time to treat water. Other respondents thought that treated water tastes stale to drink and that water does not need to be treated. The local people are around Echuya and Mgahinga are therefore highly vulnerable to water borne diseases as a result of limited methods of water treatment.

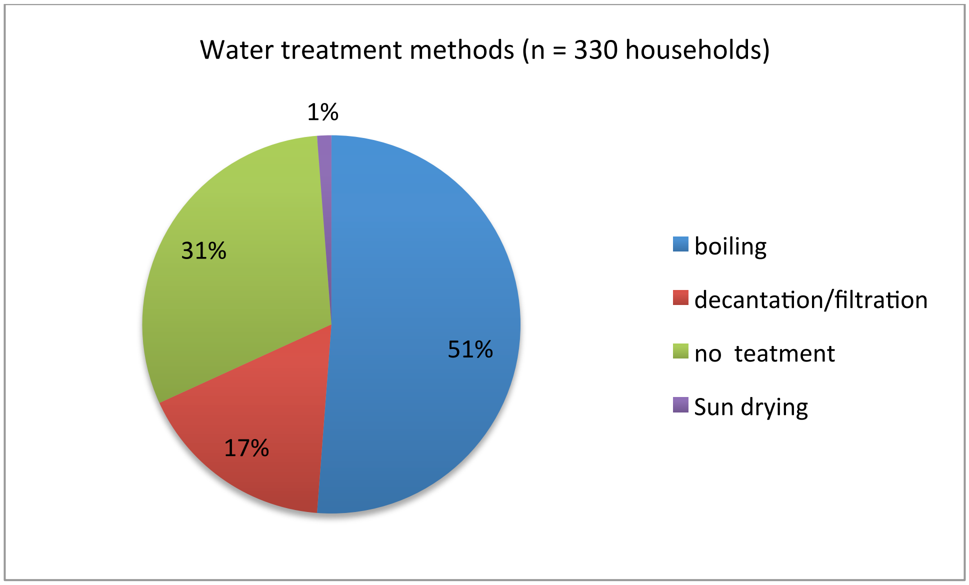


Figure 31. Main methods of water treatment in households around Echuya and Mgahinga

4.1.2.7 Management of water resources

The study looked at the management of water resources around Echuya and Mgahinga protected areas. This was intended to ascertain whether local communities and their leaders are well organized to address water related challenges and how water scarcity and quality have affected households living around the two PAs. Various stakeholders engaged in water supply and management around Echuya and Mgahinga were identified during the focused group discussions. These were Church of Uganda, GVTC, Uplift the Rural Poor (URP) and the International Gorilla Conservation Programme (IGCP), others were the Kisoro and Kabale District Local Governments.

4.1.2.8 Challenges in water use by households

Majority of the people interviewed and those who participated in Focus Group Discussions revealed that there is constant blockage of water sources especially during the rainy seasons particularly between the months of August to October. This is as a result of flooding and soil erosions as mentioned previously above. Other constraints cited included;

- Limited water storage facilities at household level
- Congestion at water sources and points while fetching water
- High costs of buying water from some water points. During the dry season, a 20 litre jerrycan of water costs UGX 1000-2000 around Mgahinga

- Poor quality of some water sources (with dirty water)
- Insufficient water supply at some water points,
- Limited water harvesting containers
- Competitions of water on some water points by humans and livestock
- Long spells of dry seasons that lead to drying up of some water sources, it was reported that water levels go very low during dry seasons that most water sources and points drying up in the month of July.
- Increased human populations that have increased the demand for water yet water supply is reducing

Plate 3. An example of a poor water source (seasonal) near Echuya forest.

4.2 Hydrological modelling of floods and landslides

4.2.1 Surface runoff

Surface runoff varied between 793 mm to 1302 mm of rainfall around the Echuya landscape. Figure 32 represents the spatial variation of surface water runoff across the parishes surrounding Echuya Forest reserve while Figure 33 shows how surface runoff varied across the sub-watershed level of Echuya forest.

Surface water runoff was lowest within the forest boundary but increased from the forest edge to local community lands, this demonstrates the significance of vegetative cover in controlling surface water runoffs. The model output indicates that, Muhindura, Kagezi and Chimbumba parishes are likely to be at higher risks of floods than the parishes of Karengyere, Ikamiro, Kacherere, Kishanje and Kashasha (Figure 31).

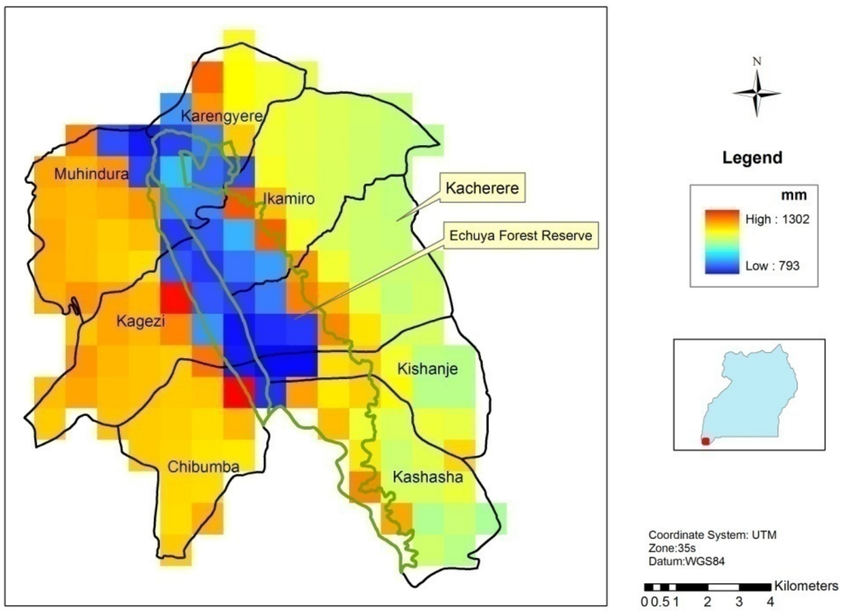


Figure 32. Runoff map for Echuya Central Forest Reserve Landscape, Uganda, by Parish

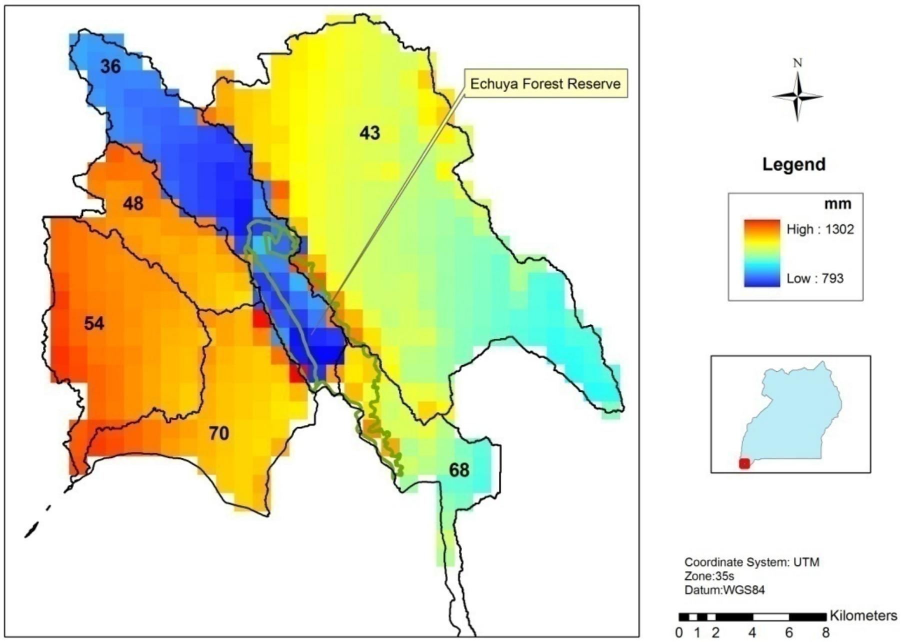


Figure 33. Runoff map for Echuya Central Forest Reserve Landscape, by watershed

Figure 34 illustrates the spatial variation of surface water runoff across the parishes that surround Mgahinga Gorilla National Park while Figure 35 illustrates spatial variation of surface water runoff at sub-watershed level of Mgahinga. The model output illustrates that; surface water runoff is highest within the park boundary compared to the surrounding areas. This could be explained by the high rate of change in elevation within the park boundary, with slopes greater than 30%. Using runoff as an indicator of the risk of flooding, for the local community areas, Rukongi and Gisozi parishes are likely to be at higher risk of floods than Gitenderi.

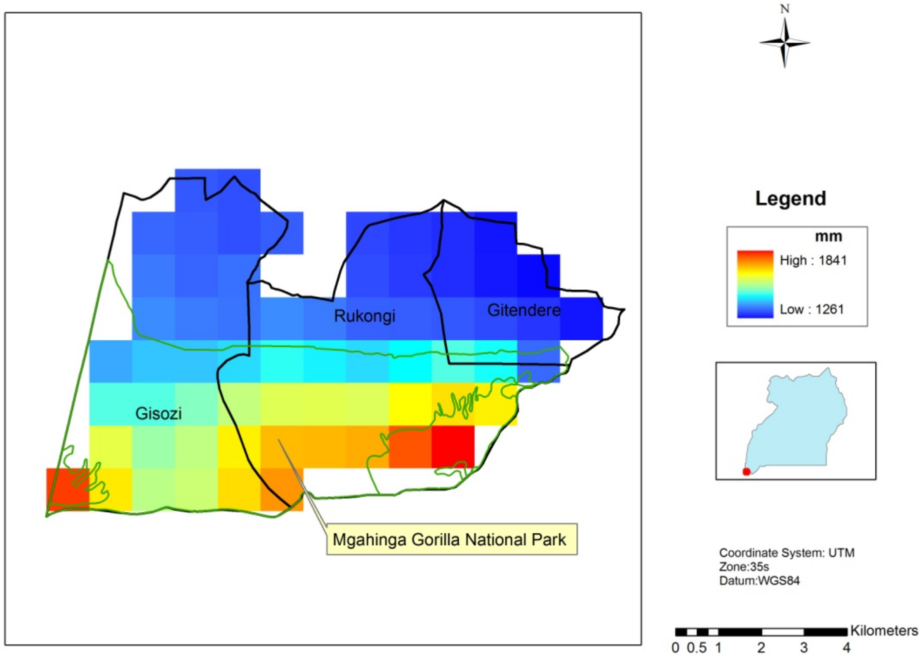


Figure 34. Runoff map for Mgahinga Gorilla National Park Landscape, Uganda, by parish

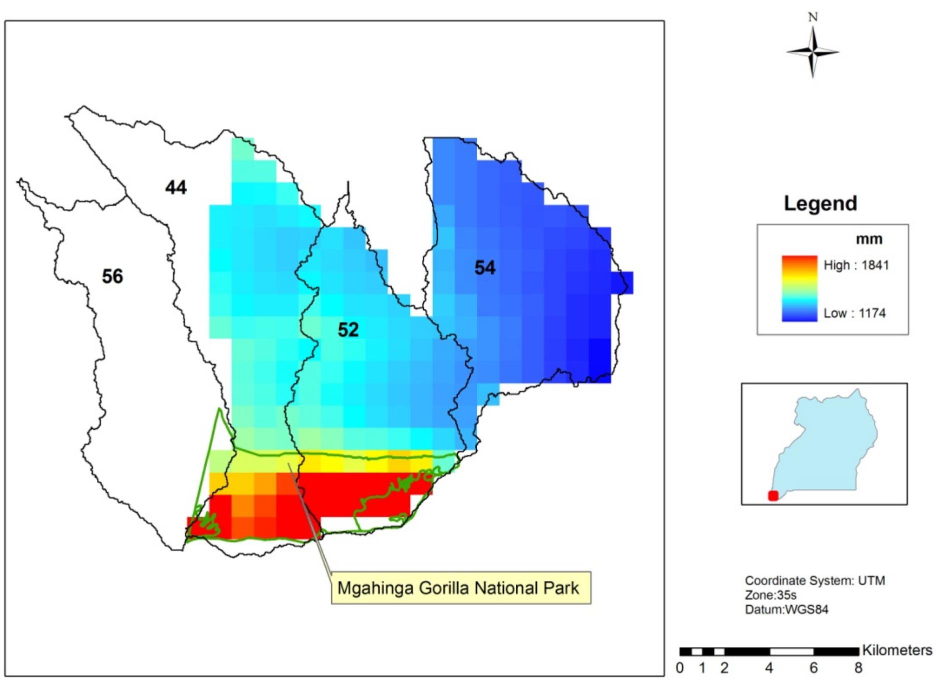


Figure 35. Runoff map for Mgahinga Gorilla National Park Landscape, Uganda, by watershed

4.2.2 Soil erosion mapping and risk assessment

Parishes surrounding Echuya landscape were evaluated for soil erosion risk, considering tolerance limits (3 to 11 t/ha/yr) that define the maximum acceptable level of soil loss from an area (Mhangara *et al.*, 2011; El-Swaify *et al.,* 1982). Percentages of the areas affected by soil erosion per parish were computed for the Echuya landscape and the outputs are shown in Figures 36 and 37. From the two figures, Kagezi parish with an area of 24 km^2 (about 20.8%) of the area, Chibumba parish with an area of 16km^2 (about 18.8%), Muhindura parish with an area of 22 km^2 (13.6% of the area) and Karengyere parish with an area of 16 km^2 (12.5% of the area) all experience soil erosion above the acceptable tolerance limit. The above values however indicate moderate levels of soil loss in the landscape. For Ikamiro, Kacherere, Kashasha and Kishanje the soil loss was below the tolerance limits. This might be due to lower elevations and slopes, and firmer soils (with clay particles) than the other parishes. Furthermore this might also suggest that the local communities around these parishes may be practicing soil conservation practices such as agroforestry and the establishment of woodlots in the landscape.

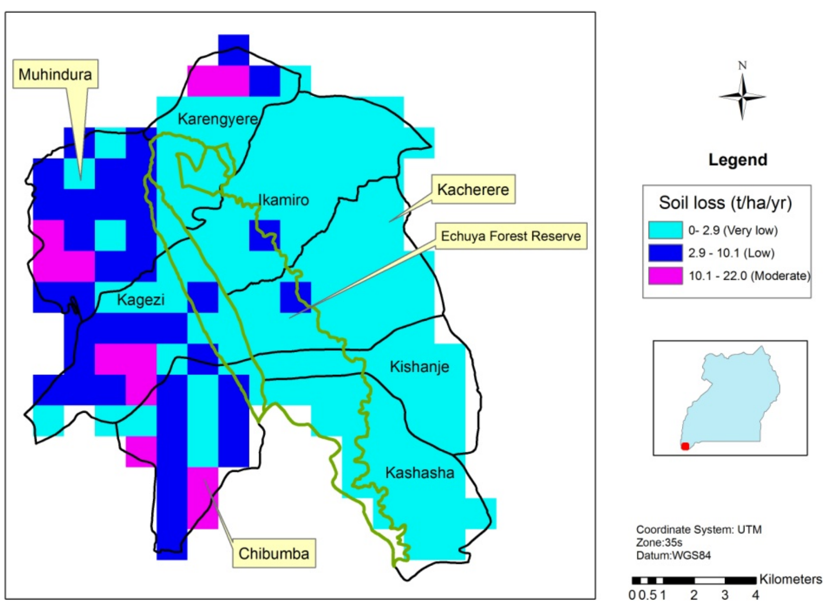


Figure 36. Soil erosion map for Echuya Central Forest Reserve landscape, Uganda, by parish

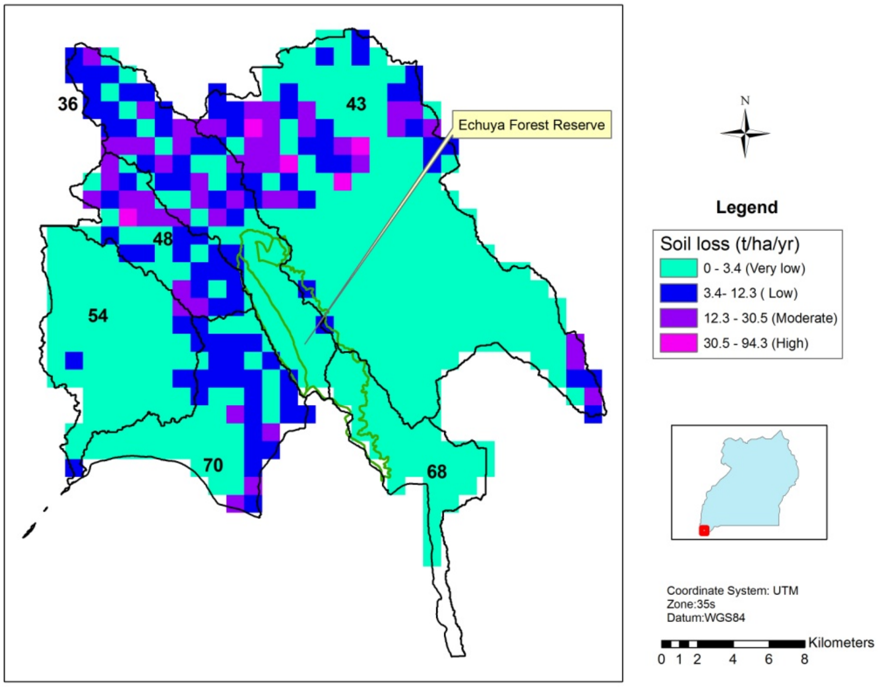


Figure 37. Soil erosion map for Echuya Central Forest Reserve landscape, Uganda, by watershed

For Mgahinga area, the model output suggests that the Mgahinga landscape experiences high proportions of soil loss inside the park and most especially in Rukongi and Gisozi parishes that were above the set tolerance limits (3 to 11 t/ha/yr). This could be due to the high slope (>30) in the area and less vegetation cover type. For Gitenderi parish soil loss is within set tolerance limit levels (Figures 38 and 39). For all the parishes, areas outside the park, soil loss is at low levels than in the park perhaps contributed by the fact that areas outside the Mgahinga National Parks are at lower elevations than those in the parks and this affects the slopes and elevations used to model the flood hazard areas ouput.

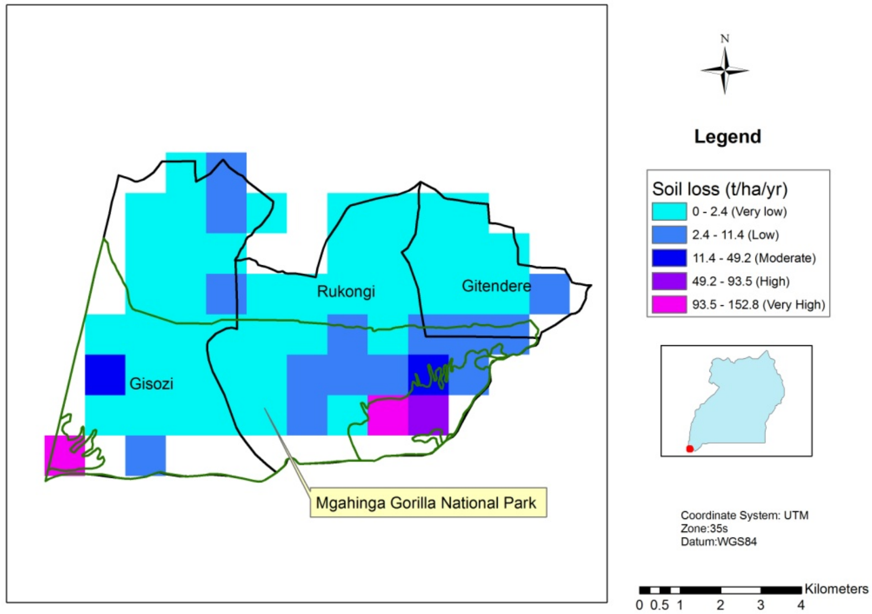


Figure 38. Soil erosion map Mgahinga Gorilla National Park Landscape, Uganda, by parish

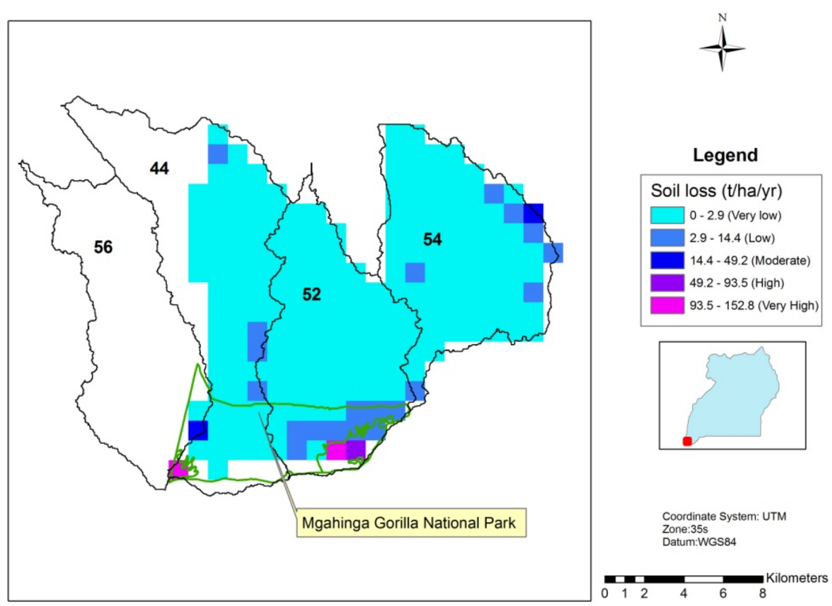


Figure 39. Soil erosion map Mgahinga Gorilla National Park Landscape, by watershed

Model parameterization could be improved in future by mapping the different soil conservation practices being applied in the study area, using a detailed land cover map and having more weather stations to allow for interpolation of precipitation data in the study area.

The models highlight the level of runoff and soil erosion around Echuya and Mgahinga landscapes. It is noticeable that the low levels of water runoff/soil erosion are closely linked to the boundaries of Echuya forest reserve and that the high levels of runoff in the Mgahinga landscape start within the park. This could be due the differences in vegetation structure and the rate of change in elevation in the two landscapes. Flooding is less likely around the Echuya landscape since a significant portion of rainfall is absorbed in the forest ground floor and is slowly discharged to streams/rivers that reduce the amount of runoff into streams and rivers during a storm event.

For the parishes in which soil erosion was predicted to be above the acceptable tolerance limits, soil conservation practices that are economically viable can be encouraged.

The field surveys about the water sources accessed by the different communities in the two landscapes indicates that the people living around the Echuya landscape (Table 5) have a wide variety of water sources compared to the communities living around the Mgahinga landscape (Table 6). The runoff suggests that the rate of groundwater recharge in the landscapes might be linked to the severity of surface runoff, which could be impacting on the number of water sources available to the communities in the two landscapes.

Table 5. Water sources around Echuya Forest Reserve, Uganda

Parish	Tank Concrete	Unprotected spring	Tanks	River points	Protected spring	Ponds	Gravity tap	Dams
Chibumba	5	6	8	16	29	1	10	
Ikamiro	8	9	6	7	21	2	50	
Kacherere	7	6	10	3	19	3	56	
Kagezi	4	6	23	8	10	10	18	3
Karengyere	12	5	7		7		13	8
Kashasha	1	14	8	17	24	2	10	
Kishanje	5	5	4	4	21	1	5	1
Muhindura	11	15	18	13	7		8	5
Grand Total	**53**	**67**	**84**	**68**	**138**	**19**	**171**	**18**

Table 6. Water sources around Mgahinga National Park, Uganda

Parish	Tanks	Gravity tap	Seasonal river	Wetland	Dam
Gisozi	22	6	1	1	1
Gitendere	17		3		
Rukongi	10	9			
Grand Total	**49**	**15**	**4**	**1**	**1**

4.3 Hydrology and physical conditions of Mgahinga and Echuya Landscape

4.3.1 Main drainage systems, regimes and character of streams and rivers in S.W Uganda

The major drainage systems in S.W Uganda consist of lakes, rivers and wetlands all interconnected together. The lakes include: Bunyonyi, Mulehe and Mutanda, while the rivers include Ruhezamyenda, Kashasha and Ntebeko (Figure 40). Most of these drainage systems are crossboundary between Uganda, DRC and Rwanda and are a major supply of water to the local communities for household, livestock and agricultural use. Because of its volcanic nature of soils, Mgahinga and its surrounding areas has very few permanent rivers. Apart from the numerous streams flowing northwards from the mountains, there is a crater lake on Mt Muhabura and a swamp crater on Mt Gahinga summit. There are also swamps in the saddles between the three volcanoes that retain water all year round, while the plains at the foot of the volcanoes are characterized by deep volcanic ash, and run-off from the mountains rapidly disappears underground. The main source of the north-flowing surface water is the Kabiranyuma swamp in the Muhabura - Gahinga saddle. River Kabiranyuma drains the swamp and is an important source of water for the populations around. It is the only river that does not dry up completely in the driest months of June to August. River Ntebeko drains the Rugezi Swamp in the Gahinga - Sabyinyo saddle northwards to the DRC, while Nyabirerema stream drains Mt. Sabyinyo northwards to DRC. Around Mgahinga National Park, discharge varied from 0m^3/day at Gitendere to 29196.5 m^3/day in Gisozi parish (Figure 40) making Gitendere parish the most water stressed parish around Mgahinga. The main source of water in Gisozi parish is the seasonal Ntebeko River that only flows during the wet season.

The main rivers draining Echuya forest and the surroundings mostly flow into L Bunyonyi and they include Rivers Kashasha, Ikamiro, Kagoma, Kihorongwa, Kishanje and Echuya river all forming the upper catchment of lake Edward. All streams eventually join river Kaku that flows through Busanza subcounty in Kisoro District and later into DRC. The mean discharge of rivers per parish within the Echuya landscape is shown in Figure 41. Mean discharge varied from 4554 m^3/day in Kishanje Parish to 28820.5 m^3/day at Kashasha parish based on wet season discharge values. Kalengyere and Ikamiro are the parishes with the least discharge around Echuya and therefore require urgent interventions to supply water to the communities (Refer to recommendations).

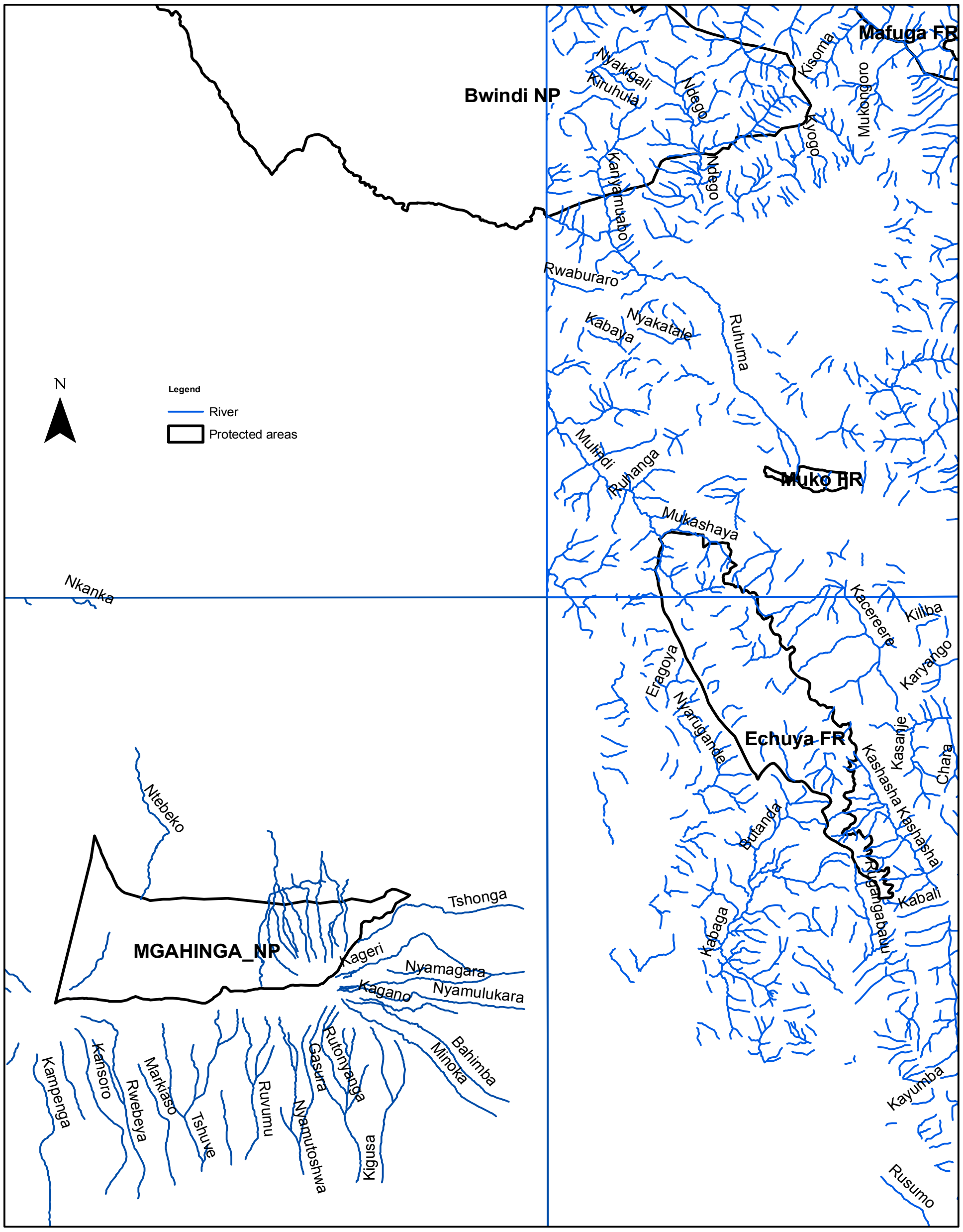


Figure 40. The main drainage systems in and around Mgahinga and Echuya Forests-Uganda

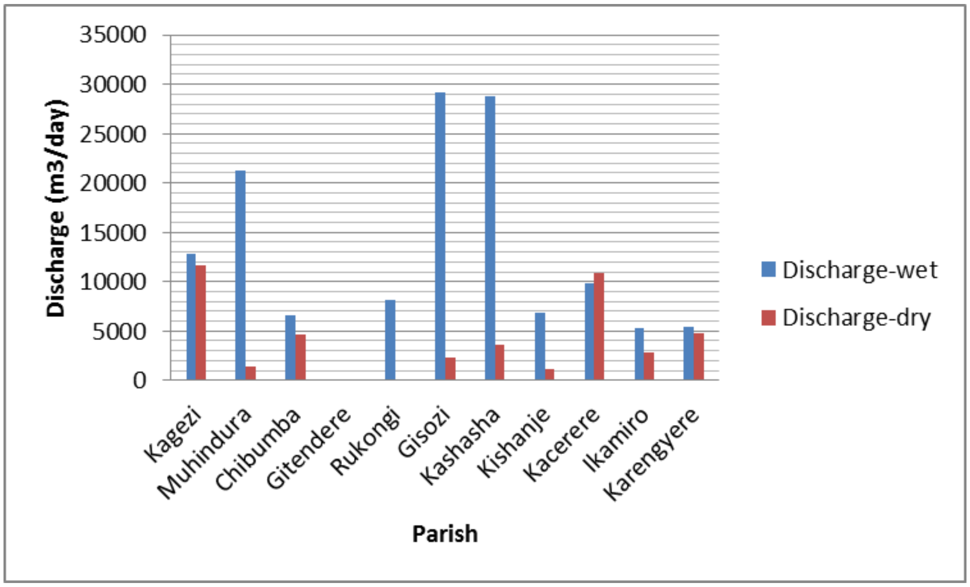


Figure 41. Variation in discharge in Mgahinga and Echuya Parishes-Uganda

4.3.2 Distribution of major geological formations in S.W Uganda

The geological history in S.W Uganda is complex and expands along period recording of several phases of folding, erosion, flattening and sedimentation. The region is affected by a breaking tectonic shift that is behind the schistosity, joints, and seams. The region is full of metamorphic, igneous and sedimentary rocks including: schists, quartzite, sandstone, gneiss, mica schist, shale, carbonatites, conglomerates, amphibolites, lava flows, and limestone (Figure 42). Mgahinga Gorilla National Park (MGNP) has three volcanoes that are part of the Virunga volcanic range in East Central Africa, expanding to the Albertine Rift on the Rwanda, DRC and Uganda border, north and north east of Lake Kivu. The three volcanoes in MGNP are thought to have arisen in the early to mid-Pleistocene era, and to have formed through a deposition of layers of ash and cinders from successive lava flows (Kingston, 1967). Sabyinyo is believed to be the oldest volcano, followed by Gahinga, which is younger, and with a swamp crater of about 180m diameter at the summit. Muhabura is believed to be the youngest volcano. It is cone-shaped with a small crater lake approximately 36m in diameter at its summit. There are numerous caves on the slopes of the mountains, caused by lava tubes. Coombe and Simons (1933) described these lavas on the mountains as follows; Sabinyo-Andesite, Mgahinga- Tracytei Leucite Basanite and Muhavura- Limburgites and Trachytic Leucite Basanites. These mountains are separated by narrow saddles, which permits each to stand in V-shaped structure. Of tourist attraction existing important cave recognized as Garama cave on flat surface probably was formed as results of the lava flow tubes, and wields historical strings of Batwa tradition.

Echuya forms part of the mountainous Rukiga Highlands on the eastern flank of the western rift, having been moulded from Precambrian gritstones, mudstones and sandstones (Combe & Simmons, 1933). The area is associated with up warping of the western rift valley, and its underlying rocks are generally phyllites and shales, with some quartz and granitic outcrops of the Karagwe-Ankolean System. These sediments have suffered metamorphosis and extreme distortion, and they dip at very steep angles, sometimes even vertically. The anticlines which are formed by the folding of the strata have been entirely eroded away, leaving high synclinical hills. The granitic intrusions which are supposed to have caused this folding have rarely been exposed in Kigezi. The K.A. strata are several thousand feet thick.

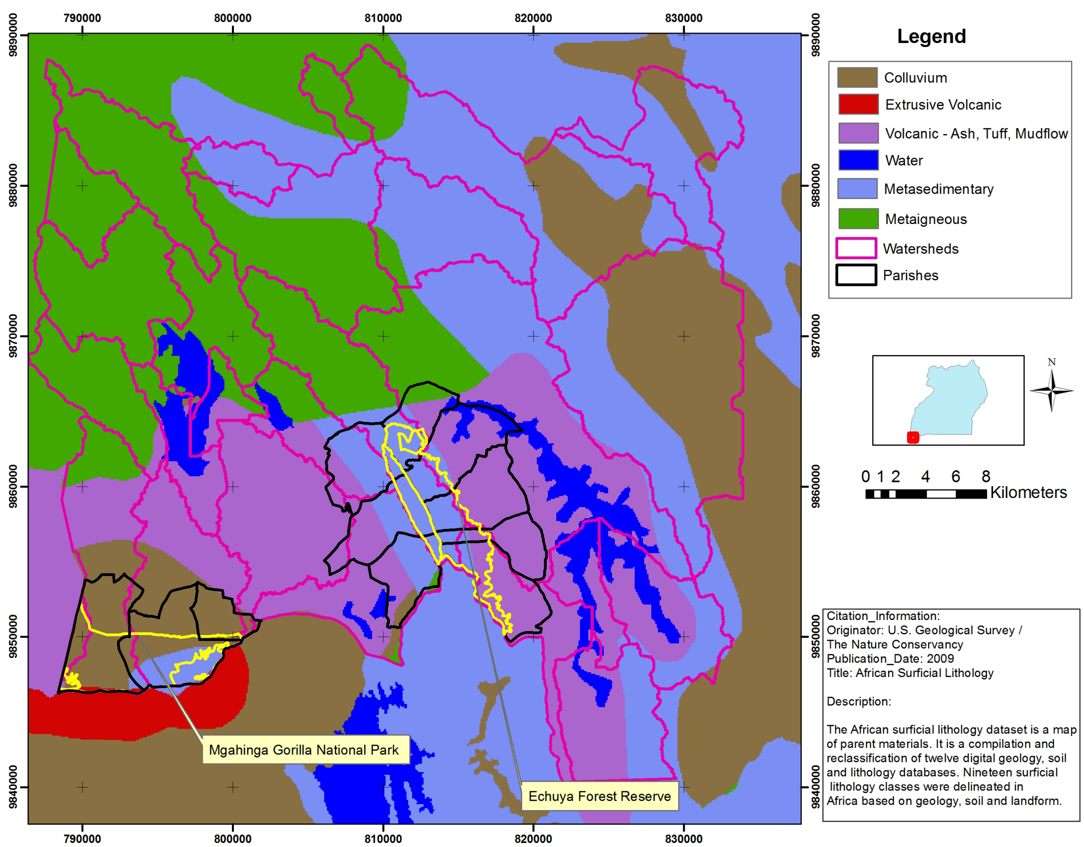


Figure 42. Distribution of the geological formations in Echuya and Mgahinga-Uganda

4.3.3 Land tenure and land use systems in Uganda

The land tenure system in Uganda consists of: the land tenure system is dived into four categories; Customary, Mailo land, Leasehold and Freehold. Land use involves the management and modification of environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pasture and managed woods (FAO, 1997a). Three categories of land use patterns were predetermined for the socioeconomic surveys. These included arable farming, woodland and livestock farming. Majority of people around Echuya and Mgahinga use land for arable farming (Figure 43 & 44). From the two Figures, the main land use pattern around Echuya and Mgahinga is agriculture (subsistence farmland) followed by other land use patterns of bushland, grassland and woodland, open water and wetlands.

The agricultural practices are mainly practiced in the region are attributes of soil erosion and flooding. Arable farming was represented by 86.1% (285) of the total respondents for both Echuya and Mgahinga. The second land use pattern reported was woodlots represented by 63.4% (210) and lastly livestock represented by 54.1% (179). This revealed that most people around Echuya and Mgahinga grow crops compared to woodlots and livestock rearing. It is vital to note that, the current agricultural practices have changed overtime around Echuya and Mgahinga. Most people have discarded the traditional land use patterns that involved terracing, bush fallowing and planting hedge crops.

The greatest attribute to land use patterns is the land tenure system in the region. The land tenure system in Kabale and Kisoro is mainly freehold. There are four types of land tenure systems recognized by the Constitution of Uganda; Customary, Mailo, freehold and lease hold. The Land Act 1998 defines 'freehold tenure' as a tenure that derives its legality from the Constitution and the written law. Freehold tenure may involve either a grant of land in perpetuity, or for a less specified time period. The Act specifies that the holder of land in freehold has full powers of ownership. Free hold land tenure system is the mostly adopted land tenure in Kigezi region (Echuya and Mgahinga). This system has influenced individual land ownership thus leading to high land fragmentation in the area. This influences agricultural practices in Kigezi region.

Through observation, there were run-off ways and big trenches that are a result of heavy rains. Local residents revealed that when it is a rainy season, crops are washed away due to poor land use practices based on individual land plots. This therefore greatly explains constant soil erosion and flooding that affect water quality and quantity.

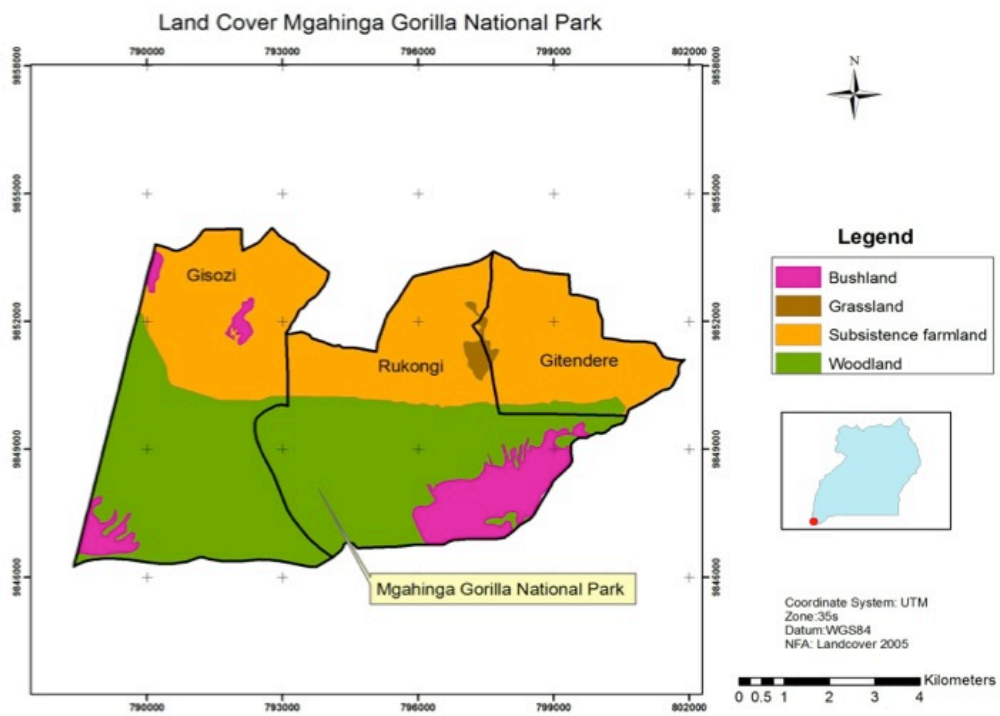


Figure 43. Landuse patterns in and around Mgahinga Gorilla National Park-Uganda

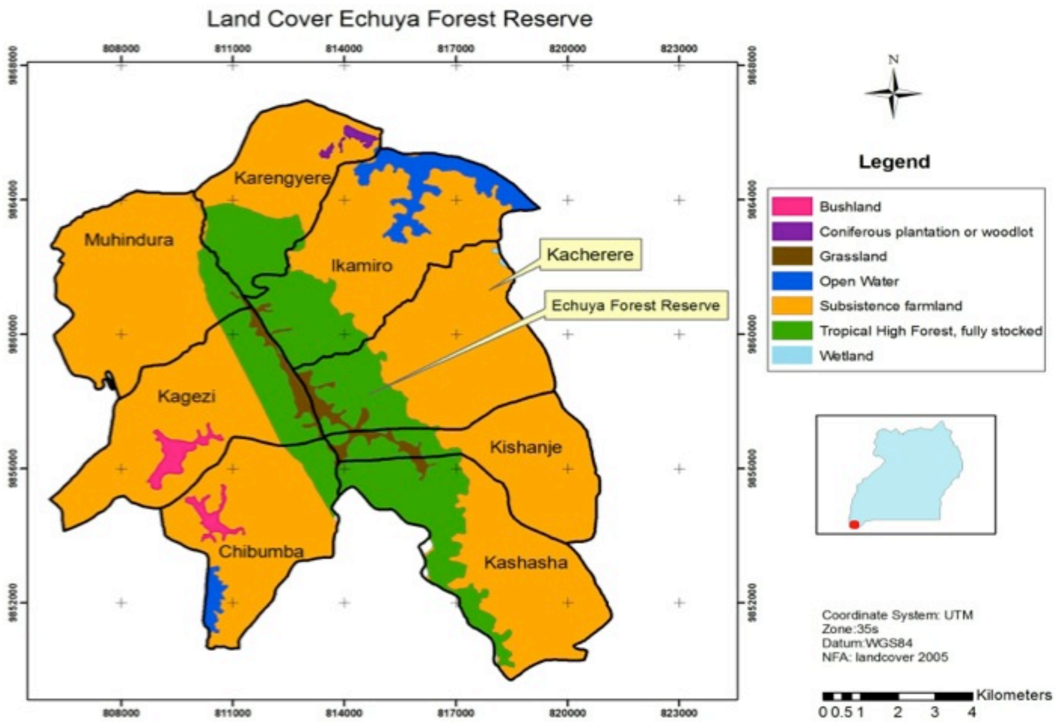


Figure 44. Landuse patterns in and around Echuya Central Forest Reserve-Uganda

Land use around Echuya and Mgahinga is responsible for the rate of soil erosion and flooding. In most areas, farming methods were poor, there were elements of high surface run-offs and soil erosion. This was ascertained by establishing the most common and widespread land use patterns in the parishes neighboring the two protected areas. Figure 45 shows the type of land use practiced in the study area and the frequency the respondents mentioned them across the eleven parishes. Arable farming, livestock keeping and woodlot are three most prevalent land use patterns practiced around Echuya and Mgahinga. Most of the arable farms that we observed did not have provisions for soil erosion prevention. There was evidence of sheet and rill erosion as well as the deep gullies as a result of sediment run-off during the wet season periods. Local residents revealed that when it rains, crops are washed away due to poor land use practices. The poor agricultural practices are responsible for the current soil erosions observed on the steep slopes in the study area. The soil erosions have led to flooding of valleys and rivers and therefore contributed to poor quality water for domestic use as reported by most respondents. This was very common in Mgahinga parishes of Gitendere and Rukongi. It was also mostly reported in the steep areas of Chibumba and Karengyere parishes around Echuya in Kisoro district.

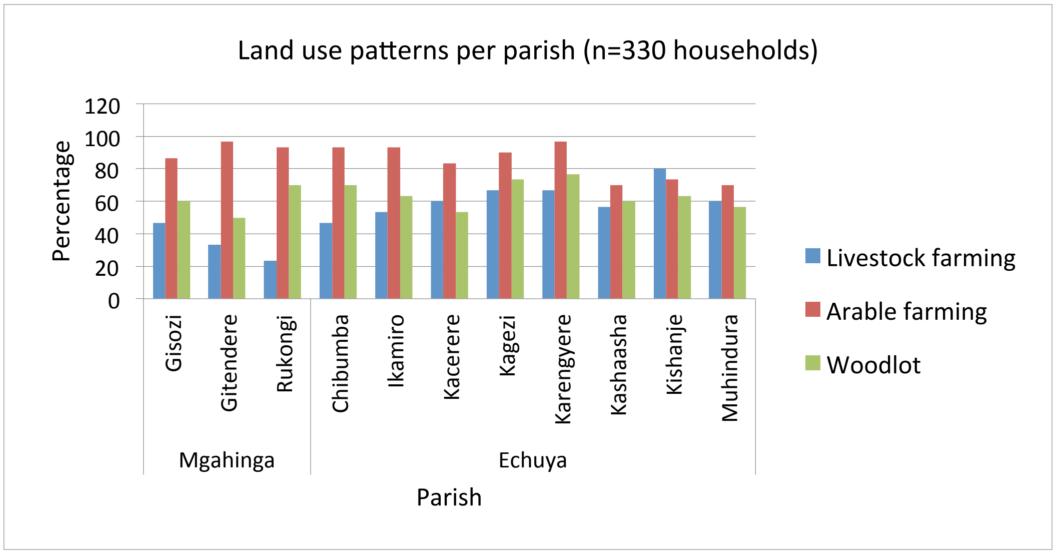


Figure 45. Land use patterns as reported by respondents in the Uganda study parishes

4.4 Water sources, quantity and quality used by households

4.4.1 Echuya water sources and points

Water sources were mapped under different categories and these were; wetlands, unprotected/protected springs, wells, gravity water schemes, streams, lakes dams, ponds and rainwater harvesting systems. Figures 46 to 54 represent the different water sources mapped in the frontier parishes of Echuya forest.

4.4.1.1Wetland water sources

Over fourteen wetlands were identified in the Echuya landscape. Muhindura parish had the highest concentration of wetlands while Karengyere and Ikamiro had no wetland identified as shown in Figure 46. Lack of wetlands in certain parishes may contribute to water scarcity in those parishes. On the other hand, accumulated organic matter and high decomposition rates in wetlands, water sourced from wetlands may not be good for household use because of humic acids concentration and the odour that is associated with decomposition processes in wetlands. Pre-treatment of the water such as through de-coloration and chlorination may be necessary to make the water good enough for human consumption. During the survey it was observed that most wetlands in the study area were under threat of drying out from agricultural encroachments. Agricultural encroachment may negatively impact on the water quality and quantity by interfering with the water retention capacity of the wetlands. Enforcement of laws and by-laws against wetland degradation is highly encouraged across the landscape.

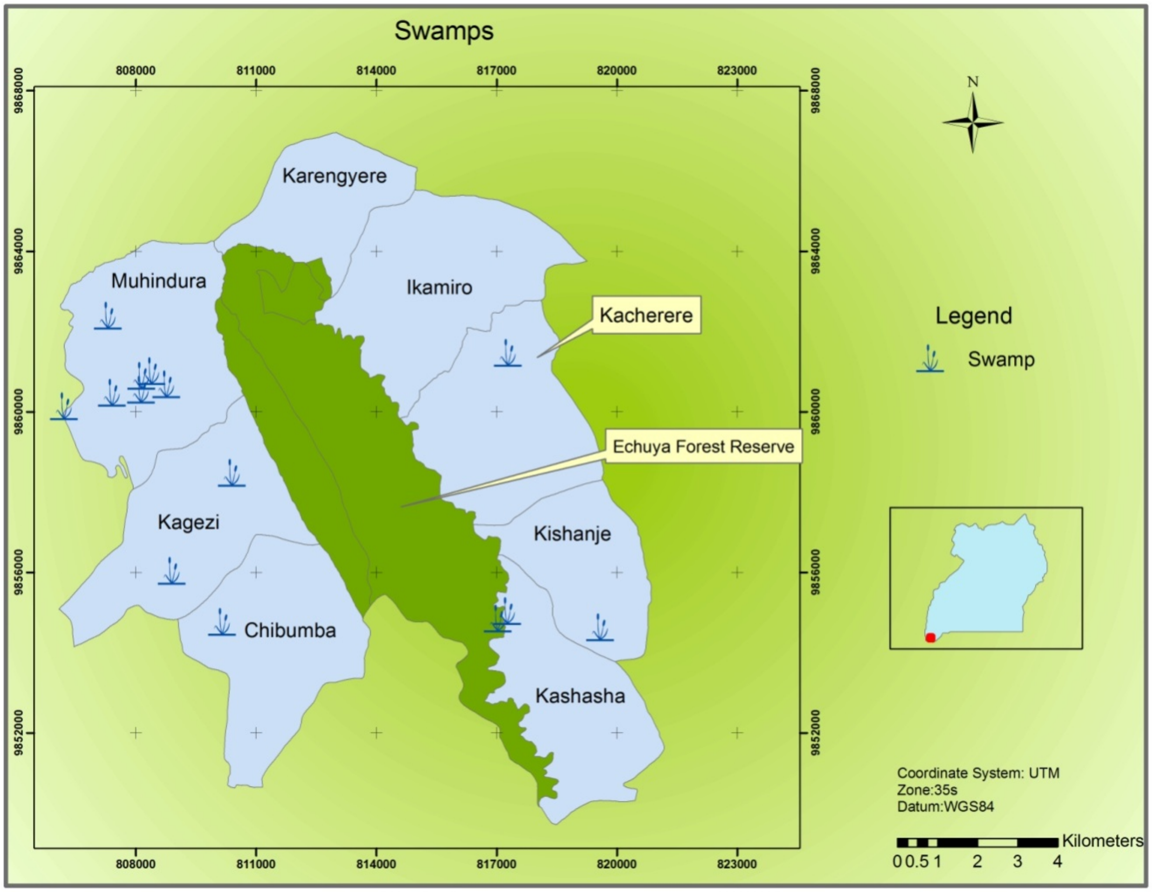


Figure 46. Distribution map of wetland water sources in parishes around Echuya forest, Uganda

4.4.1.2 Unprotected spring water sources

The unprotected spring water sources ranged from 5 in Karengyere and Kishanje parishes to 15 in Muhindura parish (Figure 47). These are the most upstream springs that are unprotected and are often the sources that are targeted for development of protected springs and gravity flow schemes. Several springs usually combine to form first order streams. Plate 4 shows an unprotected water spring in one of the parishes. The communities using unprotected spring water sources need to be encouraged to boil the water especially when it is to be used for drinking.

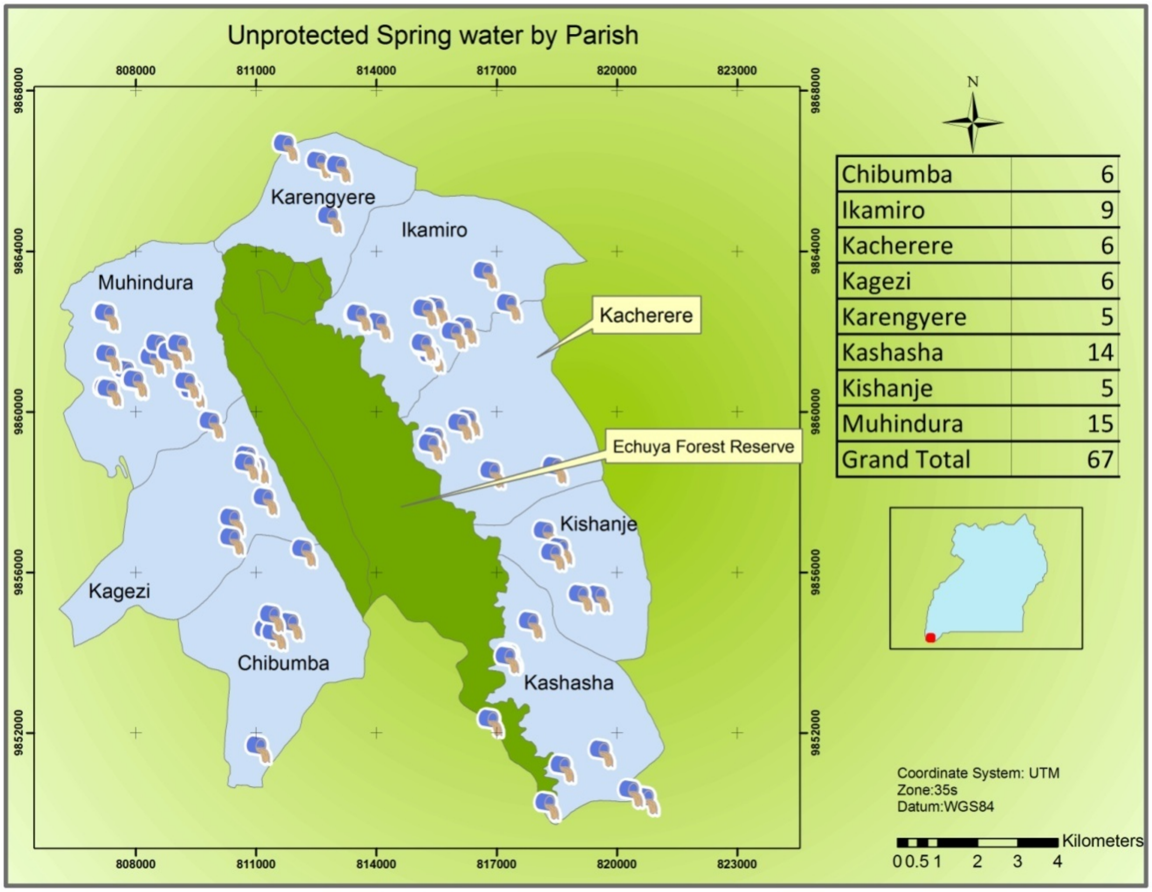


Figure 47. Distribution of unprotected spring water sources around Echuya CFR

Plate 4. Unprotected water spring in Echuya (note the clear water with algal growth and the brownish colour due to iron oxides at the basement, this can be dangerous for human use)

4.4.1.3 Protected spring water sources

The protected spring water sources were those that were developed/constructed and fitted with pipes from which water constantly flowed (Plate 5). The number of barrels on a protected spring may vary from one to around four depending on the quantity of water at the source. Around frontier parishes in Echuya, the number of protected springs ranged from 7 in Muhindura and Karengyere parishes to 29 springs in Chibumba (Figure 48). The low number of protected springs in some parishes is an indicator of water scarcity. Protected spring water was characterized by high water transparency usually above 120 cm and turbidity below 1NTU. This implies that the water in these sources can be consumed with minimal treatment costs such as through boiling or application of WaterGuard (a water treatment tablet).

Plate 5. A protected water spring with three barrels. Note the clear water and the varying flow volumes in the different pipes

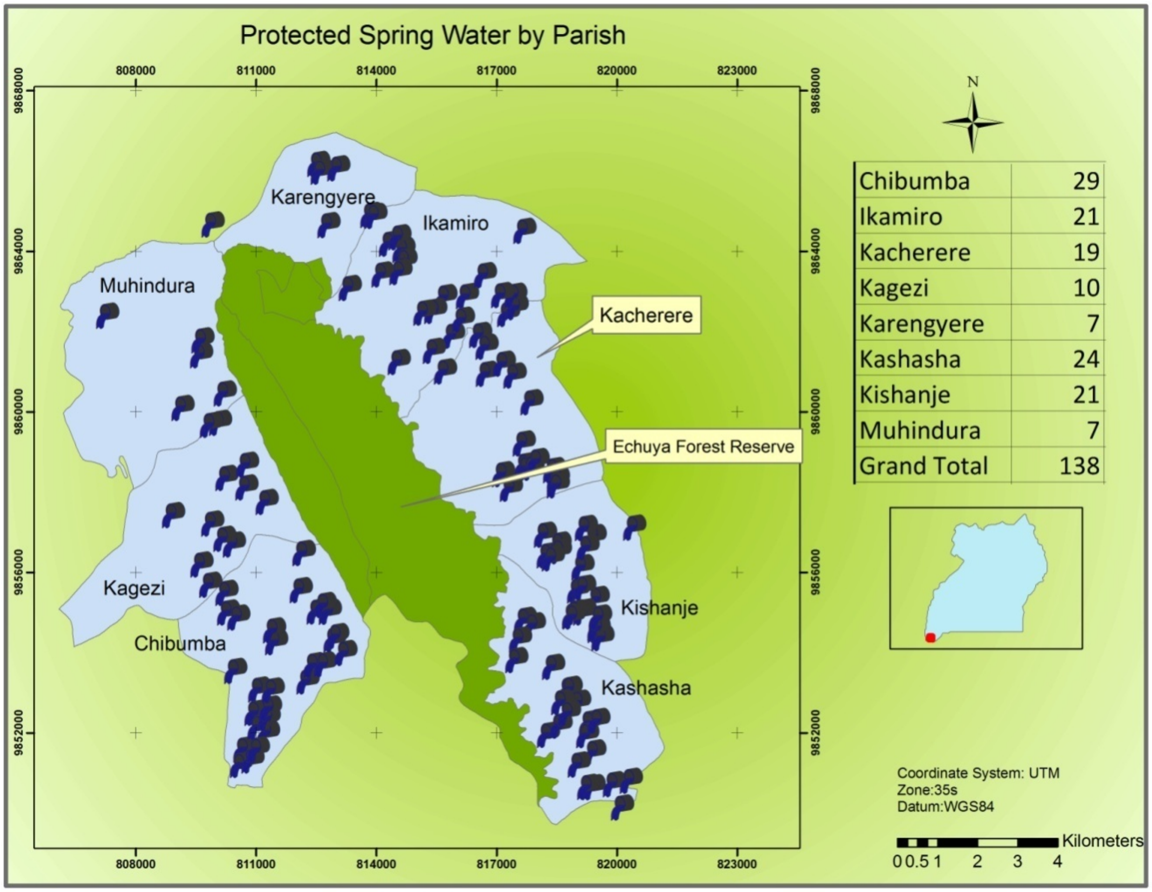


Figure 48. Distribution of protected spring sources around Echuya forest, Uganda.

4.4.1.4 Wells

The wells are unprotected water sources served by underground and surface water sources. Wells varied from none in Karengyere and Muhindura parishes to three in Kishanje parish (Figure 49). Most other parishes reported only one well. The distribution of wells appears to be influenced by the terrain of the landscape with very steep and rugged areas generally lacking wells. Although the quality of water in wells is generally not good, they act as a safety net during periods of water scarcity. With boiling, water from a well can be safe enough to be drunk.

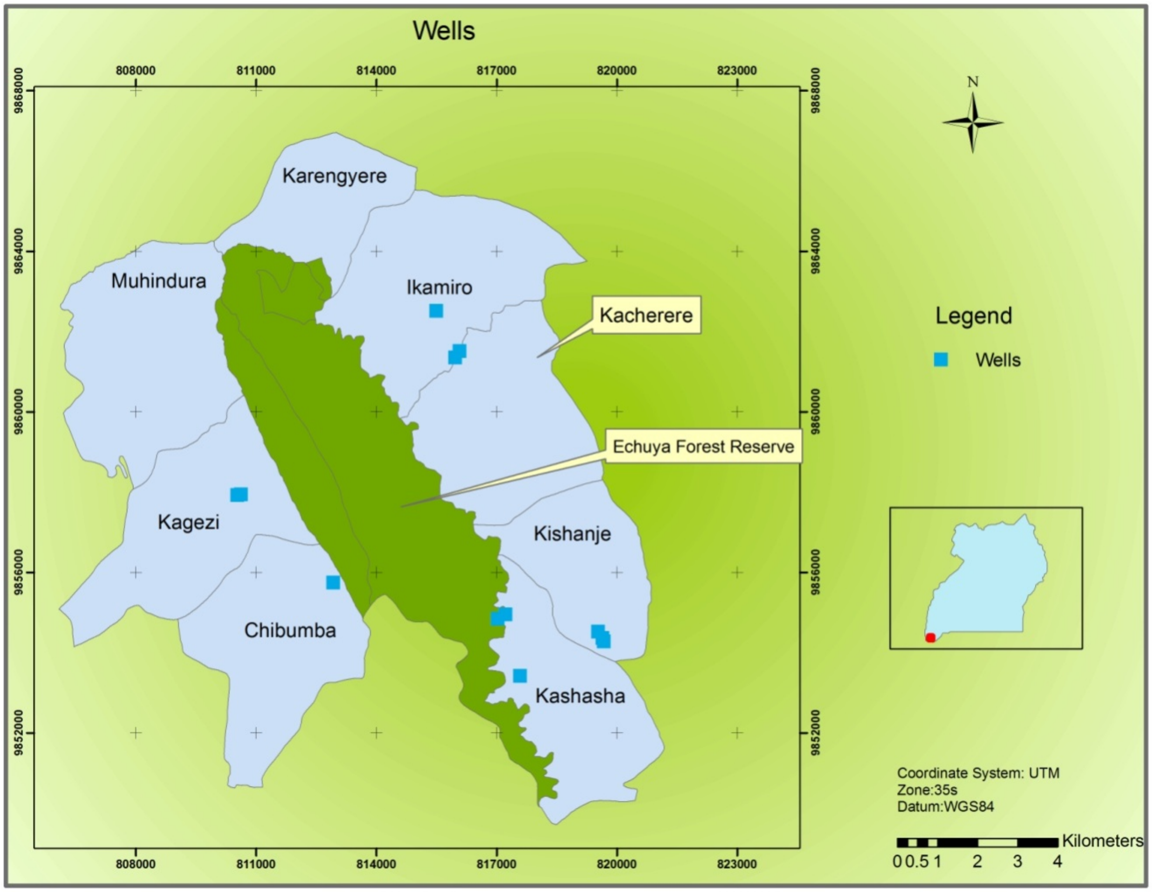


Figure 49. Distribution of wells around Echuya parishes, Uganda.

4.4.1.5 Gravity flow taps

These are usually located downstream of a gravity flow scheme and are intended to serve communities along the way. The number of gravity flow taps ranged from 5 in Kishanje parish to 56 in Kacerere (Figure 50). Water quality at the taps is always good. However, in some locations it was noted that some facilities were vandalized and on some taps water flows continuously resulting into wastage. Water user committees need to be advocated for gravity flow schemes where they do not exist and where they exist, governance issues on tap stand management need to be addressed. The water sources of the gravity flow schemes need to be protected such as through planting trees to prevent contamination and evaporation from the water sources.

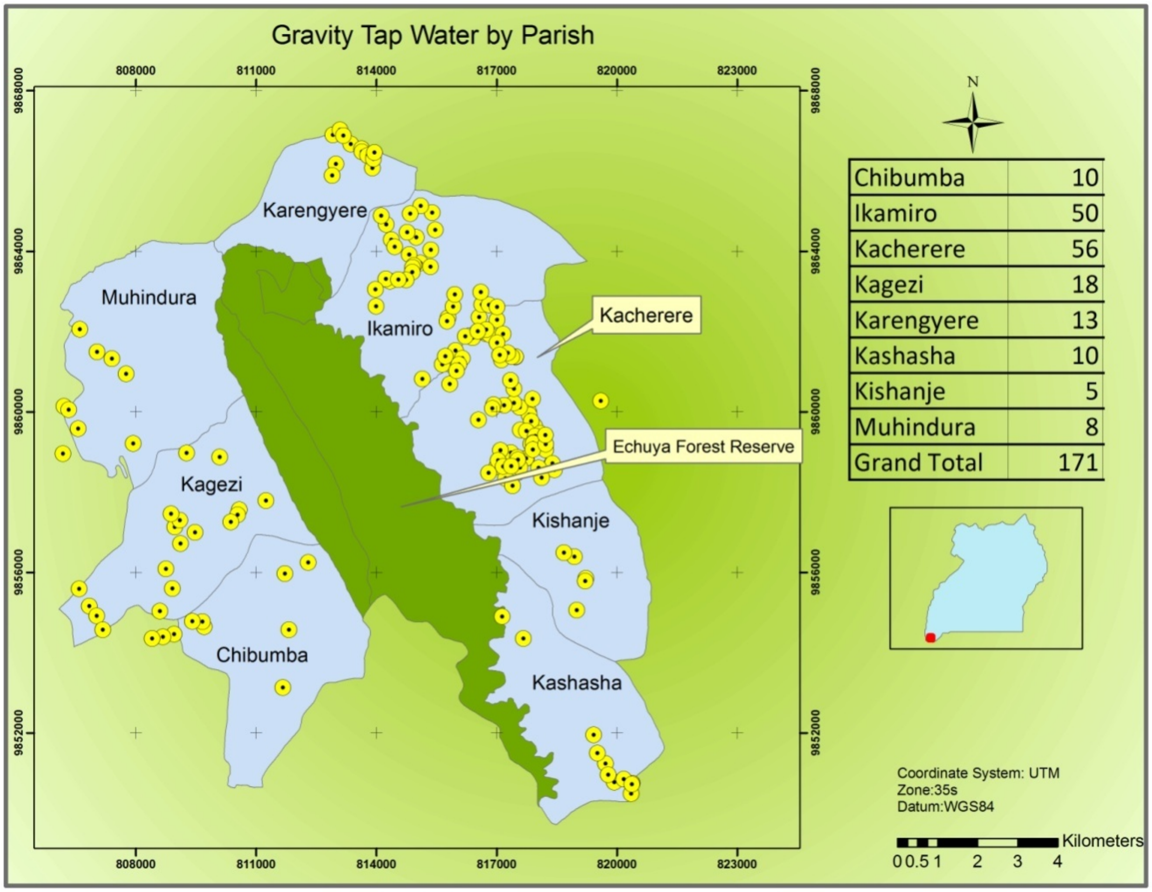


Figure 50. Distribution of gravity water taps accessed by communities around Echuya

4.4.1.6 Streams

Streams include all flowing water that was accessed by communities for domestic use and agricultural practices such as watering livestock and watering crops. The number of stream points ranged from 4 in Kishanje to 17 in Kashasha parish (Figure 51). The number of river points is an indication of stream density in a given parish. Because of the open nature of these water sources, they may not be suitable as drinking water sources without treatment. Stream water sources should be harnessed especially for irrigated agriculture during the dry spells. In some communities, this is already being practiced to irrigate vegetable gardens. Water efficient irrigation technologies need to be explored and advocated in the landscape.

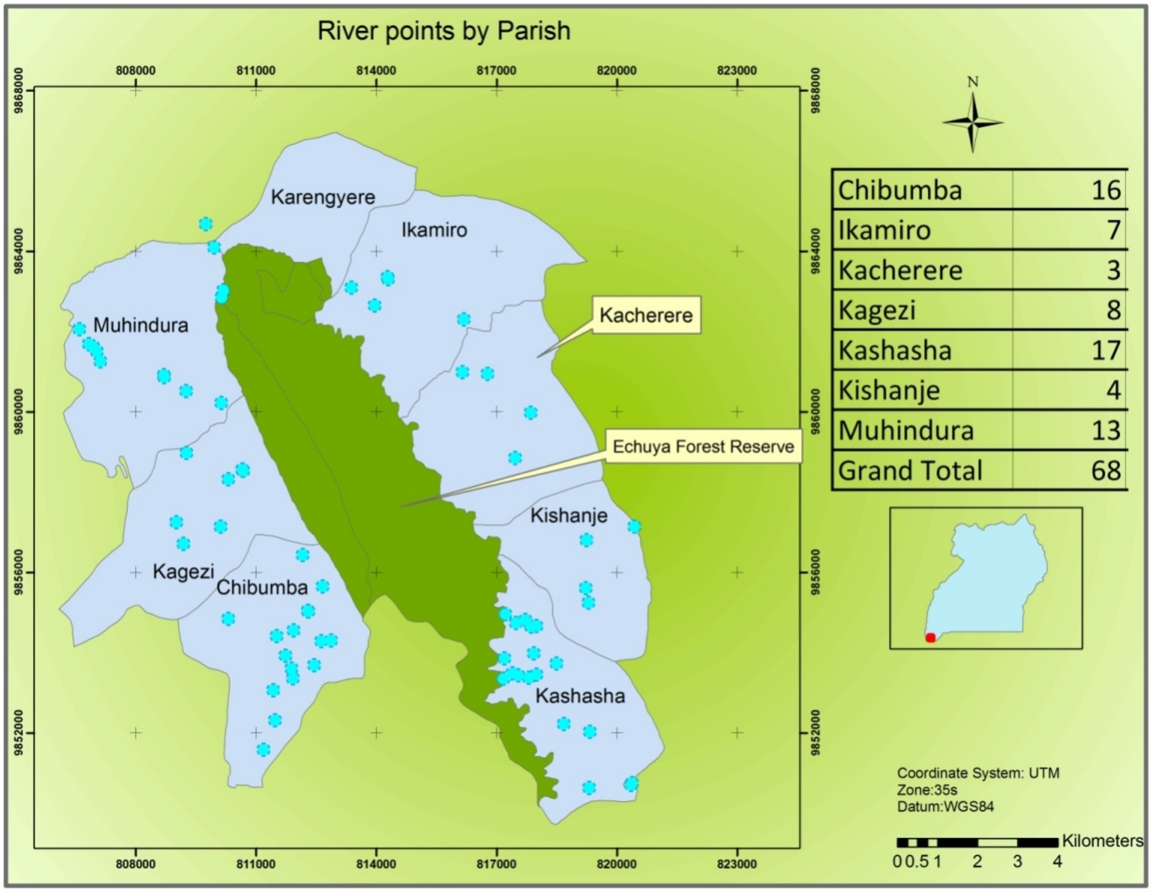


Figure 51. Distribution of stream points in parishes around Echuya forest

4.3.1.7 Dams and ponds

Dams are man-made constructions usually containing rainwater and are used mostly to water livestock and irrigate crop fields. Dams were few or none in some parishes such as Kacerere and Kashasha but tended to increase in water-scarce parishes such as Karengyere and Muhindura (Figure 52). They are also called reservoirs and retain water during wet seasons and the water is mostly used during the dry seasons. Plates 6 and 7 show the seasonal changes in water quality and quantity at Mukashayo dam in Kalengyere parish. Ponds are natural depressions in the drainage system where the water table is low, thus supplying water from underground sources. Pond numbers were low in most parishes ranging from none in Muhindura and Karengyere parishes to 10 in Kagezi parish. Ponds are normally used for watering animals but during time of scarcity, the water may be consumed domestically as was witnessed in Karengyere parish.


Plate 6. Mukashayo water dam near Echuya forest; this photo was taken during the dry season


Plate 7. Mukashayo water dam near Echuya forest; this photo was taken during the wet season

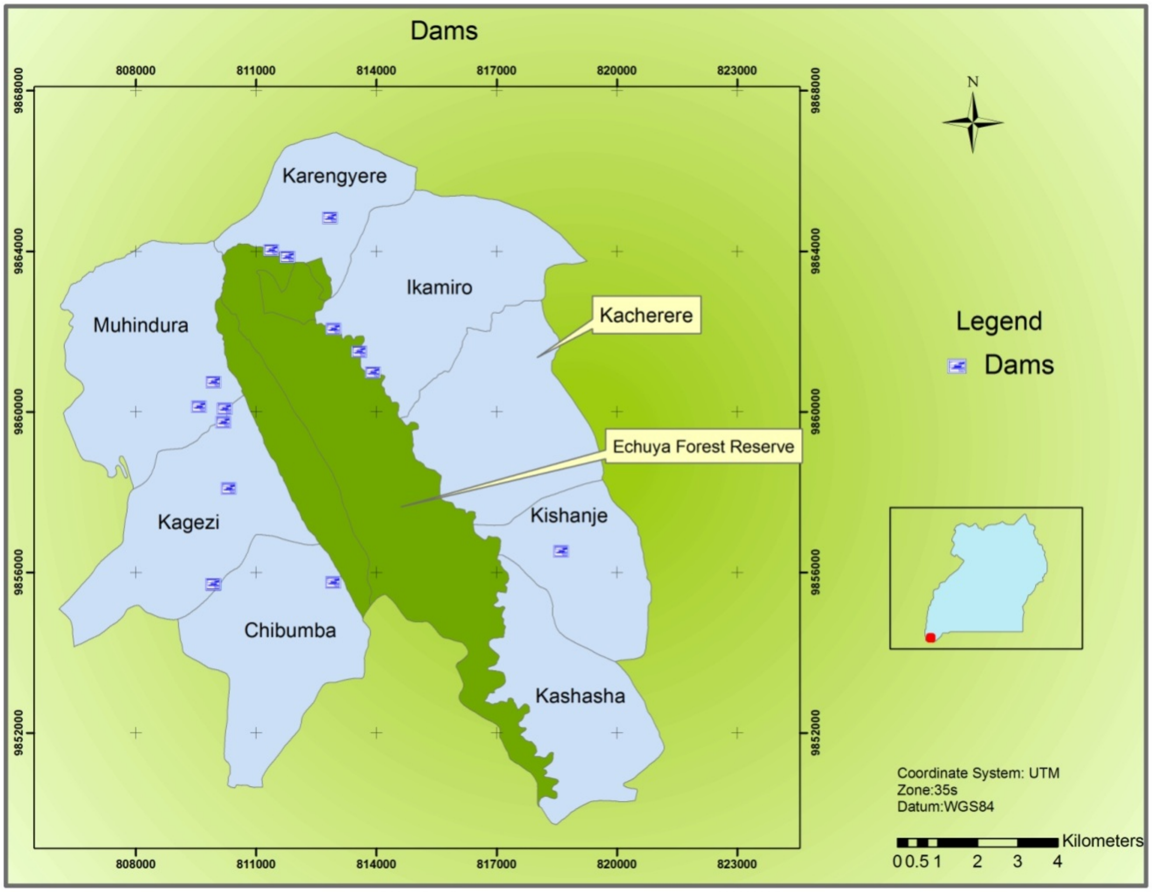


Figure 52. Distribution of water dams in parishes around Echuya forest

4.4.1.8 Lakes

Some parishes around Echuya forest border Lakes Bunyonyi and Kayumbu from which they get water for domestic, livestock and crop irrigation uses. Some communities in Ikamiro parish access water from Lake Bunyonyi while those in Chibumba parish get water from Lake Kayumbu.

4.4.1.9 Rainwater harvest systems

These were composed of concrete and plastic water tanks at community and household levels. The facilities are used to tap rainwater especially in areas with few or no natural water sources but also used to supplement other water sources. The number of concrete water tanks ranged from 1 in Kashasha parish (ostensibly the parish has other several water sources) to 11 and 12 in Muhindura and Karengyere parishes that are the most water-stressed parishes around Echuya (Figure 53). Plastic water tanks ranged from 0 in Karengyere parish despite its water scarcity status to 11 in Muhindura parish (Figure 54). Overall concrete water tanks were more than the plastic water tanks probably due to the high cost of purchasing plastic water tanks. Plastic water tanks were quite common at government facilities such as schools and dispensaries.

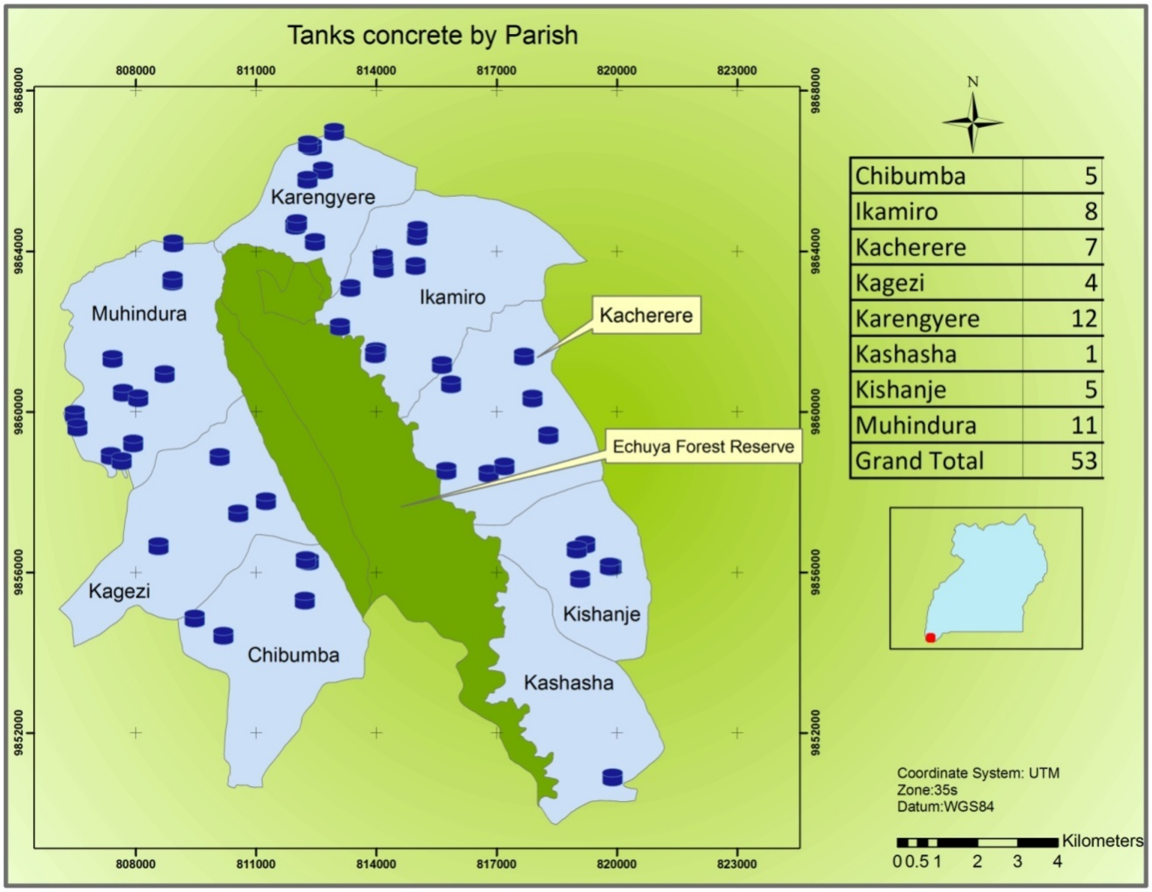


Figure 53. Distribution of concrete water tanks in parishes around Echuya forest

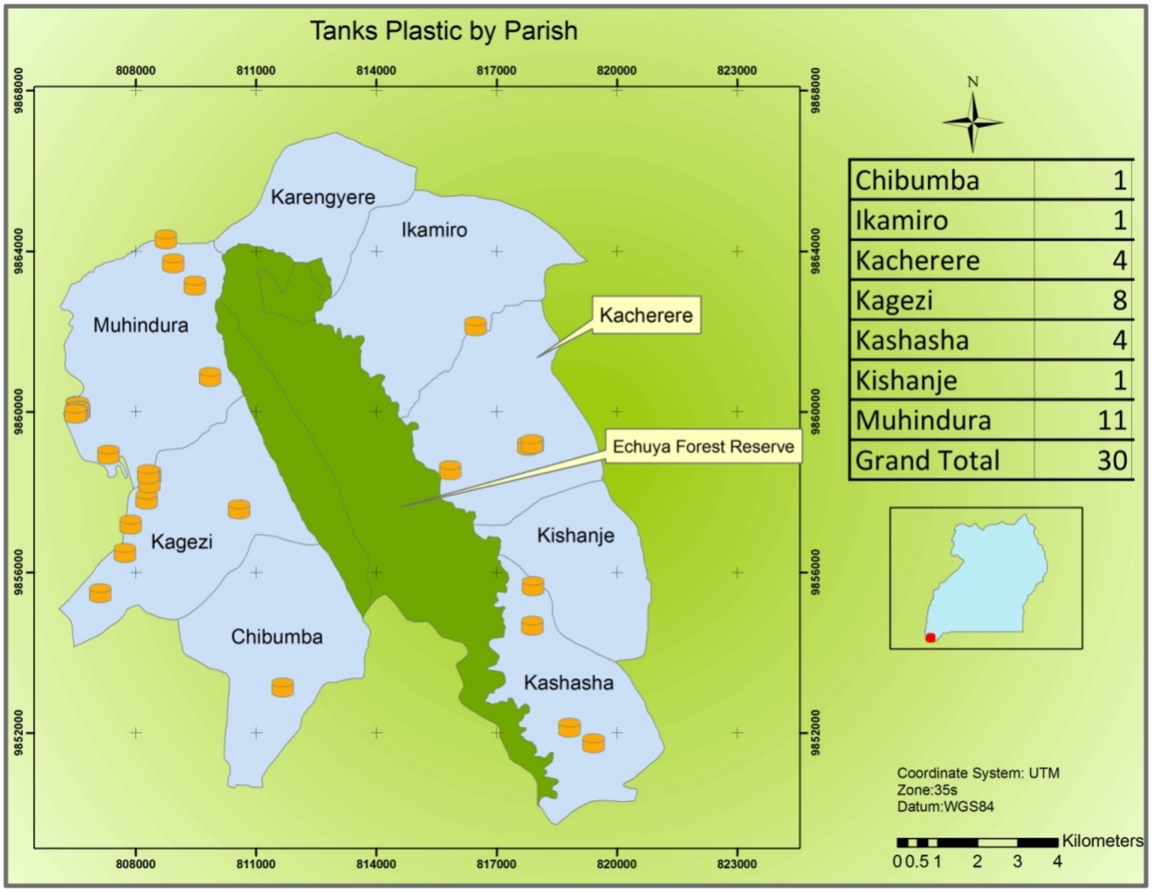


Figure 54. Distribution of plastic water tanks around Echuya parishes

4.4.2 Mgahinga water sources

In Mgahinga, households had the least number of water sources recorded with most of them being rainwater facilities at community level (Figures 55 to 58). Because of the volcanic nature of the rocks, there are few surface water sources save for some high altitude wetlands, seasonal streams and some perched aquifers. It can be generalized that parishes around Mgahinga Gorilla National Park are stressed for water with communities travelling long distances to access water. Most of the water harvesting facilities in the communities were constructed with donor support. Some households have bought or constructed water tanks at their facilities for supplying water during periods of scarcity such as dry seasons.

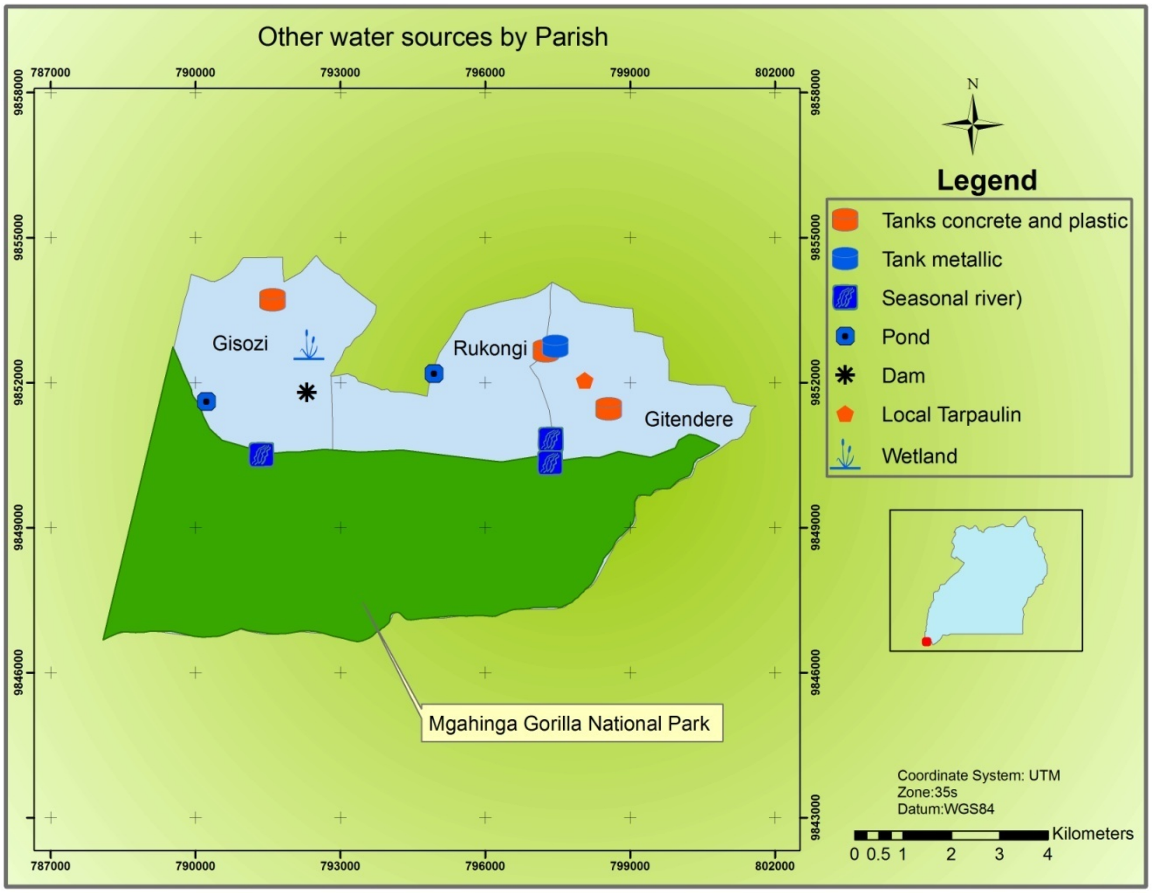


Figure 55. Distribution of different water sources in Mgahinga parishes

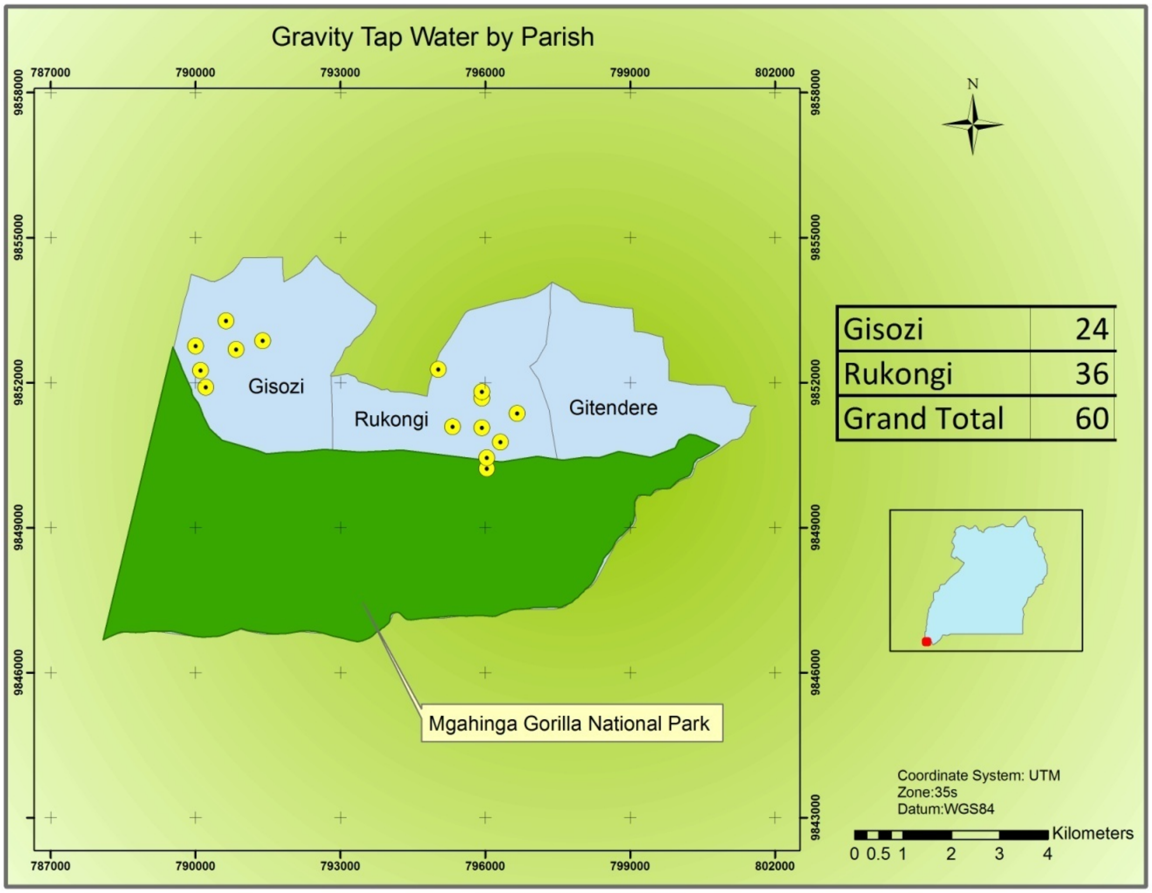


Figure 56. Location of gravity flow water taps in Mgahinga parishes

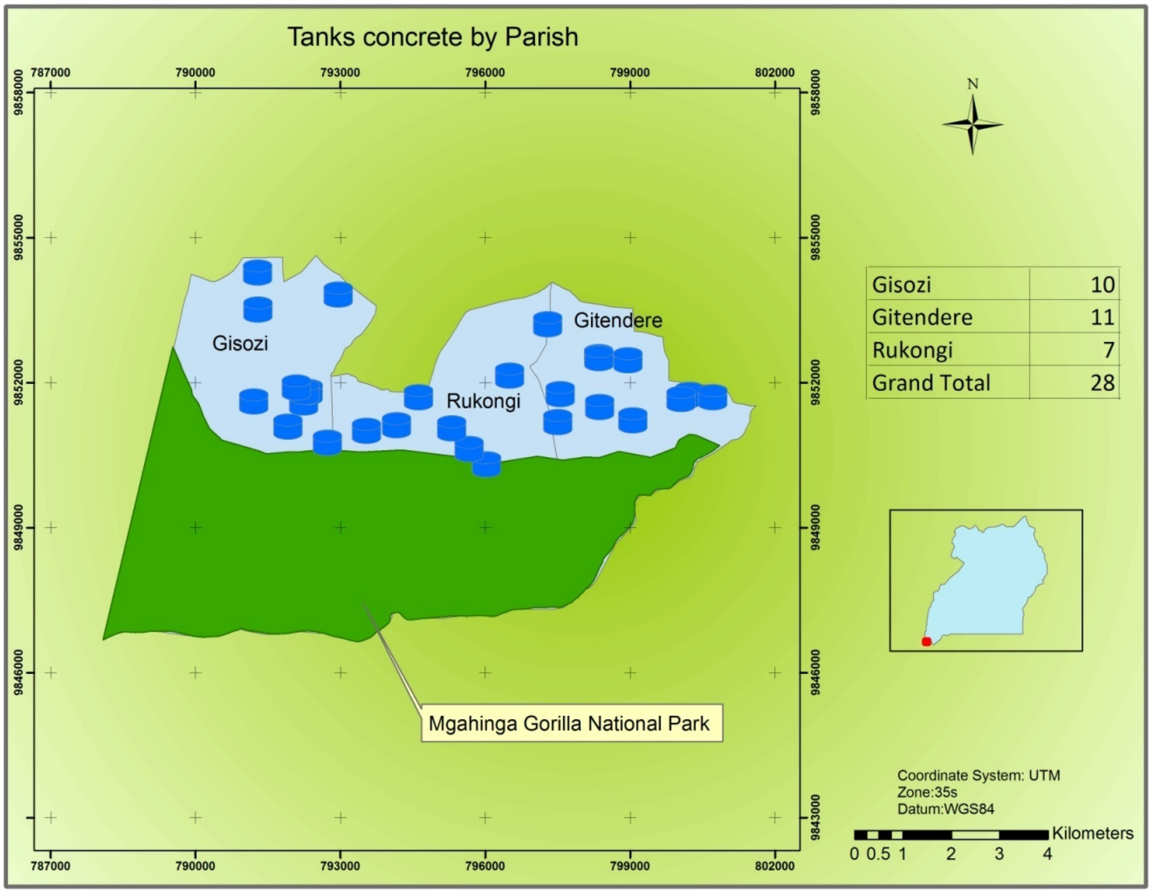


Figure 57. Distribution of concrete water tanks around Mgahinga

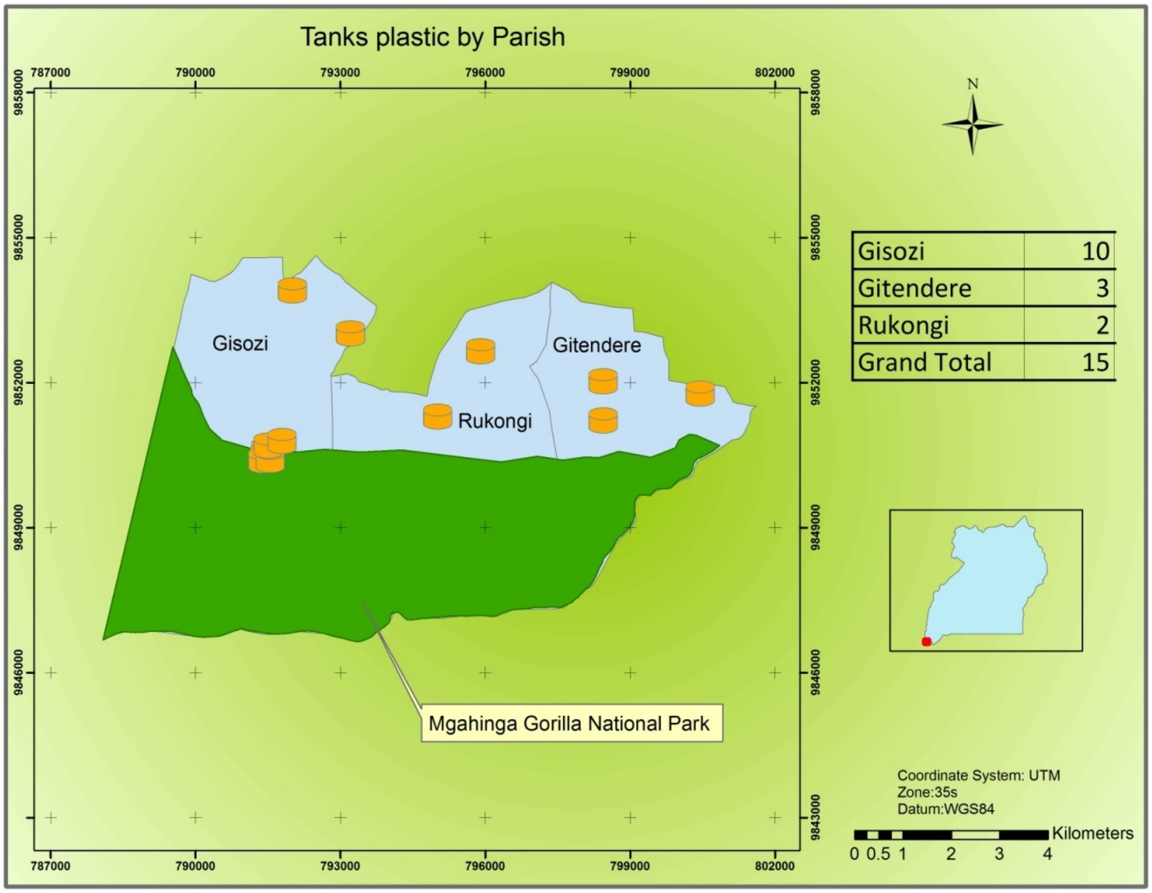


Figure 58. Distribution of plastic tanks around Mgahinga, Uganda

4.4.3 Variation in water quality variables (onsite measurements)

4.4.3.1 Water pH used by households

Mean pH ranged from 6.14 in Kashasha parish to 6.98 at Karengyere parish during the dry season (Figure 59). Using Kriging interpolation in ArcGIS 9.3, the parishes with very low pH were Kashasha and Kishanje while in other parishes it tended be high but still acidic (Figure 60). This implies that all water samples taken during the dry season were generally acidic and mostly outside the maximum permissible range for Ugandan portable water standard of 6.5 to 8.5. Very acidic waters were generally found in protected spring sources and in swampy areas with pH values as low as 4.5 being recorded, while alkaline water sources were mainly recorded in lake sources such as Lake Kayumbu with a pH value of 8.3. However, the highest pH of 8.5 was recorded in a freshly constructed concrete tank in Gisozi parish (Figure 61). In addition, headwater sources in upstream areas also tended to have low pH values. pH was generally neutral around 7 in most streams or river water sources. In unpolluted waters, pH is principally controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions as well as other natural compounds such as humic and fulvic acids (Chapman, 1992).

Mean pH during the wet season varied from 6.5 at Kashasha parish to 8.2 in Lake Bunyonyi waters. pH tended to become neutral during the wet season with improvements towards the national standard. It appears the increased water volumes during the wet season may cause a dilution effect of the acidic waters. Consumption of acidic water with pH below 6.5 may cause abdominal discomfort especially for communities who drink untreated protected spring water. Soda ash in appropriate doses may be used to treat acidic water to make it fit for human consumption.

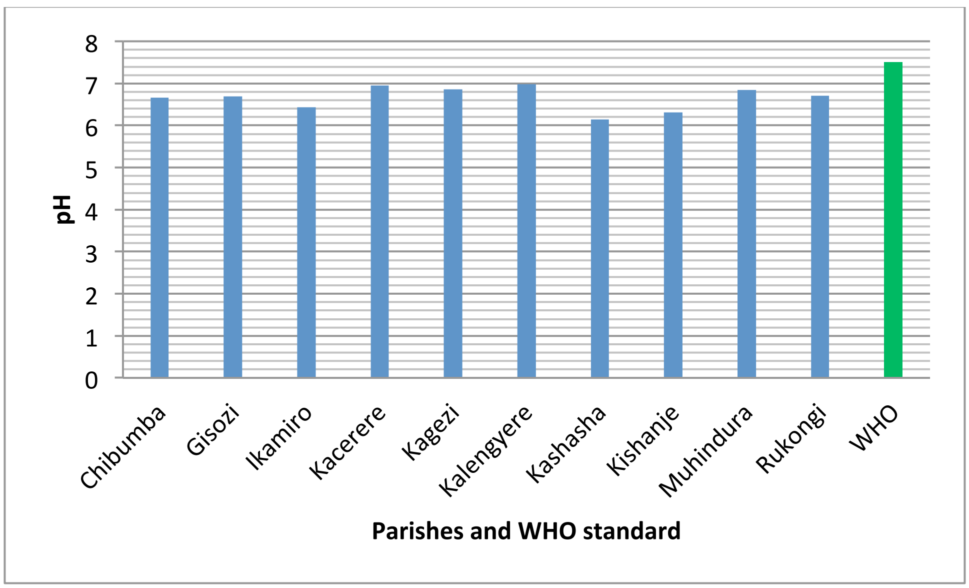


Figure 59. Variation in pH of water sources across parishes. Note that all the water sources were lightly acidic

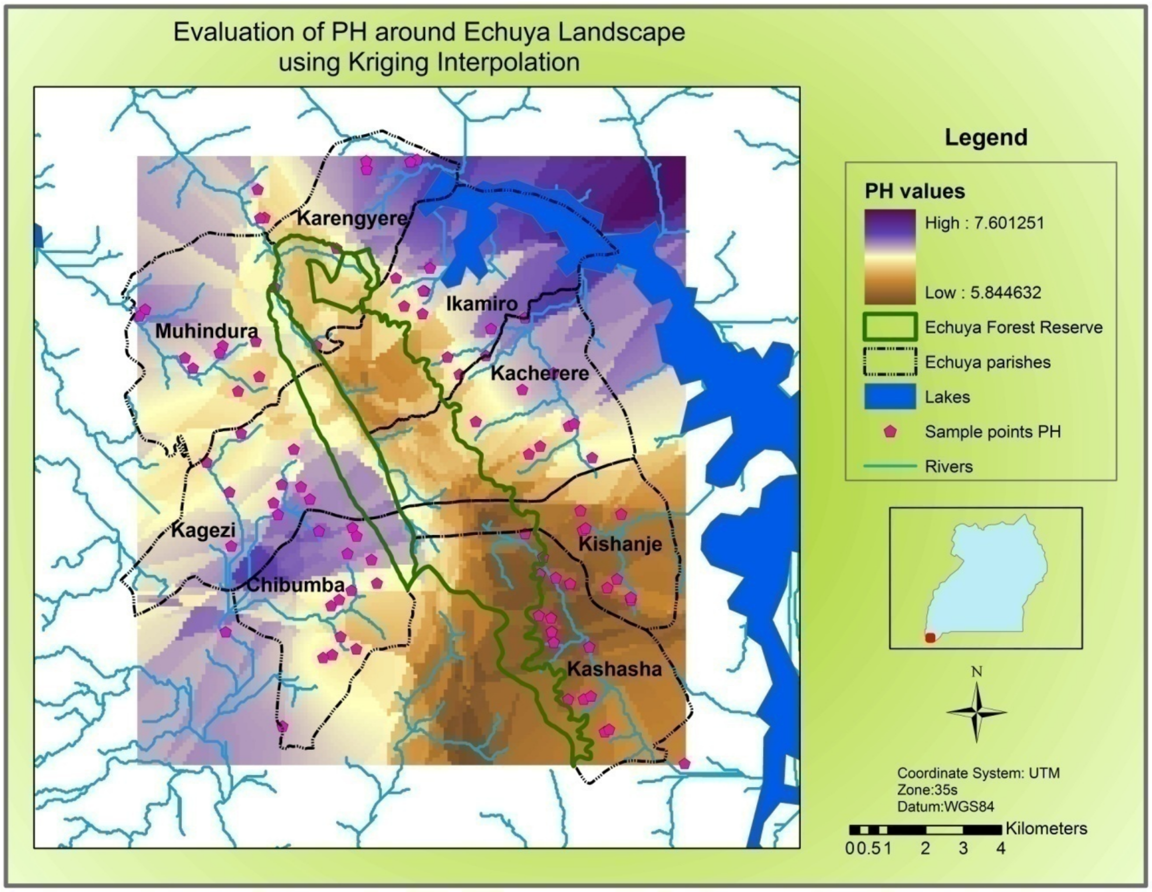


Figure 60. Variation in pH values around Echuya forest parishes

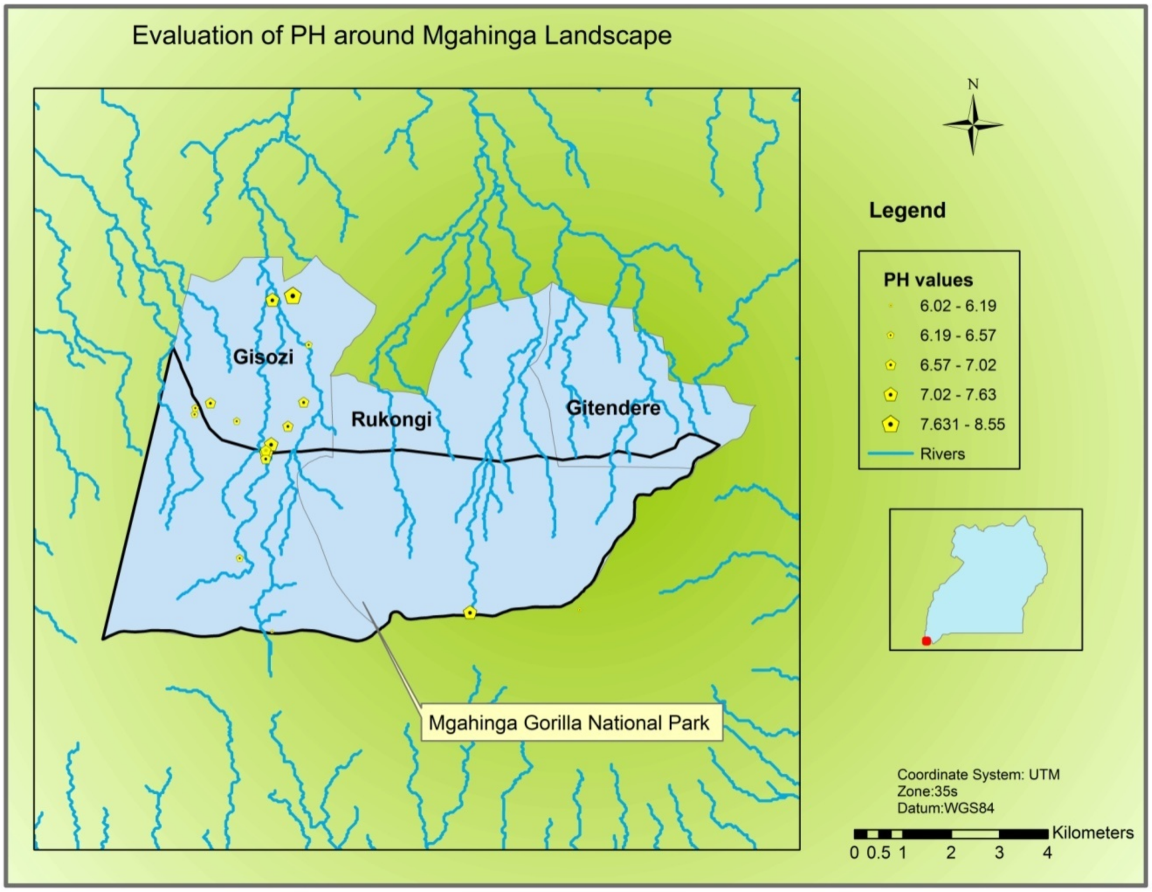


Figure 61. Variation in pH around Mgahinga National park parishes

4.4.3.2 Water transparency

Water transparency was measured using a transparency tube 120 cm long and fitted with a miniature secchi disc. Water transparency varied from 57.6 cm in Kashasha parish next to Echuya forest to 101 cm in Rukongi parish in Mgahinga Gorilla National Park (Figure 62). The results show that Kashasha parish had the lowest water quality when water transparency is used as an indicator of water quality. Kriging interpolation of water transparency for Echuya landscape showed that transparency was high in Muhindura parish while it was very low in Kashasha and Kishanje parishes (Figure 63). Water transparency may be affected by human activities such as poor agricultural practices that may result in increased runoff from the fields. Low water transparency is an indication of heavy silt loading from agricultural fields that may be exacerbated by the steep slopes of the mountainous terrain. The minimum water transparency dropped to 52.7 cm at Kashasha but increased or improved to 120 cm at Gitendere parish and to 117 at Rukongi. Overall protected spring water sources had the highest water transparencies followed by rainwater sources and stream sources within Mgahinga Gorilla National Park. Water sources within Echuya Central Forest reserve had very low transparencies depicting low levels of protection of the water sources. For example, watering of livestock and grazing is a common sighting in the forest where trampling and defecation may lower water transparency. In addition, the rampant illegal activities within the forest reserve has left the forest heavily degraded and thus negatively affecting the watershed functions of the forest such as water purification. At Kamirafumbiri source of Kashasha river located inside the forest, transparency was 43 cm during the dry season but improved to 53cm during the wet season. Water transparency levels for sites inside Echuya forest are very low when compared to streams of Bwindi National park (Kasangaki *et al.,* 2006, Kasangaki *et al*., 2008) and Rwenzori Mt. National Park streams (A. Kasangaki, unpublished data). Water transparency was generally high reaching a maximum of 120 cm in all protected spring sources and in-forest sites and rainwater harvesting facilities mostly around Mgahinga national park parishes (Figure 64). Low water transparencies in agricultural and settled areas are an indication of poor land use practices such as cultivation up to stream banks and unprotected water sources that allow flow of debris and soils into water sources. Very low water transparencies (e.g., 1cm at Hakisementi in Kalengyere parish) were generally recorded in stream water sources especially after heavy rains. In terms of ecosystem service provision of clean water to the communities, the communities near Echuya forest are accessing clean water via underground water sources of protected springs, with surface water sources having water quality that is below national portable water standards. Most surface water sources would require treatment and or purification before it can be consumed locally.

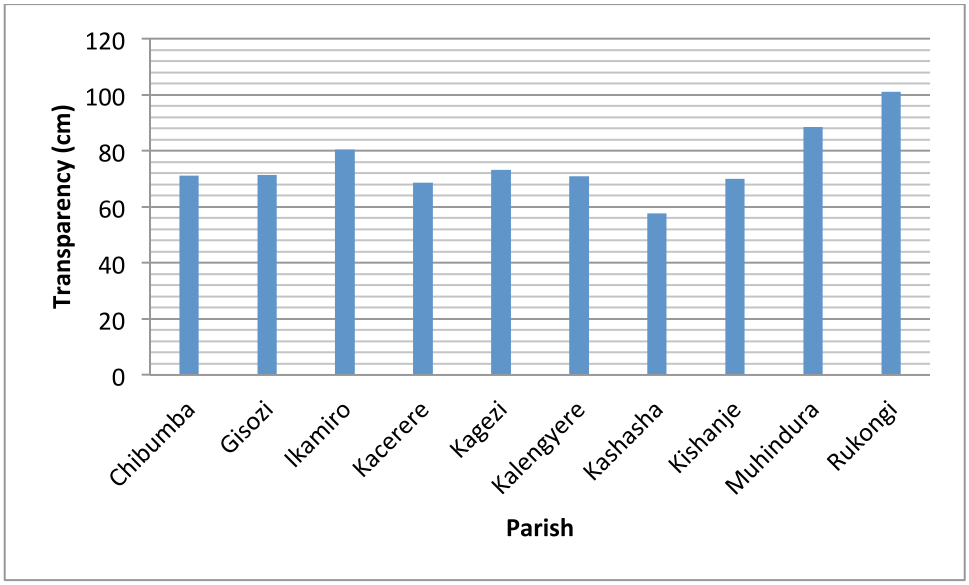


Figure 62. Variation in water transparency

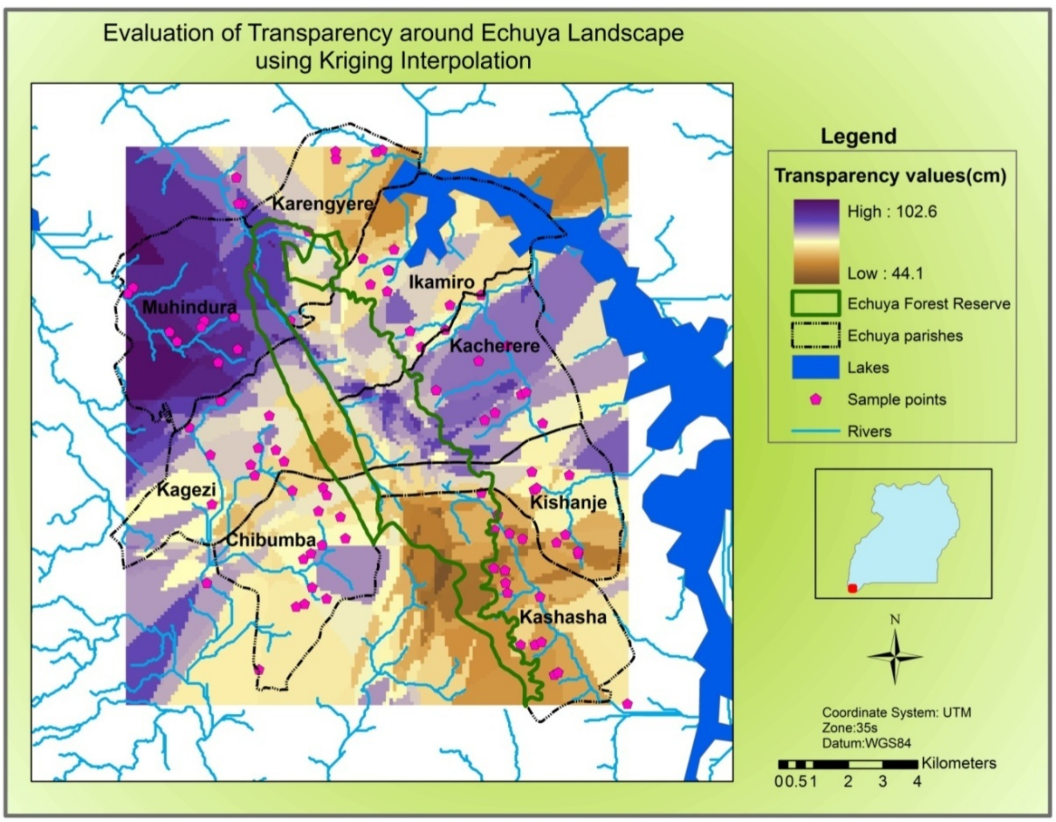


Figure 63. Variation in water transparency values around Echuya forest parishes

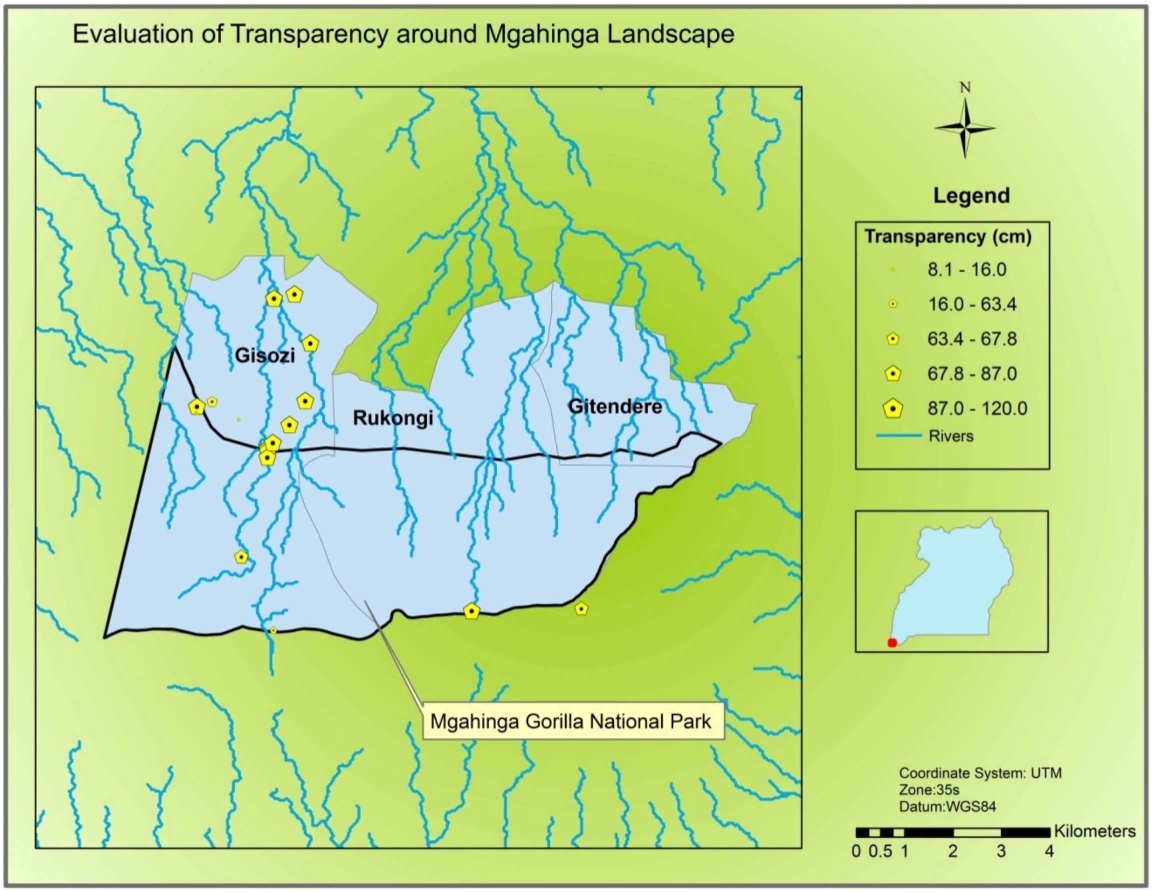


Figure 64. Variation in transparency across Mgahinga parishes

4.3.3.3 Water Turbidity

Mean turbidity that is inversely related to water transparency was lowest at Rukongi with a value of 8.2 NTU and was highest at 97.2 at Karengyere during the dry season (Figure 65). All the mean values were above the National standard value for Uganda of 5NTU indicating that most water sources were not suitable for portable water. However, most protected spring water sources had turbidity values of below 1NTU with some sites such as Nyamabare protected spring in Kashasha and Gatongo perched aquifer in Muhindura parish recoding values of 0 NTU. High turbidity at Karengyere was skewed highly by a very high value of 541NTU recorded at a pond in Mukashayo that was almost dried out during the dry season. The Kriging interpolation map for turbidity around Echuya parishes showed that Kalengyere had the highest turbidity (Figure 67). The pond is used for watering cattle and for domestic use especially by the Batwa community nearby. During the wet season sampling, the lowest turbidity was 3.51NTU at Rukongi parish and the highest mean value was recorded at Kashasha with a value of 119.7 NTU. Very high turbidity is expected during the wet season in areas where agricultural activities are not sustainable thus allowing runoff to enter surface water sources.

Water with very high turbidity can be treated by sedimentation and chlorination to reduce turbidity. Turbidity is commonly treated using either a settling or filtration process. Depending on the application, chemical reagents will be dosed into the wastewater stream to increase the effectiveness of the settling or filtration process. Potable water treatment and municipal wastewater plants often remove turbidity with a combination of sand filtration, settling tanks and clarifiers.

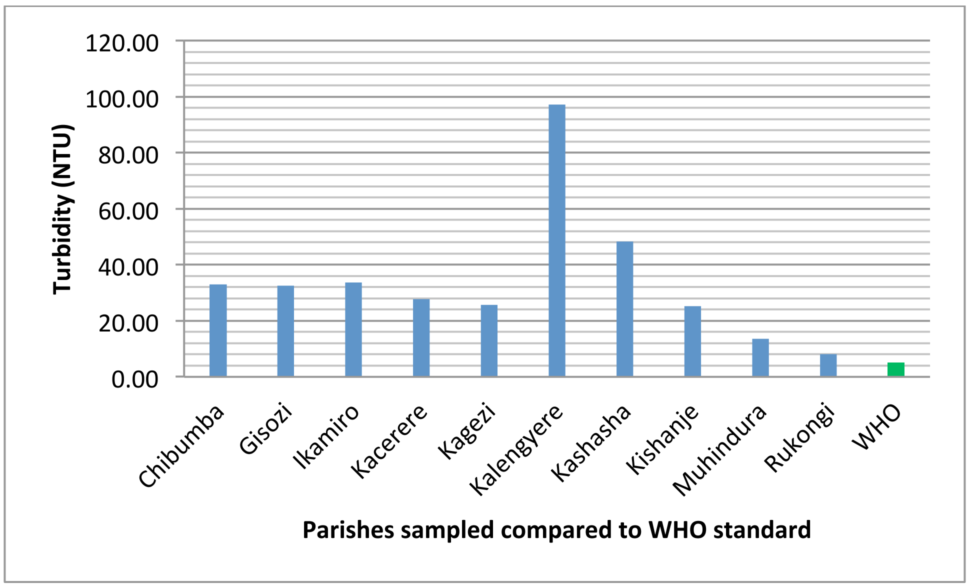


Figure 65. Variation in water turbidity across the parishes.

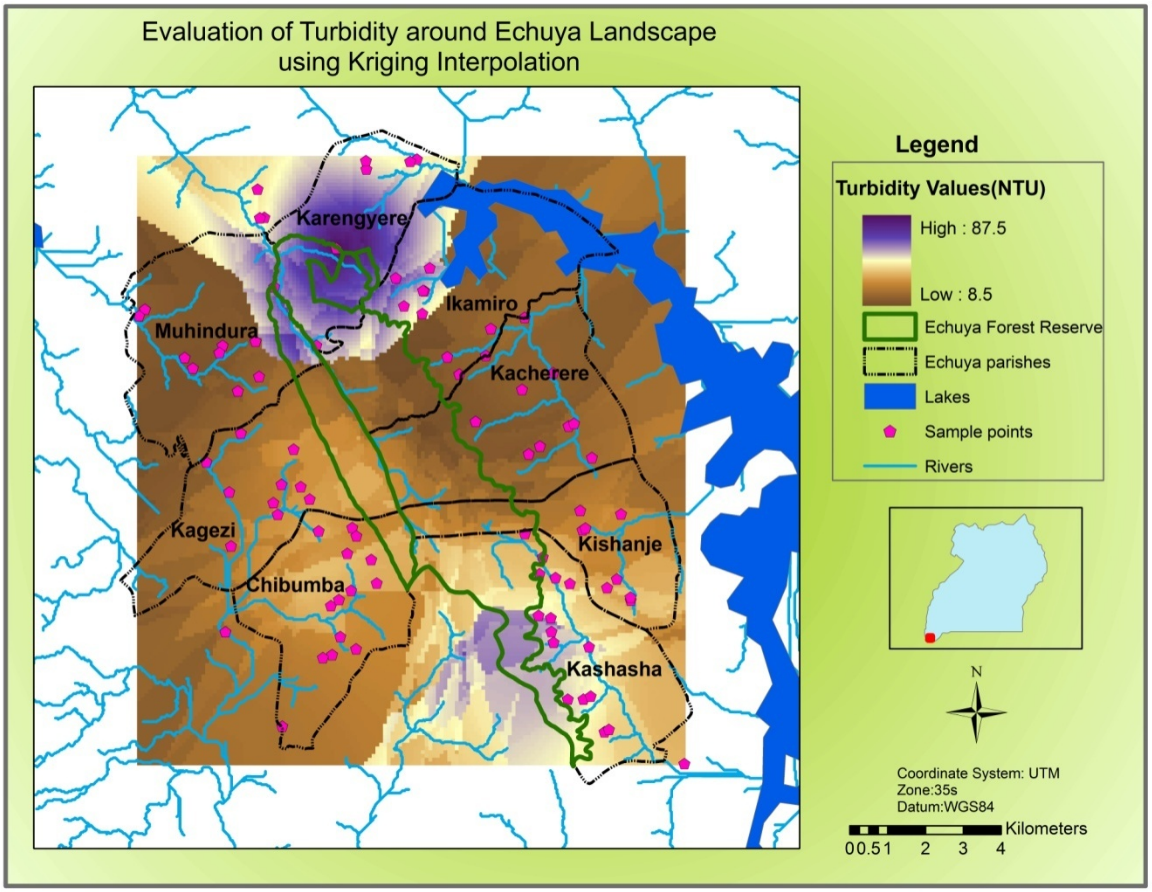


Figure 66. Variation in water turbidity around Echuya forest parishes

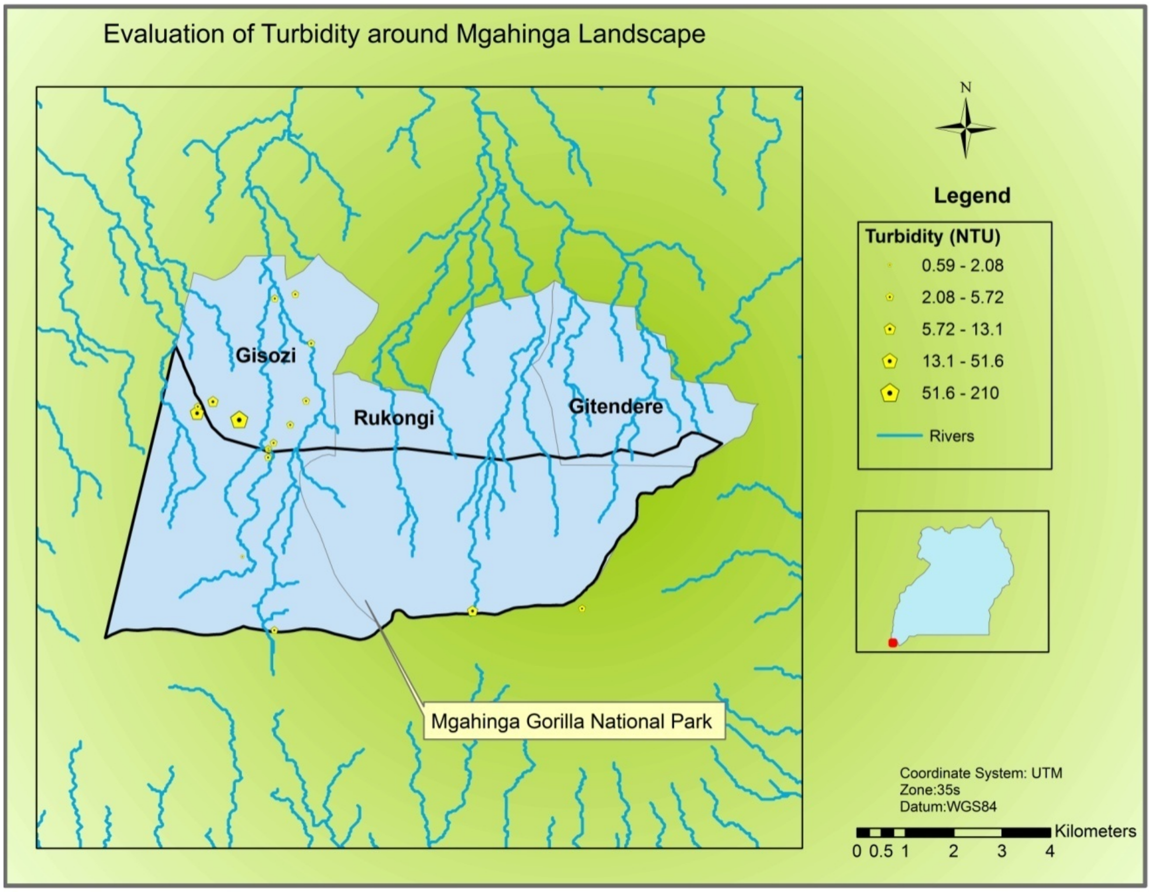


Figure 67. Variation in water turbidity across Mgahinga National park parishes

4.4.3.4 Total dissolved solids (TDS)

Mean TDS varied from 26.1 mg/l at Rukongi to172.9 mg/l at Karengyere (Figure 68, 69 & 70). Like turbidity, the high TDS value at Karengyere was caused by a high value at Mukashayo pond. The wet season values ranged from 27.6 at Gitendere parish to 197.8 mg/l at Ikamiro. Wet season values were slightly higher than dry season values. Both dry season and wet season values are below the maximum permissible value of 700 mg/l recommended by national portable water standards and therefore most water sources may not require treatment for this particular variable. There was no significant difference in TDS between the wet and dry season ($p<0.11$).

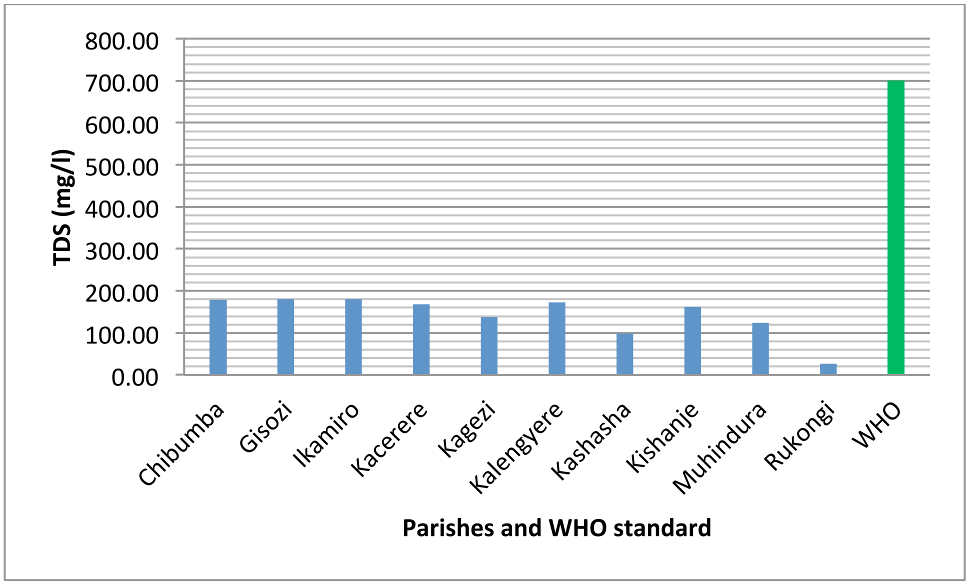


Figure 68. Variation in total water dissolved solids. All values were below the national standard of 700mg/l

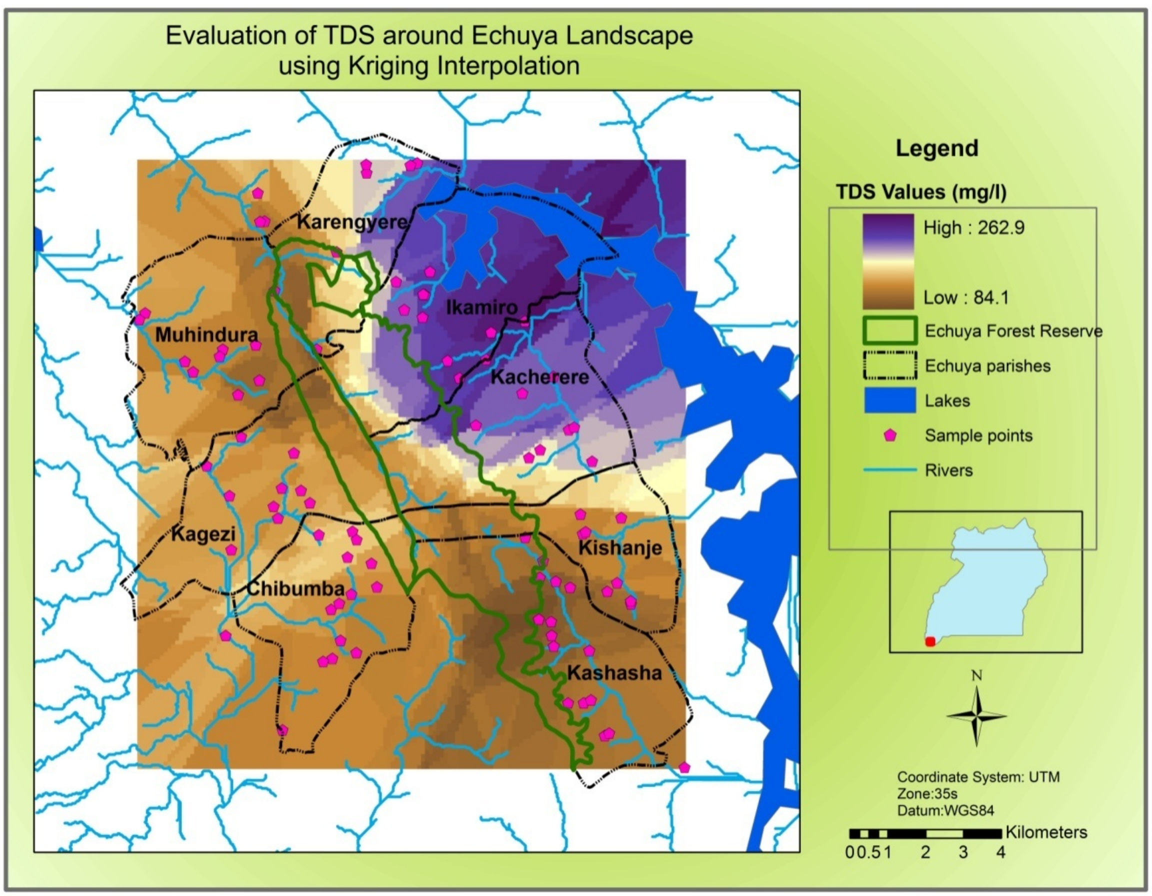


Figure 69. Variation in TDS around Echuya forest parishes. Ikamiro and Kacerere had the highest values.

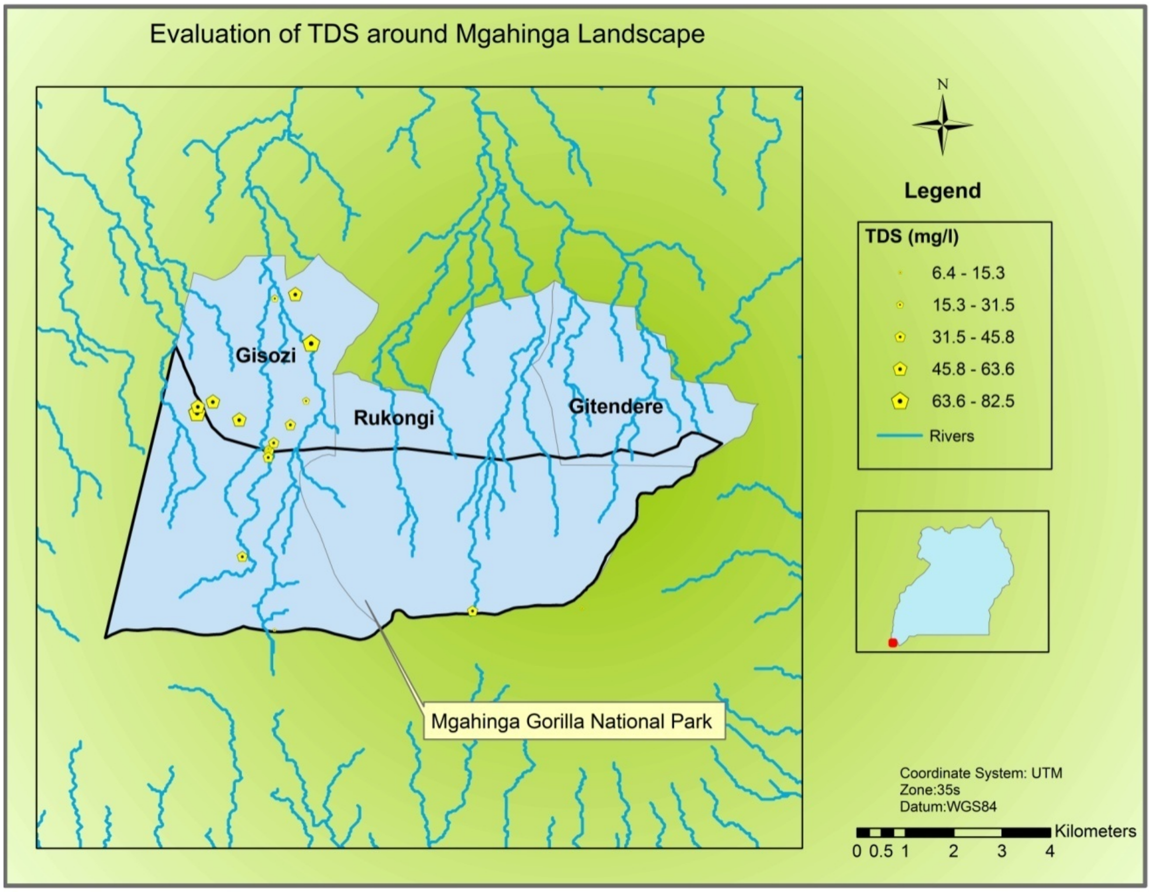


Figure 70. Variation in TDS across Mgahinga National Park parishes

4.4.3.5 Electrical conductivity

This is the measure of water to conduct an electric current through it. Mean conductivity during the dry season was lowest at Rukongi parish (40.2) and highest at Kalengyere parish at 265.9 µS/cm (Figures 71, 72 & 73). Conductivity varies with the concentration of ions in water with a high value indicating high concentration of ions and total dissolved solids. The source of ions is mainly the earth's crust and atmospheric pollutants. Wet season conductivity values ranged from 42.4 at Gitendere parish to 360.7µS/cm at Ikamiro. Conductivity values during the wet season are expected to be lower than during the dry season due to the dilution effect. However, in this study mean conductivity did not differ significantly between the wet and dry season (t-test, $p<0.2$). In this assessment, however, conductivity values tended to increase during the wet season. The probable explanation for this anomaly could be due to the increased ions from agricultural runoff or due to the fact that rains were not heavy enough to cause dilution of water sources or the water residence time of rainwater within the landscape is very low.

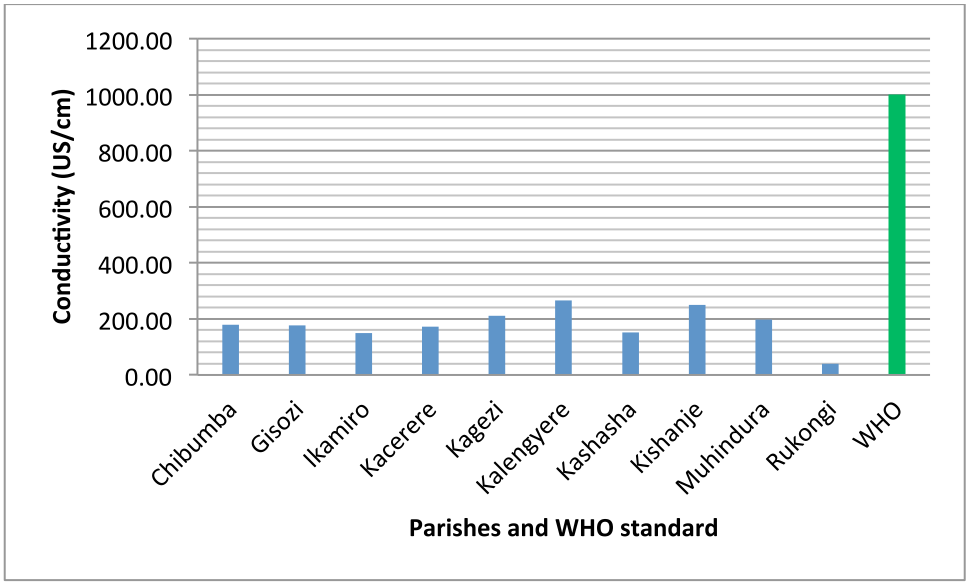


Figure 71. Variation in water conductivity across the sampled parishes

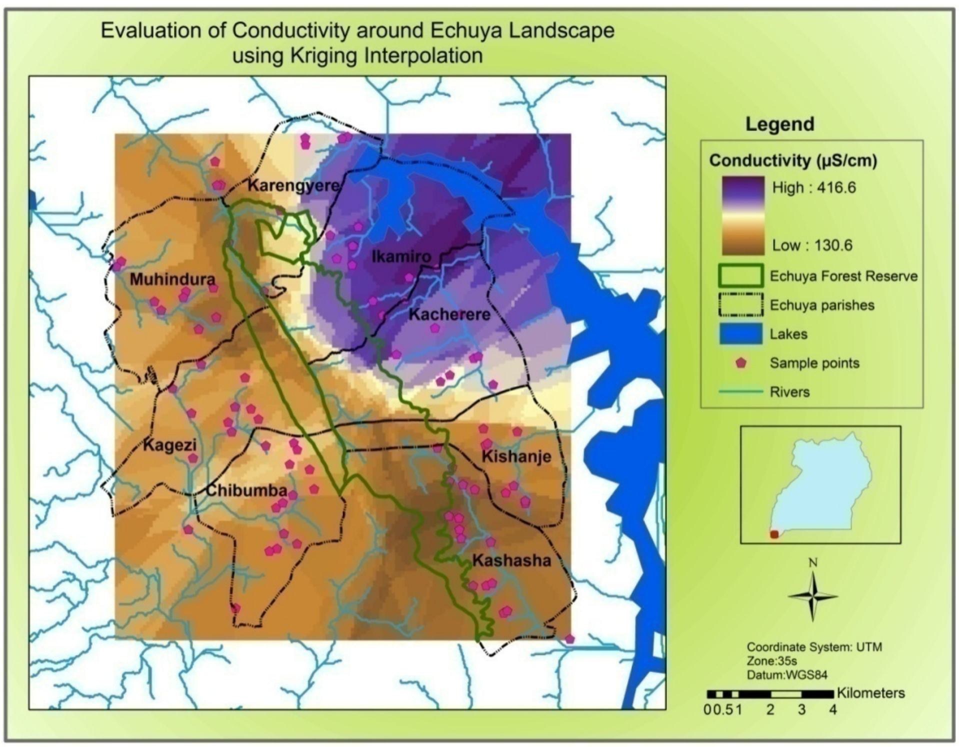


Figure 72. Variation in water conductivity across Echuya forest parishes

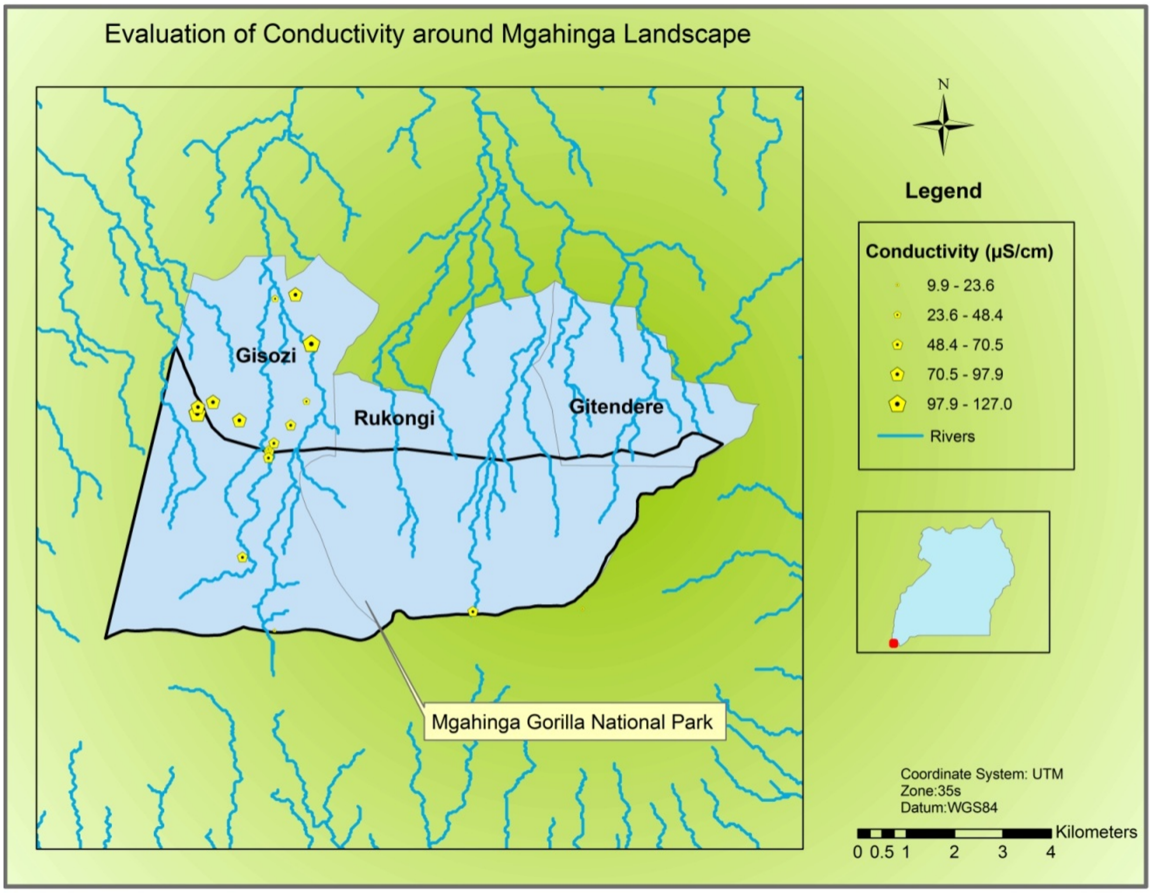


Figure 73. Variation in water conductivity across Mgahinga National park parishes

4.3.3.6 Dissolved oxygen in water

Dissolved oxygen in water ranged from 4.23 mg/l at Karengyere parish to 6.17 mg/l at Kashasha parish. Generally, dissolved oxygen tended to be very low in protected spring, perched aquifers, and wetland water sources because these sources are not open to aeration from the air and because the high decomposition rate in wetlands consumes oxygen during the process. Dissolved oxygen was generally high in stream water sources because of constant mixing during flow and dissolution of oxygen from the atmosphere. There was a slight increase in dissolved oxygen during the wet season with the value varying from 4.74 at Kalengyere to 6.94 mg/l at Rukongi parish. High dissolved oxygen in water is an indicator of good water quality. Low dissolved oxygen indicates organic enrichment and the breakdown/decomposition of which consumes oxygen from the water.

4.4.4 Variations in water parameters measured in situ (laboratory)

4.4.4.1 Water Color

Water color ranged from 17.3 at Chibumba parish to 136.6 PtCo at Kashasha parish (Figure 74). Color in water is usually due to the presence of coloured organic matter (humic and fulvic acids). Drinking water should ideally have no visible color. Overall color tended to be high in intensively cultivated areas such as Kashasha and water sources draining wetland areas such as in Muhindura parish with sources in Echuya swamp and in water sources in Mgahinga wetlands. During the wet season sampling color ranged from 14 at Gitendere (rain water sources only) to 3724 at Karengyere parish. The high value at Karengyere was influenced by an abnormally high value at Hakisementi where the sample was taken after heavy rains. Apparent colour is caused by coloured particulates and the refraction and reflection of light on suspended particulates. Polluted water may, therefore, have quite a strong apparent color (Chapman 1996). Rain water sources had the lowest color values when compared to other water sources.

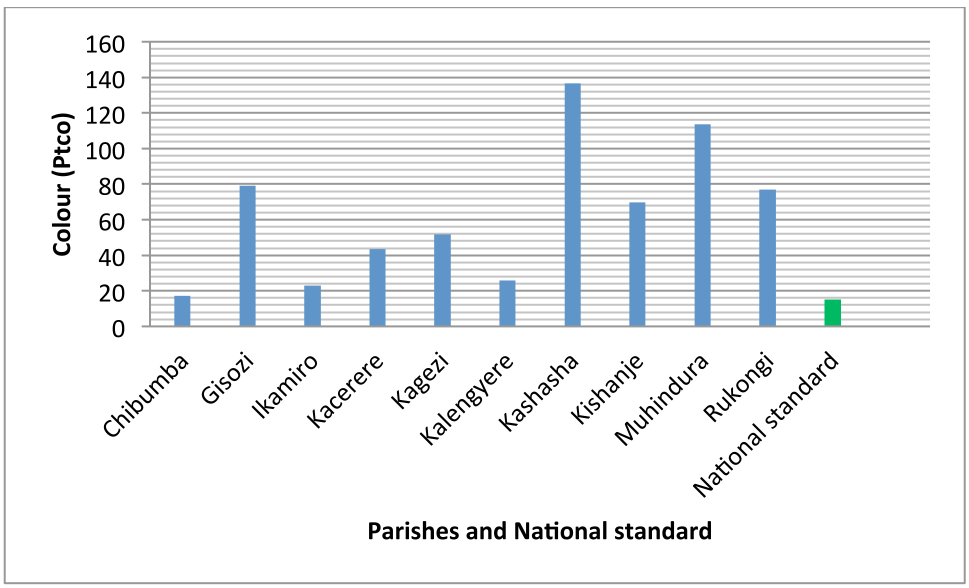


Figure 74. Variation in colour apparent across the parishes

4.4.4.2 Total Suspended Solids (TSS)

This is a water quality measurement usually abbreviated as TSS. Mean TSS varied from 5.2 mg/l at Muhindura parish to 24.1 mg/l at Kashasha during the dry season (Figure 75). It is important to note that the highest value of TSS (156 mg/l) was reported in Gisozi parish at an overused perched aquifer well called Ruborooga. During the wet season, TSS varied from 4mg/l at

Rukongi parish to 1125 mg/l at Kalengyere parish. The value at Kalengyere parish was influenced by a very high measurement (6680 mg/l) at Hakisementi site that was sampled after a heavy downpour. It is important to note that some protected spring water sources had TSS values of 0 thus conforming to the national permissible maximum value. Most other water sources had values above the national standard and would therefore need to be treated before consumption at household level or communally treated at the source.

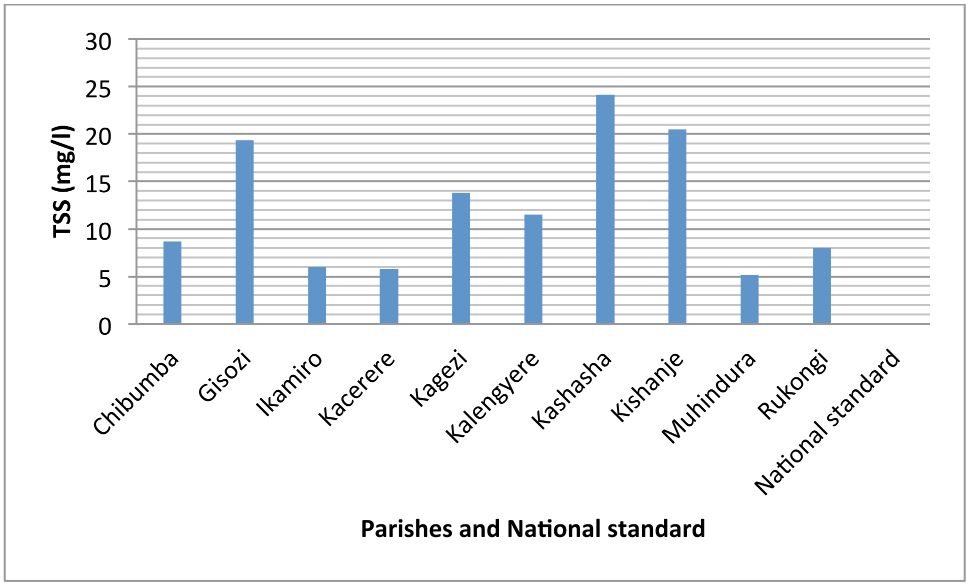


Figure 75. Variation in mean total suspended solids across the parishes

4.4.4.3 Iron total

Iron is found in natural freshwaters at levels ranging from 0.5 to 50 mg/l (WHO 2011). Total iron during the dry season ranged from 0.23 mg/l at Chibumba parish to 1.26 mg/l at Rukongi parish. The highest value of 2.5 mg/l was recorded at Kabiranyuma stream that feeds into the gravity flow scheme. During the wet season, total iron values dropped to 0.04 mg/l at Rukongi and 0.76mg/l at Muhindura parish. The drop in iron content during the wet season may be due to the dilution effect following the heavy rains. At levels above 0.3mg/l iron stains laundry and plumbing fixtures. In some unprotected springs sources, iron oxides (reddish brown) were visible as water from underground flowed over rock surfaces.

4.4.4.4 Total alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids. Alkaline compounds in the water such as bicarbonates (baking soda is one type), carbonates, and hydroxides remove H+ ions and lower the acidity of the water (which means increased pH). During the dry season, total alkalinity was lowest at Rukongi with 24 mg/l and highest at Kalengyere with 111.5 mg/l (The highest value of 158mg/l was recorded at Kabisha stream. During the wet season, total alkalinity ranged between 22.67 at Gisozi parish to 96.7 mg/l at Kalengyere parish. All recorded total alkalinity values were below the national maximum permissible value of 500 mg/l. The total alkalinity should be of no concern to the water resource managers in the affected areas.

4.4.4.5 Total hardness

Hard water is water high in mineral content. During the dry season, water hardness ranged from 24 mg/l at Rukongi parish to 132.5 mg/l at Kalengyere. Hardness was lowest in rainwater sources such as the Maregamo Health Centre water tank but was highest in upstream water sources served by groundwater. During the wet season, hardness varied from 27.4 at Gisozi parish to 165.3 mg/l at Kalengyere. It appears that water sources in Kalengyere consistently had relatively higher levels of hardness when compared to other parishes sampled. All values of hard water were lower than the maximum standard value of 500mg/l. Hard-water does not form leather easily with soap and therefore consumes a lot of soap in laundry. Hard water can be treated by softening (by precipitation or iron exchange), but this in not necessary in all the water sources sampled as the values were below the maximum permissible standard.

4.4.4.6 Calcium ($Ca2+$)

Calcium ion concentration during the dry season ranged between 16.8 at Rukongi to 33.3 mg/l at Kishanje parish. Rainwater and ground water sources had the lowest values of calcium. During the wet season, mean calcium values dropped at Gitendere rainwater sources at 5.33 mg/l but remained relatively stable 33.5 mg/l at Kalengyere parish. The drop in mean calcium levels was influenced by the low levels of the ions in rainwater in Gitendere parish that was not sampled during the dry season because the tanks had run out of water. The lowest level of calcium during the dry season was recorded at Maregamo Health center water tank in Chibumba parish with a value of 3.2 mg/l while the highest value of 52.8 mg/l was recorded at Kayungwe spring in Kacerere parish. In both the dry and wet season samples calcium levels were below the national standard value of 75 mg/l and as such most water sources may not need treatment to increase the values. There was a significant difference in calcium between the wet and dry season with values being higher in the dry season (t-test $p<0.05$). Calcium is an important determinant of water harness, and it also functions as a pH stabilizer, because of its buffering qualities. Calcium also gives water a better taste.

4.4.4.7 Magnesium ($Mg2+$)

Magnesium levels in water during the dry season were lowest at Kagoma river in Kashasha parish and Muhabura Crater lake in Rukongi parish with a value of 0.96 mg/l while the highest level was recorded at Nyamatembe downstream site with a value of 25.9 mg/l. Mean magnesium value per parish was lowest at Rukongi with a value of 1.44 mg/l and it was highest at Kalengyere parish with a value of 14.3 mg/l. During the wet season, magnesium was lowest in rain water sources in Gisozi parish with a value of 0.96 mg/l while it was highest in Chibumba parish at Mumigeshi stream with a value of 22 mg/l. The mean values for the parishes were lowest at Gisozi with 2.49 mg/l and was highest in Kishanje at 12.75mg/l. Seasonal variation in magnesium levels was not very pronounced although a slight drop especially in the mean maximum per parish was noticed.

Magnesium and other alkali earth metals are responsible for water hardness. Water containing large amounts of alkali earth ions is called hard water, and water containing low amounts of these ions is called soft water. It can be generalized that water in the sampled areas was generally soft in nature. Magnesium levels were below the national maximum permissible value of 50mg/l.

4.4.4.8 Phosphates

Mean phosphates ranged from 0.11 mg/l in Rukongi parish to 0.37 mg/l in Chibumba parish during the dry season. The lowest phosphate values of 0.03mg/l were recorded at Muhaburacrater lake and Kagano downstream sites while the highest value of 0.66 mg/l was recorded at Ginya perched aquifer in Gisozi parish. Other low levels (<0.1 mg/l) were recorded in protected spring water sources. During the wet season, mean phosphate values ranged from 0.07mg/l at Gitendere parish (rainwater sources) to 0.4 mg/l at Muhindura parish. The lowest value of 0.01mg/l during the wet season was recorded at Mataramo tank in Gisozi parish and Ndeego A tank in Gitendere parish both of which are rainwater sources. The highest value of 0.93 mg/l was recorded in Kagoma river of Kashasha parish, the major inflow into Lake

Bunyonyi. It is the main river combining all the drainage of Kashasha parish. Overall, the phosphate values were low in rainwater sources and protected spring sources that have no or little input from agricultural runoff. The high levels of phosphates seem to be associated with agricultural activity in the watershed with downstream sources such as rivers having the highest concentrations. In particular, sources close to grazing fields such as Ginya perched aquifer and Kabisha stream draining a cattle farm at Muko parish. The amount of vegetation cover in most areas needs to be improved so as to prevent phosphates from reaching water sources. Mean phosphate values in most parishes were greater than 0.1mg/l, a maximum value acceptable to avoid accelerated eutrophication meaning that most water sources in the study area are eutrophic.

4.4.4.9 Nitrates and nitrites

Nitrates during the dry season ranged from 0.02 mg/l at Kashasha parish to 0.09 mg/l at Chibumba parish. Nitrates were not detected in 13 out of the 57 water samples analyzed during the dry season indicating low levels of nitrates overall, the highest value of nitrates was recorded at Kirangara protected spring in Kashasha parish . During the wet season nitrates ranged from 0.02 mg/l at Kishanje and Kashasha parishes to 0.09 at Chibumba parish. The highest value of nitrates was recorded at Ruzibaziba stream in Kagezi parish. No predictable trend in the amount of nitrates was observed in the sampled water sources. Nitrites did not vary much across the sampled sites and were generally low being less than 0.1 at most sites. The implications of the findings are that the low levels of nitrates may be an indication of lack of fertilizer application in the studied landscapes. Nitrates are therefore of no health concern within the landscape but should continue to be monitored when fertilizer usage increases.

4.4.4.10 Sulphates

The mean sulphate levels during the dry season ranged from 2 mg/l at Rukongi parish to 63.2 mg/l at Kacerere parish. The lowest value of sulphates of 0mg/l was recorded in a rainwater tank in Gisozi parish while the highest value of 106 mg/l was recorded at Ngasire upstream in Kishanje parish. High values of sulphates tended to be associated with headwater sources. In the wet season mean sulphate levels were lowest at Gitendere parish with a value of 0.33 mg/l and highest at Kishanje and Kacerere parishes with a value of 65.4mg/l. The lowest value of sulphate was 0mg/l recorded mostly in rainwater sources while the highest value 0f 126mg/l was recorded at Kishanje parish at Muko protected spring. Overall rainwater sources had the lowest levels of sulphates while the values tended to increase at upstream/headwater sources. Sulfate is classified under the secondary maximum contaminant level (SMCL) standards. The SMCL for sulfate in drinking water is 250 milligrams per liter (mg/l), the Ugandan maximum permissible level is 200mg/l. All the values measured were below the national standard and therefore no water source is in need of being treated to manage the sulphates.

4.4.4.11 Fluoride

Mean fluoride during the dry season varied from 0mg/l at Kacerere parish to 0.5 mg/l at Kagezi parish. The value of 0 was recorded at several sites while the maximum value of 0.87 mg/l was recorded at Gikongogo wetland in Kagezi parish. During the wet season, mean fluoride levels varied from 0mg/l at Gitendere parish to 0.46mg/l at Muhindura parish. The highest level recorded was at Gatongo perched aquifer with a value of 0.93mg/l showing a slight increase during the wet season. However, a t test performed on wet and dry season means showed no significant differences. All the fluoride values were below the maximum permissible level of 1mg/l following the national standards for Uganda.

Fluoride compounds are salts that form when the element, fluorine, combines with minerals in soil or rocks. Exposure to excessive consumption of fluoride over a lifetime may lead to increased likelihood of bone fractures in adults, and may result in effects on bone leading to pain and tenderness. Children aged 8 years and younger exposed to excessive amounts of fluoride have an increased chance of developing pits in the tooth enamel, along with a range of cosmetic effects to teeth. Although Kisoro district is reported to have high concentrations of fluorides in water, this was not the case in the water samples analyzed.

4.4.5 Microbiological indicators

a) Total coliforms: includes both faecal and environmental species. They are used to assess the cleanliness and integrity of water resources. Mean total coliform counts during the dry season varied from 5.5 CFU/100ml at Chibumba parish to 278.3CFU/100ml at Kishanje parish. Total coliform counts varied highly being mostly 0 in protected spring sources and water sources located inside protected area systems and was highest at Kishanje combined stream with a value of 750 CFU/100ml. During the wet season mean total coliforms varied from 1.8 CFU/100ml at Ikamiro parish to 410 at Kishanje parish (Figure 76). The lowest value was zero at several water sources but was highest at

Kishanje combined stream with a value of 810 CFU/100ml. The results indicate that water in most of the areas is not fit for human consumption without treatment or boiling. The coliform maybe responsible for outbreaks of waterborne diseases as was reported for low-lying areas in Kacerere parish.

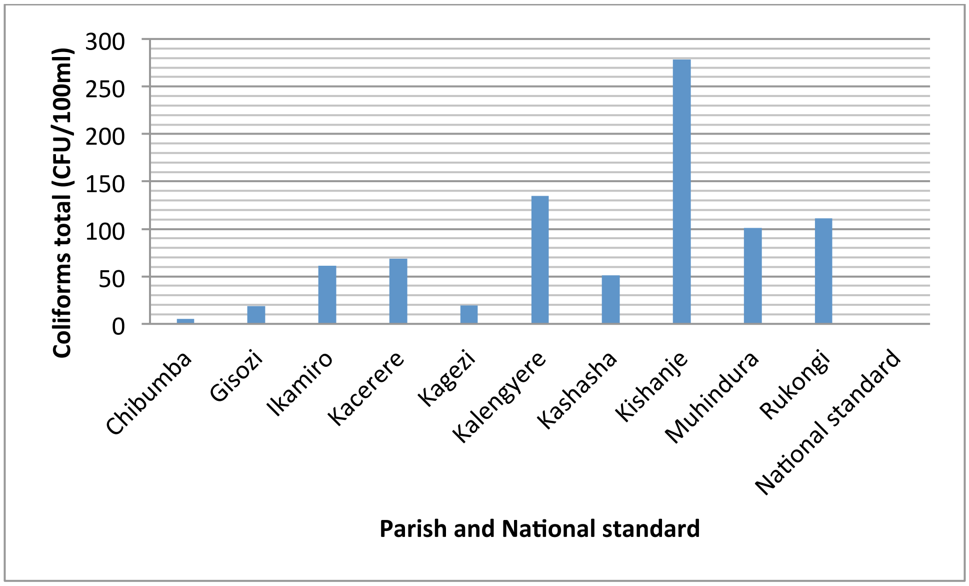


Figure 76. Variation in total coliforms across the parishes. All values were above 0 the permissible value.

b) *Escherichia coli* (*E. coli*) ranged from 0.67 CFU/100ml at Chibumba parish to 56 at Kishanje. Several water sources had zero counts including protected spring sources and rainwater sources. During the wet season, E.coli counts ranged from 0 at Gitendere parish to 83 CFU/100ml at Kishanje. Kishanje, Kashasha and Kagezi parishes were the most infested with E.coli (Figure 77). The water sources need to be treated before domestic use. It is possible that pit latrine coverage in these parishes is very low resulting in open defecation that contaminates the water sources. In some of the villages, human feces were a common sighting along the footpaths and even at water collecting points in certain instances. The communities need to be educated about the dangers of defecating in the open and general sanitation and health education to limit fecal contamination.

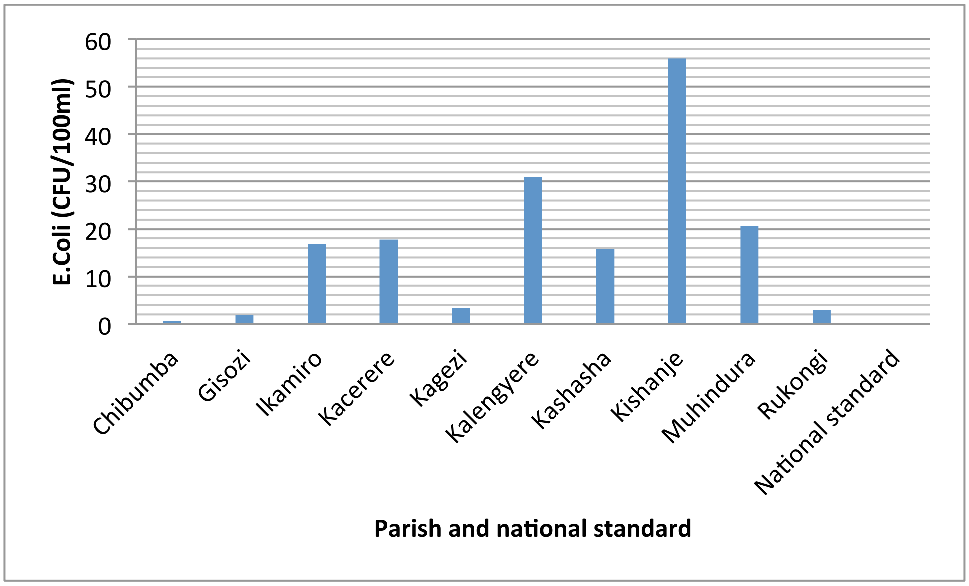


Figure 77. Variation in *E. coli* across the sampled parishes

4.5 Water quantity

Water quantity in flowing water sources was estimated from flow measurements that were converted to discharge values. Flow measurements were measured at 70 flowing water sites. The number of sites per parish ranged from 2 in Rukongi parish to 14 sites in Kashasha parish. The number of sites where flow was estimated depended on the intensity of the rivers in the drainage system.

Discharge during the wet season varied from $0.06m^3/s$ at Ikamiro parish to $0.34\ m^3/s$ at Gisozi parish. Although Butare parish is not a frontier parish of Echuya forest, two sites were sampled for flow measurements on Ruhuura river, the main outflow of Lake Bunyonyi that constitutes the main drainage of Echuya forest. Mean discharge at the outflow was $7.3\ m^3/s$ or 7300 l/s flowing out of Lake Bunyonyi. Several spring and stream sources within the landscape have been tapped for gravity flow schemes and other with potential still exist in parishes around Echuya. Water quantity especially for standing water sources was not estimated due to technical impediments and difficulty in accessing the middle of the sources. Water quantity in most parishes apart from Kalengyere and Mgahinga parishes seemed sufficient but the problem is that distribution within a parish is clumped and as such water scarcity was common. There is therefore need for extending the distribution systems where water is abundant, and establishment of alternative systems such as rainwater harvesting facilities large enough such as reservoirs that are able to sustain communities in both the wet and dry seasons.

4.6 Stakeholders involved in water resource management in the landscape

Table 7 shows a multiplicity of stakeholders operating in Mgahinga and Echuya Landscapes and carrying water management interventions. They have various roles in water supply, usage and management. The matrix reveals uncoordinated roles of stakeholders leaving other roles especially maintenance unattended to. This calls for an integrated approach to reallocate roles and responsibilities to all players and actors to better position water management interventions. This would necessitate inter and intra-stakeholder engagement to aid conflict of interests and un coordinated roles. Since Great Virunga Transboundary Collaboration plays are coordination role, it would be vital if various stakeholders refocused their operations.

Table 7: Water Stakeholder Analysis in Mgahinga and Echuya landscape

Who is involved?	**Roles played**	**Length of involvement in WRM**	**Scope/spatial area of operation**	**Limitations**
BMCT	• Construction of water tanks	Since 1994	Bwindi Mgahinga Conservation Area (BMCA)	• Poor coord and targetin programmes
CARE	• Construction of water tanks	Since 1994	Albertine rift	• Insecurity • Wild animals break pipes ins park. • Limited funds
GVTC	• Funding implementers such as URP • Coordination • Technical support	Since 2007	Virunga Massifs	• Insecurity • Limited Fundi more extension.

URP	• Provision of water through tanks construction	2009-up to date	Kisoro district	• Limited funding
IGCP	• Construction of water tanks in Gitendere and Rukongi	Since 1991	Virunga massif in Rwanda, DRC and Uganda	• Limited fundin
UWA	• Support of Kabiranyuma water scheme • Construction of water tanks	Since 1991	Communities boardering National Parks	• Wide mandate • Limited te ability
AFRICARE	• Construction of group water tank in Kagezi and Muhindura	Not sure	Kagezi and Muhindura (Echuya)	• Limited funding • Hilly terrain
UNICEF	• Construction of water tanks	Not sure	Kacerere (Echuya)	• Landslides • Limited fundin
RED CROSS	• Construction of water tanks	Since 2010	Gisozi parish (Mgahinga) and Kacerere (Echuya)	• Limited funds • Corruption
Japan organization	• Construction of water Tank	Not sure	Mgahinga-Kagoote	• Limited funds
AICM	• Construction of water tanks and a water springs		Kacerere and Ikamiro parishes (Echuya)	• Poor managem water users • Limited fundin
Raising the Village.	• Construction of 3 tanks	4 years ago	Gitendere parish (Mgahinga)	• Limited funds
WASH/(USAID funding)	• Construction of water supply networks	Since 1986	Rwanda/Uganda/DRC	
VHTs	• Sensitization of the community on hygiene • Monitoring water usage		Since 2006	• Competing i that coordination • Low levels

				education and capacity
Water Management committees	• Monitoring water installations and usage • Maintenance of water sources and points • Community mobilization • Conflict resolution at local level • Organizing meetings • Collecting and managing local financial contribution	Indefinite	• Mgahinga • Echuya	• Limited fi capacity • Uncoordinated management strategies • Limited understanding definition • Corruption an of transparency
Local Councils	• Monitoring water supply and usage • Community mobilization and sensitization • Supervisory work of water infrastructure • Organizing and conducting meetings • Putting up bye-laws and local policies • Water sources/points maintenance	• Indefinit e	• Mgahinga and Echuya landscape	• Limited instit capacity • Perception volunteerism • Corruption
Kisoro DLG	• Construction of protected water springs, tanks, gravity water scheme and piped water	• Indefinit e	• Gisozi • Rukongi • Muhindura • Kagezi	• Limited funds • Poor road netv the rural areas district.

			• Kacerere • Kishanje • Ikamiro • Kashaasha.	• Limited insti capacity
Stretcher groups	• Monitoring water sources and points • Community mobilization • Sensitization of community members • Community contribution such as buying land for water tanks • Water maintenance and repairs • Grass root water management	• Indefinit e	• Mgahinga and Echuya communities	• Limited inform • Corruption in management • Being in the areas.
Church of Uganda	• Donation of water jars and tanks • Construction of protected water springs	Since 1990	• Rurembwe Parish (COU) • Kashambya • Karengyere • Matakara, • Katembe • Bigyegye • Ikamiro • Rwamahano • Karengyere	• Limited Funds
Compassion	• Construction of	Since 2000	Kishanje parish-Echuya	• Limited funding

International	protected water springs		landscape	• Wide mandate
Private individuals	• Donation of water jars and tanks • Construction of protected water springs	-	Kisoro district (Murindi, Kifumba and Muhindura)	• Limited f capacity • Politics of delivery
Households	• Maintenance of water sources and points • Administering water usage • Attending meetings • Construction of Own tanks	Indefinite	Mgahinga and Echuya landscapes	• Limited funds • Limited capacity

4.7 MS ACCESS DATABASE FOR THE MGAHINGA AND ECHUYA LANDSCAPE

An MS Access GVL regional database of the different parameters and variables listed above was developed for monitoring and evaluating water resources data in the Echuya and Mgahinga landscpe. This will be shared and agreed with GVTC and other regional stakeholders in region (see appendix for a manual on the database). This database contains all the variables and parameters of the GVL region database such as those of socioeconomic surveys, Hydrological modeling and the Hydrological assessment.

5. Discussion

5.1 Socioeconomic assessments

5.1.1 Land use patterns and their implication to water resources

The land use practices around Echuya and Mgahinga could be major factors that affect water quantity and quality. Most respondents reported to be practicing arable farming with limited mitigation measures for run-offs and soil erosion. Most land around Echuya has been fragmented into small pieces that may not support proper terracing and bush fallowing or any other sustainable land management practices. The need to integrate protected areas into the wider landscape has never been more urgent than now, and will only become more so each subsequent year, because of the synergies and negative feedback loops between fragmentation and climate change (Ervin, 2010:26). It is important to note that fragmentation of land impairs the ability of a species to adapt to the rapidly shifting habitat patterns and ecological processes that result from climate change, further weakening their resilience, and increasing the likelihood of local and widespread extinctions. It is also an accelerator for soil erosion.

Most of the poor quality water reported in Kishanje, Kagezi and Muhindura were greatly attributed to poor agricultural practices in the region. Local leaderships have relaxed on compelling local communities to practice good agricultural practices. This would be done through sensitization campaigns and administering of penalties to the culprits as it was in the past. Residents in higher slopes do not leave space for run-offs and cultivation has been done closer to water sources. Terraces are no longer in place to reduce the level of soil erosion. The study observes that, local communities ought to reverse agricultural practices in order to address high-runs off, soil erosion and uncontrolled flooding.

5.1.2 Water sources and access by local communities

The study reveals that there are existing water sources around Echuya that have not been tapped to supply water in most parishes that do not access sufficient water. The challenge rotates on the institutional arrangements to enable people access available water. In Mgahinga, there are limited permanent water sources especially in Gitendere and Rukongi. Important to note is that, access to safe water is a requirement by World Health Organisation (WHO). It has been documented from field surveys around Echuya and Mgahinga that local residents do not access sufficient and safe water for their household use. This access to safe water varies from parish to parish and Mgahinga and Echuya. For instance in the parishes of Gitendere and Rukongi around Mgahinga, access to safe water is a big challenge compared to any other parish. Gisozi is relatively fine compared to Gitendere and Rukongi.

On the other hand, some parishes around Echuya such as Karengyere, Muhindura and parts of Kagezi were found to be facing a serious challenge of water access and more so water quality. This was mainly attributed to limited permanent water sources, terrain of the area, soil erosion and flooding. It is important to note that the provision of sustainable safe drinking water by 2015 to half the world's population is a Millennium Development Goal number 7 (MDG 7). For any interventions, there are location dynamics that have to be understood before implementation programmes. Some of the existing water schemes are not functional. This is mostly attributed to poor management systems at local levels. It is important to note that, there are various water sources that could be utilized to supply water in areas where access is hard. If safe water scarcity cases of the Great Virunga Landscape are not addressed, then it will become hard to achieve this target. More to that, the emerging effects of water scarcity and poor quality are likely to affect community welfare and at the end hinder sustainable development strategies.

Although endowed with major forests, the GVL experiences acute safe water scarcity for local people downstream compared to those upstream. A case in point is the Jinya aquifer in Gisozi where water comes from the ground downstream and hence benefiting residents in those localities. This constraint is place despite the large watersheds provided by the forested national parks (USDA Forest Service, 2008). High quantities of water are generated in the forested mountains but are unavailable to the local people downstream. This is because most of the water sources are located inside the protected area systems and because of the porous nature of the volcanic soils in the GVL, surface water is very scarce at the base of the mountains (USDA Forest Service, 2008). As such during the dry seasons, the local people often enter the PAs to collect water for domestic and other uses. This sometimes has contributed to increased pressure on the PAs through illegal activities and disease transmission from and to wild animals and the local people. This is a potential source of conflicts between PAs management and the adjacent local people. Therefore, as generally noted, interventions to address water scarcity in Mgahinga and poor quality around Echuya ought to be looked at seriously by government and development agencies since water is life and a big component for survival.

5.1.3 Water use, demand and supply

As noted by Postel (2000), ensuring the provision of reliable and safe water supplies to a high local population of about 600 people/km^2 while at the same time maintaining the ecological integrity of the local habitats is a considerable challenge that needs urgent attention. The hydrological conditions documented and analyzed around the two Protected Areas are not different from what was noted by WHO (2012), that a considerable number of people in today's world have to rely on small community water supplies for their daily basic needs, both in industrialized and in less developed countries. These communities, often in remote places, tend to lack capacities for essential management, operation and maintenance, and implementation of technical improvements.

Increased human populations combined with increased shortage of arable land have contributed to deforestation and unsustainable farming practices resulting in increased incidences of hydrological related hazards such as diseases, soil erosion, landslides and floods (USDA Forest Service, 2005); Ervin, 2010; Bitariho, 2007)). This has been exacerbated by lack of conservation-based land-use systems in the area. Furthermore, it has been reported that some water sources have dried and some such as Chuho have had reduced water levels, probably related to effects of climate change in the region.

Also noted from the study is that, the demand for water in most communities is higher than the available water. People have been forced by nature to use what is available to them. However, the current number of jerricans used by respondents for domestic chores, livestock and arable farming do not reflect water demand. In some communities, people have resorted to bathing once a week and sometimes once a month (FGD in Nzogera, Gitendere parish). This is a dangerous health hazard. Failure to meet water demands is likely to result into unprecedented effects that may be difficult to reverse.

5.1.4 Perceptions on water quality

Most people around Mgahinga and Echuya perceive the water they use for domestic chores as fairly clean. Few people mentioned about accessing very clean water. This is challenge to achieving WHO and MGD targets of communities accessing safe water by 2015. Hydrological measurements in the two PAs are essential for the interpretation of water quality data and for water resource management useful for the local people. It was also found out that, majority of the respondents do not treat water to improve its quality. This was attributed to limited sensitization and awareness of some of the methods for water treatment. The majority who mentioned boiling water also cited challenges emanating from cultural constructions such as the tradition of people taking unboiled water. Therefore, in order to counteract cultural and traditional constructions as well as limited awareness, Government and Non-Governmental Organizations should focus on sensitization campaigns that will help people understand and appreciate methods of improving water cleanliness since most water accessed especially around Echuya gets contaminated due to soil erosion and flooding.

5.1.5 Water management, challenges and effects

The management of water regimes around Echuya and Mgahinga is still a serious challenge. The limited water sources and points in place are still not well maintained and monitored. The positive aspect, however, is that in most parishes we visited, water management committees were in place although not functional. However, committee roles ought to be revamped in order to improve water management in the region. Since southwestern Uganda is vulnerable to flooding due to its mountainous features and rampant unsustainable farming practices on the steep sided slopes (Perotto-Baldiviezo *et al*., 2003), there is need for much empowered committees that can put in place strong early warning mechanisms in collaboration with other development partners and ensure compliance to the different bye laws set in place for effective water management.

Further still, there were natural factors that challenge the quality and quantity of water received. Variations in hydrological conditions have important effects on water quality. In rivers, factors such as the discharge, the velocity of flow, turbulence and depth will influence water quality. Despite the high vulnerability of the region to flooding, no attempts have been made to model out the spatial distribution of flood hazards, and the influencing factors. This would be done if water management committees had a strong working relationship with the districts of Kisoro and Kabale as well as Development Agencies. It is noted that prediction of flood hazard through effective flood/soil erosion modeling could help mitigate the worst effects of such disasters by identifying vulnerable areas using simple maps of potential floodwater distribution (Al-Sabhan*et al*., 2003).

5.2. Hydrological modelling

The model outputs illustrate the spatial distribution of runoff and soil erosion patterns in and around Echuya Central Forest Reserve and Mgahinga Gorilla National Park Landscapes. Hydrological modeling was carried out at a wider extent in order to capture the topological relationships (water flow and draining patterns) that shape watersheds and how they are related to parishes in the study area.

Surface runoff occurs when rainfall intensity exceeds the infiltration capacity. Flood risk zones are likely to constitute all areas that experience high runoff values. Using runoff values as an indicator of the likelihood of the flood hazards, the Mgahinga landscape is likely to experience more flood hazards than the Echuya landscape. The 200m buffers around delineated perennial and seasonal rivers/ streams in the study area approximate the flood plain. The buffers show areas that are likely to be affected by flood hazards.

Computed runoff was comparably low for all the parishes around the Echuya landscape, with Chibumba having slightly higher values. The low runoff values indicate that there is sufficient ground water recharge around the Echuya landscape. This means that the groundwater intersects with the streambed leading to the creation of perennial stream flow and households around the landscape are less prone to drought.

The high runoff values as indicated by the model outputs around Mgahinga landscape show that the rate of infiltration is low, which could be reducing groundwater recharge affecting water availability to the communities. Results from the water source survey, suggest that the water table in the area is low, as there were no perennial rivers observed. Most households around the landscape depend on rain fed water tanks for their water needs which means they are likely to face water scarcity if there is a change in rainfall regimes.

5.3 Water quantity and quality in the Echuya/Mgahinga landscape

Water sources varied within and among parishes with parishes in Mgahinga National Park having the least number of water sources composed of perched aquifers, wetland sources inside the park and gravity flow schemes originating from inside the park. Because of water source scarcity in the communities, rainwater-harvesting tanks are quite common both at household level and at communal tanks. Around Echuya, Parishes of Karengyere and Muhindura parishes had the least number of water sources and thus were the most water stressed. Other parishes such as Kashasha, Ikamiro, and Chibumba had a variety of water sources ranging from protected spring sources, streams, rivers and gravity flow schemes.

Mean pH across the sampled water sources was generally acidic and thus below the recommended national standard range of 6.5 to 8.5. Most protected spring water sources had acidic waters and thus would require treatment with soda ash before domestic consumption. Kashasha and Kishanje parishes around Echuya had the most acid waters among the sampled sites.

Water transparency was above 120 cm in most protected spring sources and rainwater sources. The transparency tended to get poor with intensification of human activities within the watersheds of the different water sources. The variable was identified as simple measurement that communities can use to monitor the quality of their water sources and in assessing the effectiveness watershed management practices in the landscape.

Turbidity was very low in rainwater sources and protected spring sources. The mean turbidity values in all parishes were below the national standard value of 5NTU. Turbidity was very high in agriculturally impacted water sources such as headwater sources and the streams and rivers thy drain into. Water conductivity in all the sampled sources was below the maximum permissible value of 1000 μS/cm. The conductivity values however tended to increase with the intensity of human activities such as cultivation on steep slopes and removal of vegetation around water sources.

Color apparent tended to be higher in water sources impacted by agriculture and in wetland water sources. Although drinking water should ideally have no colour, most water sources had some color and would therefore require treatment before consumption but may be useful for other purposes such as watering animals and in small scale irrigation of crops. Total suspended solids were above national standard in most water sources. This implies that most water sources inputs from terrestrial sources such as agricultural and road runoff that add the suspended materials to the receiving water sources.

Phosphates values were generally low across the sampled water sources but with very low values in rainwater sources and protected spring sources. Relatively higher values were associated with water sources close to livestock grazing areas such as Ginya perched aquifer and Hakisementi stream that drains a cattle farm. Runoff from the grazing fields and watering animals from the water sources may be the cause of the slightly increased phosphate levels in the water sources. Nitrates were also very low in most water sources sampled. The only likely sources of nitrates maybe the animal kraals and other animal tethering facilities in the homesteads. Phosphorous and nitrate pollution is not yet a problem in the landscape because of the low or no application of fertilizers.

Fluorides in sampled water sources were below the maximum permissible standard for portable water. This implies that the water in all parishes does not pose a health risk to the communities.

Total coliforms and *E. coli* were the microbiological tests performed for water quality. In all sampled sources, mean values per parish were above the standard value of 0. Low values of total coliforms were common in rainwater sources, protected spring sources, and water sources located inside the protected areas. The high levels of coliforms in water sources located in communities are an indication of poor sanitation facilities such as open defecation that contaminate the water with fecal material. Communities need to be sensitized on the importance of sanitation facilities and on boiling water advisories especially for drinking water.

Water quantity as measured by discharge was generally low because of the location of streams and rivers in headwater areas. The flow rates despite being low in most streams and springs, they can sustain gravity flow schemes to supply downstream communities. The main outflow out of Lake Bunyonyi was high enough to even support a micro-hydro power plant.

Water sources distribution within the parishes was not uniform and as such water was scarce in certain parts of a parish while it would be abundant in others. Overall parishes around Mgahinga National Park were the most water-stressed with limited natural water sources.Based on these findings, some parishes need urgent intervention in terms of establishing water provisioning facilities such as rainwater harvesting and construction of gravity flow schemes where clean water sources are inaccessible. The parishes in need of urgent attention are Kalengyere in Echuya forest and the three parishes of Mgahinga with Gitendere as the most water-stressed parish. Degradation and lack of maintenance around the water sources was quite common and some were often non-functional.

6 Conclusions

Despite the landscape being an area with vast water resources, communities around the landcscape do not get adequate water for household, livestock and agriculture uses. This vulnerability defers from protected area to protected area. For example, communities around Mgahinga parishes (Gisozi, Rukongi and Gitenderi) are more vulnerable than those around Echuya. It is important to note that, communities around Mgahinga and Echuya are vulnerable in terms of water quality and quantity. However, this defers from Protected Area to another, from parish to parish and village to village. Mgahinga is more prone to water challenges compared to Echuya parishes. For the interventions already in place, there is need to improve the implementation formula in order to have success during evaluation. The fact that some of the already established water sources are not functional shows institutional weaknesses more especially at the local level. Local government structures and entire local leadership ought to function in order to redeem their people from water related challenges.

For successful implementation of water interventions, it is important that community members who are to benefit from water schemes get fully involved in all processes of the project cycle. The community, particularly community leaders and decision-makers should understand the benefits of the sought interventions but not only acting as receivers. Buy-in from decision-makers for water interventions ought to be used to obtain support for changes in the operation, maintenance and management of the community water supply and to ensure that sufficient resources are available. The community as a whole can be engaged in a number of ways. From the design of water projects, the community grass root members ought to be part, if success is to be registered. It is generally more efficient and effective to identify suitable members of the community to also sensitize the rest of the community members in supporting various water interventions. This can be done through public meetings, participatory rural appraisal techniques and regular technical meetings.

The management of both Mgahinga and Echuya could allow negotiated access of water resources which are close to people around the two protected areas with a formal arrangement that deters people from committing illegal activities. This is because; the objectives of the Convention on Biological Diversity are to achieve the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising from the utilization of biological diversity (Ervin, 2010:8). Having a legal platform in place would address the already encountered illegal activities as a result of illegal access of the PAs to access water.

The number and types of water sources varied highly among the different parishes around Echuya forest with some parishes such as Kashasha and Chibumba having several water sources while parishes of Kalengyere and Muhindura had fewer water sources. Around Echuya forest, Kalengyere was the most water-stressed parish. All parishes around Mgahinga National park had very few water sourceswith most communities dependent on rainwater sources and the Kabiranyuma gravity flow scheme. Based on these findings, some parishes need urgent intervention in terms of establishing water provisioning facilities such as rainwater harvesting and construction of gravity flow schemes where clean water sources are inaccessible. The parishes in need of urgent attention are Kalengyere in Echuya forest and the three parishes of Mgahinga with Gitendere as the most water-stressed parish.

Degradation and lack of maintenance around the water sources was quite common and some were often non-functional.

7. Study limitations

1. Some permanent water sources outside the study area were not assessed and yet are still used by the local communities in the study area especially when the dry seasons are severe.
2. The time frame for this study was not enough to assess other water management issues such as costs of flood/soil erosions effects, population density dynamics and other related socioeconomic variables important for water resource management studies. This could be assessed in further studies.
3. Flooding/soil erosion risk model parameterization could be improved in future by mapping the different soil conservation practices being applied in the study area, using a detailed land cover map and having more weather stations for interpolation of precipitation data in the study area.
4. Accurate long-term records of rainfall data, river water discharges in the GVL region useful to model floods risk/soil erosion areas was not available (we used discrete data available for Kisoro/Kabale districts as such). The availability of this data was affected by the political turmoil and wars that have existed for over three decades in region.

8 Recommendations

8.1 Potential water sources available to the local communities

This study proposes potential water sources from springs located in the upper parts of the watersheds since they have clean water and are able to sustainably provide water to downstream communities using gravity flow. Perched aquifers also to have safe and clean water and can be sufficiently and sustainably developed to provide safe water to the local communities in the landscape. These water sources would have to be developed into reservoirs from where it can be supplied to distant communities using pumps. Communities living in the upper parts of the watersheds (Mgahinga) should be provided with rainwater harvest tanks to be able to tap rain water for domestic and other homestead uses. Such rainwater harvest tanks are appropriate to areas with volcanic soils in the upper parts of the watersheds that have volcanic soils and therefore need aquifers or springs. The proposed water sources include; Gatongo perched aquifer in Muhindura Parish (Echuya), Kyamuhana spring in Ikamiro parish (Echuya), Ntebeeko stream in Gisoro parish (Mgahinga) and Kazibakye perched aquifer in Gisozi Parish (Mgahinga).

8.2 Appropriated technologies for water treatment of selected water Sources

Open water sources such as streams and rivers with high turbidity and dissolved solids etc. will require treatment such as filtering, chlorination, and boiling before being proposed for use by the local people (which is not the case presently). Open water sources have high levels of fecal contamination and would also therefore have to be boiled before consumption. These recommendations are for the rivers, streams and pond water sources.

8.3 Specific Action Points for Water management in the Mgahinga/Echuya Landscape

The Specific action points for Uganda to be addressed by conservation and development partners are listed in table 8 below.

Table 8. Specific recommendations for development of sustainable water management systems in Mgahinga/Echuya landscape

Category of intervention	**Recommendation**

Potential water sources available for water supply to the communities	1. We recommend tapping the already existing water sources with sufficient quality and quantity. Tapping water from Kabiranyuma swamp is necessary after an in-depth assessment. This is because, there were indications of reduced water levels yet the swamp is the main hope to supply water to both parishes in Uganda and Rwanda. 2. There is a perched aquifer of Kabizakye- Gitendere parish that has low turbidity (below 5 NTU) and high transparency (87) and can be a potential water source in Gitendere parish. 3. Mirunda protected spring has high transparency and low turbidity (below 5 NTU). It can be a sufficient water source for Karengyere parish communities that live upland. 4. Water can also be pumped from Echuya River to supply Karengyere parish. Echuya River has low turbidity and high transparency and high water quantity. This can be a potential water supply.
Appropriated technologies of quality water provision to the community	1. Electricity pumping technology is recommended for Gatongo aquifer in Muhindura parish, Echuya area. This perched aquifer has high transparency and turbidity was 0. The ph level is acceptable. The area has hydro electric system that can aid the pumping of water to communities living upland. This can be done after construction of reservoirs for sufficient water generation. 2. Solar and wind water pumping technology is recommended to supply water to the communities in Gitendere and Karengyere for the low land water sources. Water can be pumped from lower streams such as Mirunda protected spring that have high transparency low turbidity (below 5 NTU) to the communities that live in the hill tops. This necessitates the initial construction of reservoirs to generate enough water for pumping. 3. We recommend rain harvesting technology to address water

	demand in the area. This can be done through civil society interventions to erect more water tanks in water stressed parishes of Gitendere and Karengyere. For instance, Gitendere Parish has a few permanent water sources compared to other parishes. Muhabura Crater Lake is not accessible since it is inside the protected area. The seasonal stream from Kabiranyuma wetland has already been harnessed for community use although its waters are not sufficient to supply the entire parish.
Appropriate technologies for treatment of selected water sources	1. Boiling of water in the communities around the two Protected Areas is highly recommended. This is because most water sources are of poor quality which mainly facilitate disease burden in the region.
Efficient pilot projects to deliver potable water to communities	1. Kabiranyuma gravity water scheme could be reestablished after an indepth water assessment to determine water quantity in the context of the scope of coverage. The quality of Kabiranyuma swamp is acceptable for human use. 2. Ntebeko stream is of good quality (high transparency and low turbidity and low E.coli counts) and can supply areas in Mgahinga. 3. Because of the scarcity of water sources around Mgahinga, emphasis needs to be put on rainwater harvesting facilities such as tanks and reservoirs that are big enough so as to continue supplying water even during the dry season. 4. An inventory of the dysfunctional water schemes especially gravity water should be undertaken. This can be done through socioeconomic studies in areas of Ngasire in Kishanje, Byakashara in Kashaasha, Nyakagyezi in Gisozi, Rugyeshi in Chibumba and Mivumu in Muhindura. For instance, if Mivumu water scheme was renovated and made to function, there would be good water supply in Muhindura parish which of now seriously faces water

	scarcity.
General Recommendations	1. Integrated water shed management from protected areas to communities is recommended to address sedimentation. This can be done by putting up vegetation buffer strips along the channels and ensuring good agricultural practices. This can be done by the technical teams from protected areas and Local Governments. River water shed management for Kishanje stream is recommended to protect the stream since it was evidenced from water quality assessment to be having highest level of turbidity (71.1 NTU) and with low transparency below standard. Water shed management can also be adopted for Kashasha river system. 2. Collaborative implementation approach of all stakeholders and development agencies be used. This means that Non Governmental Organizations that come on board collaborate with the district department of water and NGO collaboration themselves. This would avoid duplication of water activities. Depending on the local regulatory environment, it is wise to ensure upfront that regulatory requirements or restrictions for the water supply system are taken into account while making such interventions. 3. Gender gaps have been identified in this baseline survey. Strategic and practical gender needs ought to be further explored and addressed. It is important to focus particularly on women, as they are often responsible for water collection and family health, and school children, who can study aspects of the biodiversity system. This can be done if an affirmative action is done to integrate women on water management committees. There were very few women on water management committees which limit their participation in water management. 4. Increased sensitization of local communities around Echuya and

	Mgahinga is vital. This should be focused on water access especially taking advantage of rainy seasons so that households can retain water for the dry spells. Sensitization should also focus on hygiene and water treatment. In Kishanje and Kagezi, people are adamant in maintaining their water sources. This has resulted into heavy disease burden. Water day and events can be organized to raise awareness on water safety, water quality, sanitation and hygiene, organized in the community. This would raise interest and may make it possible to generate the resources for improvements.
General Recommendations	1. Integrated water shed management from protected areas to communities is recommended to address sedimentation. This can be done by putting up vegetation buffer strips along the channels and ensuring good agricultural practices. This can be done by the technical teams from protected areas and Local Governments. River water shed management for Kishanje stream is recommended to protect the stream since it was evidenced from water quality assessment to be having highest level of turbidity (71.1 NTU) and with low transparency below standard. Water shed management can also be adopted for Kashasha river system. 2. Collaborative implementation approach of all stakeholders and development agencies be used. This means that Non Governmental Organizations that come on board collaborate with the district department of water and NGO collaboration themselves. This would avoid duplication of water activities. Depending on the local regulatory environment, it is wise to ensure upfront that regulatory requirements or restrictions for the water supply system are taken into account while making such interventions. 3. Gender gaps have been identified in this baseline survey. Strategic

	and practical gender needs ought to be further explored and addressed. It is important to focus particularly on women, as they are often responsible for water collection and family health, and school children, who can study aspects of the biodiversity system. This can be done if an affirmative action is done to integrate women on water management committees. There were very few women on water management committees which limit their participation in water management. 5. Increased sensitization of local communities around Echuya and Mgahinga is vital. This should be focused on water access especially taking advantage of rainy seasons so that households can retain water for the dry spells. Sensitization should also focus on hygiene and water treatment. In Kishanje and Kagezi, people are adamant in maintaining their water sources. This has resulted into heavy disease burden. Water day and events can be organized to raise awareness on water safety, water quality, sanitation and hygiene, organized in the community. This would raise interest and may make it possible to generate the resources for improvements.
Priority Action points	**Action1:** Establishment of community rainwater harvesting facilities in Karengyere parish and extension of these facilities in Mgahinga parishes. In Mgahinga priority should be given to Gitendere parish. This is premised on the fact that Gitendere is overpopulated yet has insufficient water sources. The demand is high yet supply is low. **Action 2:** Initiate and enforce water source protection at all established water facilities such as gravity flow schemes and protected springs. In addition, overall catchment protection should be promoted in all parishes to maintain water quality and quantity. **Action 3:** Establish riparian vegetation buffers to protect running water sources such as stream and rivers. This would result in improved water

	quality and quantity in these sources. The forests of Echuya and Mgahinga are important water towers providing communities downstream with the valuable water resource. Echuya forest parishes had the most abundant freshwater sources serving the communities downstream. However, the quality of water originating from Echuya is of low quality because of the rampant human activities such as grazing and watering animals inside the forest. These activities need to be halted if the quality of water originating from the forest is to be improved. **Action 4:** Liaise with National Forestry management to halt illegal activities especially around water sources. This will go a long way in improving water quality of receiving downstream communities. On the other hand, the quality of water of sources located inside Mgahinga national park such as Kabiranyuma swamp and the seasonal Ntebeeko stream were of good quality (high transparency and low turbidity and low E.coli counts). Because of the scarcity of water sources around Mgahinga, emphasis needs to be put on rainwater harvesting facilities such as tanks and reservoirs that are big enough so as to continue supplying water even during the dry season. The most clean water sources around Echuya forest were protected springs and gravity flow schemes with very high transparency and low turbidity. However, these water sources had little or no protection observed onsite. The sites need protection in such as the establishment vegetation buffers around them to avoid polluting the ground water sources. The most polluted water sources were streams and rivers draining agricultural landscapes. These had high turbidity levels and high faecal contamination. In order to improve the quality of water in these landscapes, communities need to engage in watershed management practices such as

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Appendix 1: MS Access Database User Guide

The Echuya and Mgahinga Hydrological systems database

By:

Institute of Tropical Forest Conservation (ITFC)

User Guide

February 2014

1. Getting Started

1.1 Introduction

The Ms Access database has been built to capture data from the survey on hydrological systems in the Great Virunga Landscape in order to assess the water demand and supply in and around Mgahinga Gorilla National Park and Echuya Central Forest Landscapes. It covers both socioeconomic and Hydrological aspects of the project to be used for future monitoring and evaluation of the water resources, quality and quantity in Mgahinga and Echuya landscape.

The database was developed, programmed, and hosted using Microsoft Access Database Management System. The Structured Query Language (SQL) was used to generate Tables and Queries whereas the Visual Basic Access Programming Language to automate some database processes such as generating of queries.

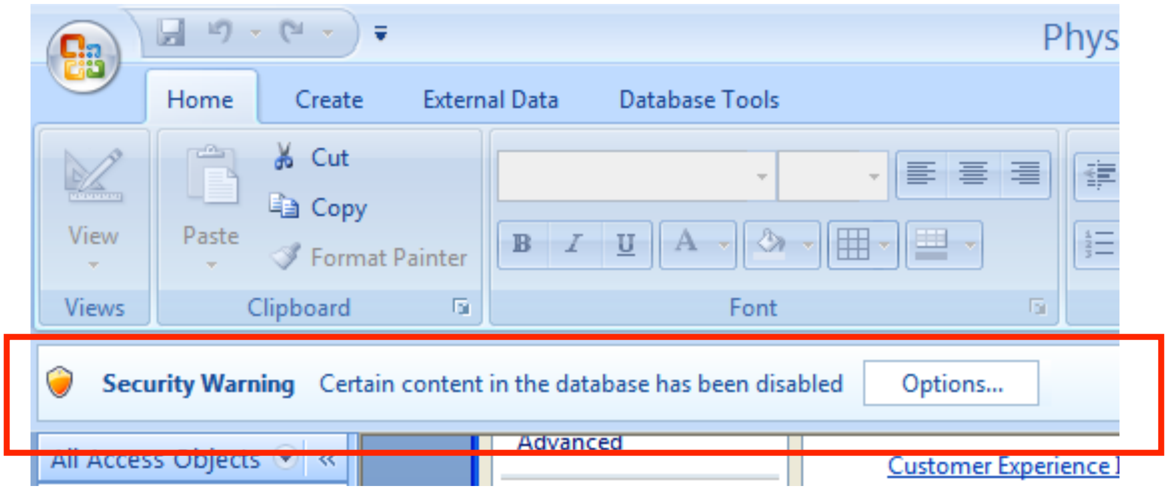
1.2 Installation

Ensure that you using a computer with Microsoft Windows Xp/Vista/7. Also make sure that you have Microsoft Access 2007 installed as part of your Microsoft office software package.

Last but not least, ensure that your Microsoft Access installation is configured to allow macros to run. If you are not sure, please enable the macros. This is because this system depends on them and it will not work well if they are disabled.

If macros are disabled and you start the system, it will display a warning message in yellow, reading “System NOT working well, please Enable Macros”. See illustration below:

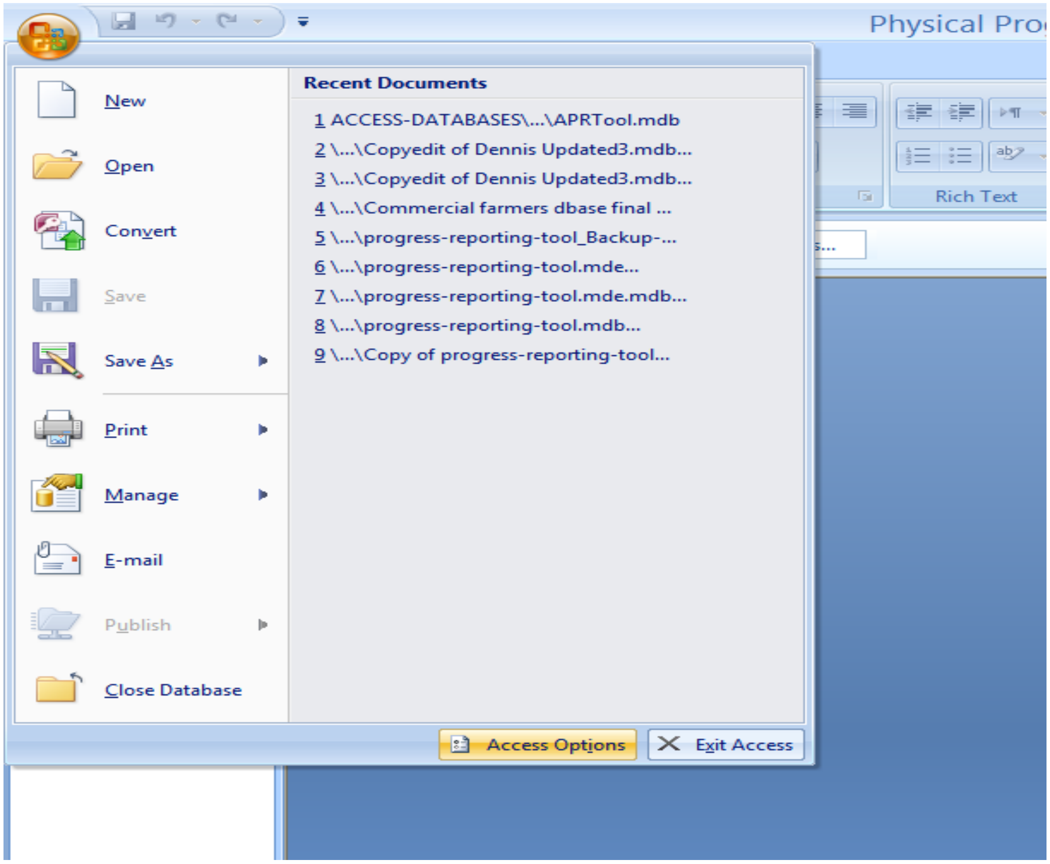
Microsoft Access will also display a warning message that reads “Security Warning: Certain content in the database has been disabled”.



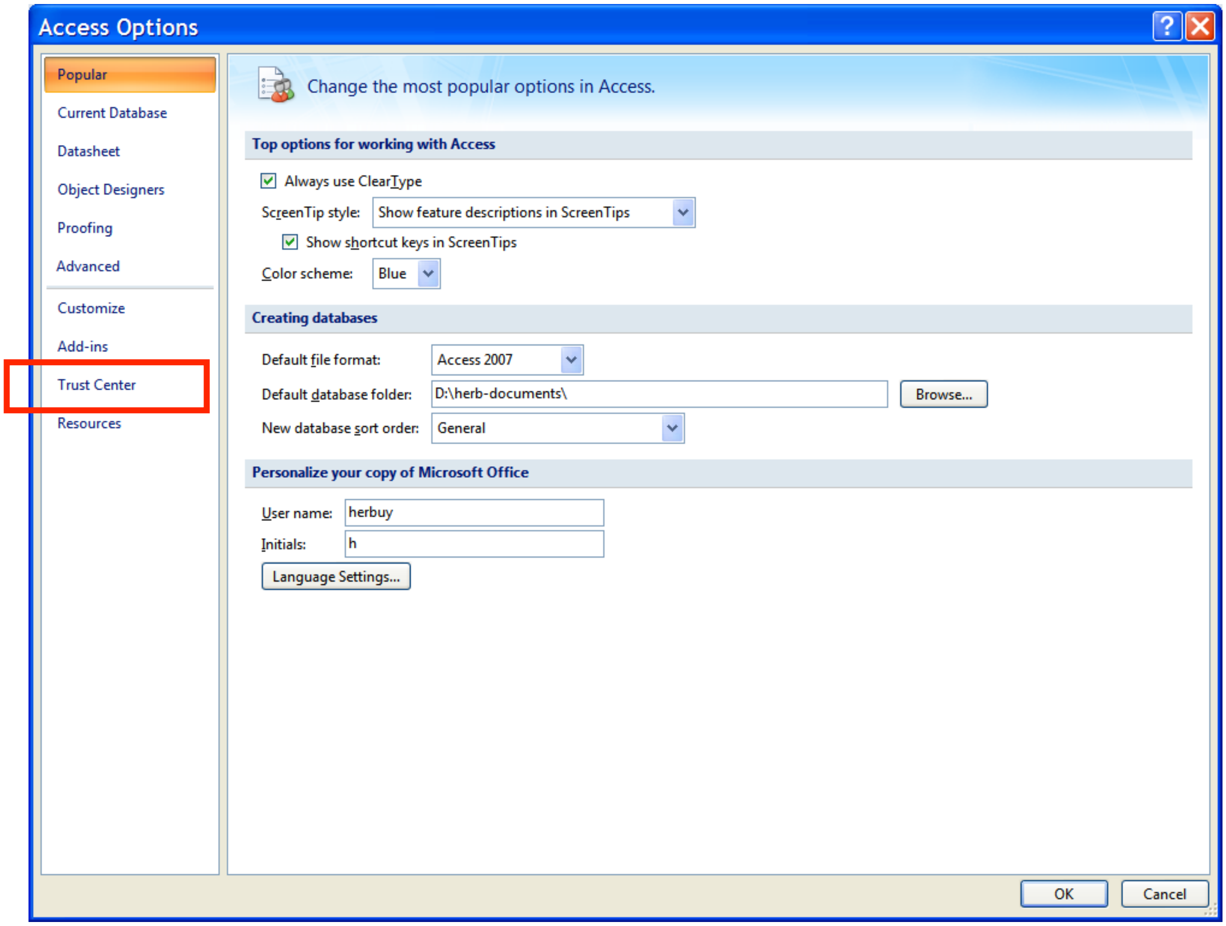
To rectify the problem and ensure the system functions well, please enable macros by following the following steps.

How to Enable Macros

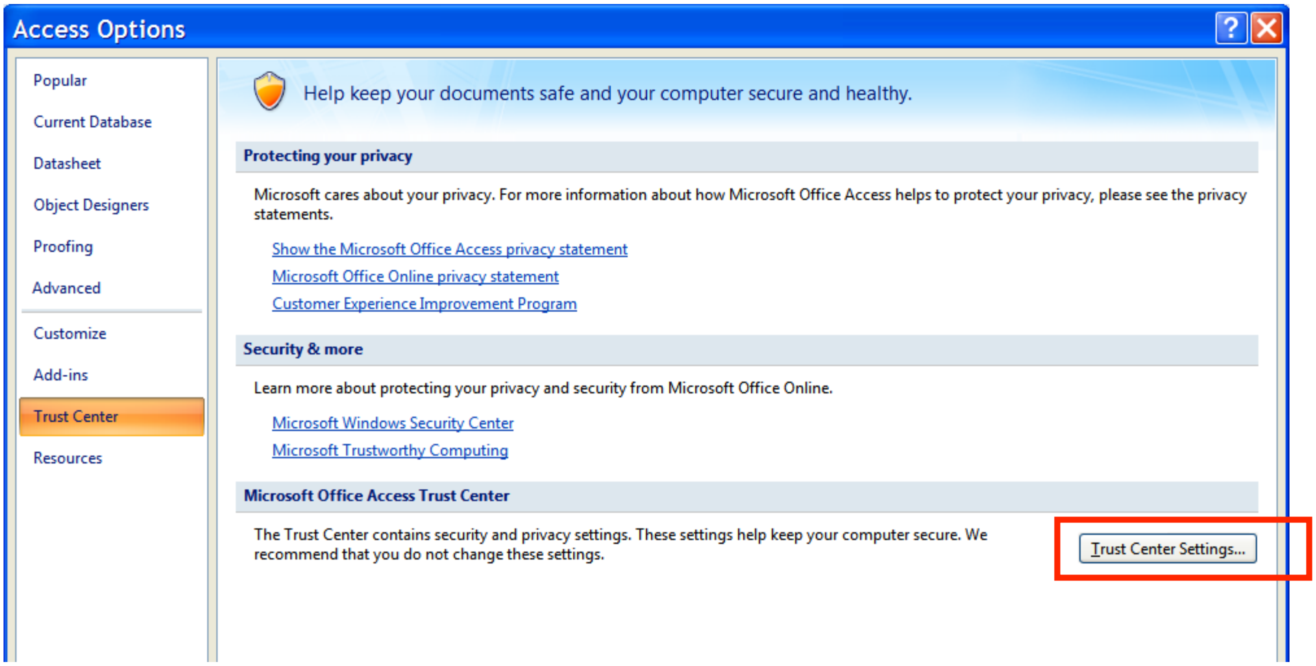
Click the office tab located in the top-left corner to display a pop-up menu. Seek to the bottom until you find the button labeled “Access Options”.



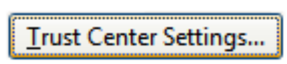
Click the “Access Options” button. This will display the following dialog box.



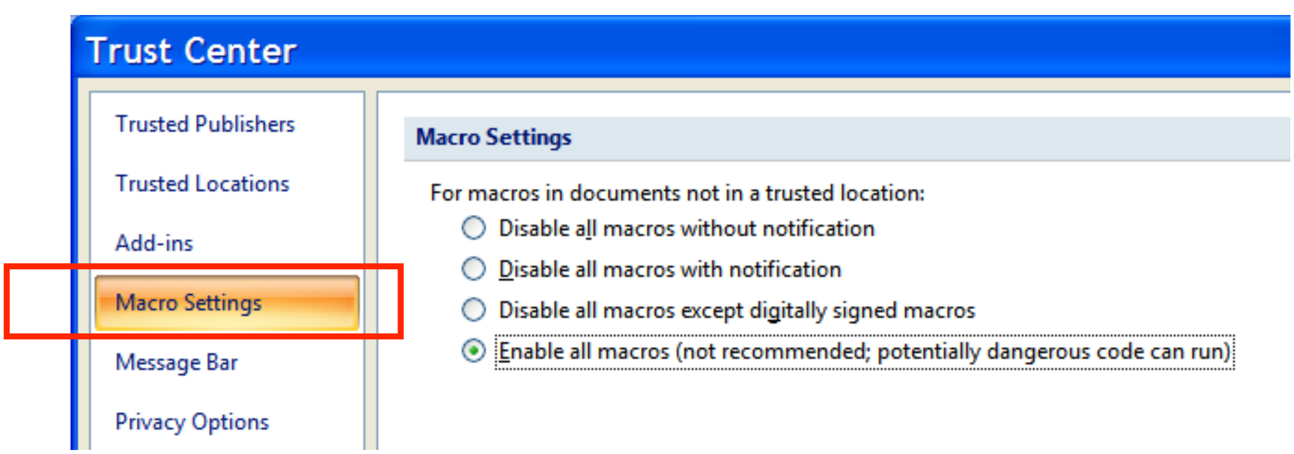
In the menu displayed on the left side of the dialog box, search for a button labeled "Trust Center" and click it. This will display the "trust center" dialog box. This dialog box is used to set the trust level, which determines whether the system should trust code and macros, basing on the criteria set.



Click the button labeled "Trust Center Settings" in the lower right corner.



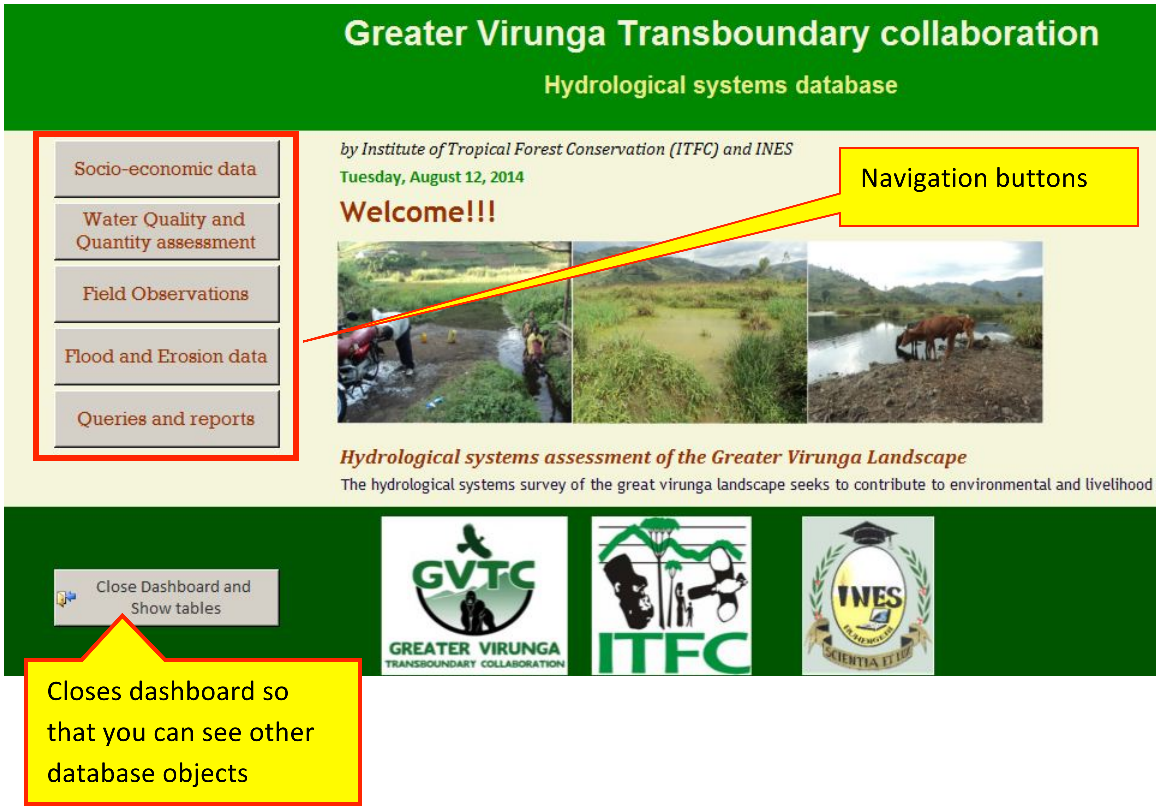
Under the trust center settings, click "Macro settings" and select the option "Enable all macros", as shown below.



Close Microsoft Access and restart it.

1.3 Running the System

Double click the file "GVL_hydro_db Master database" to open it with Microsoft access. It will display the database dashboard, as illustrated below.

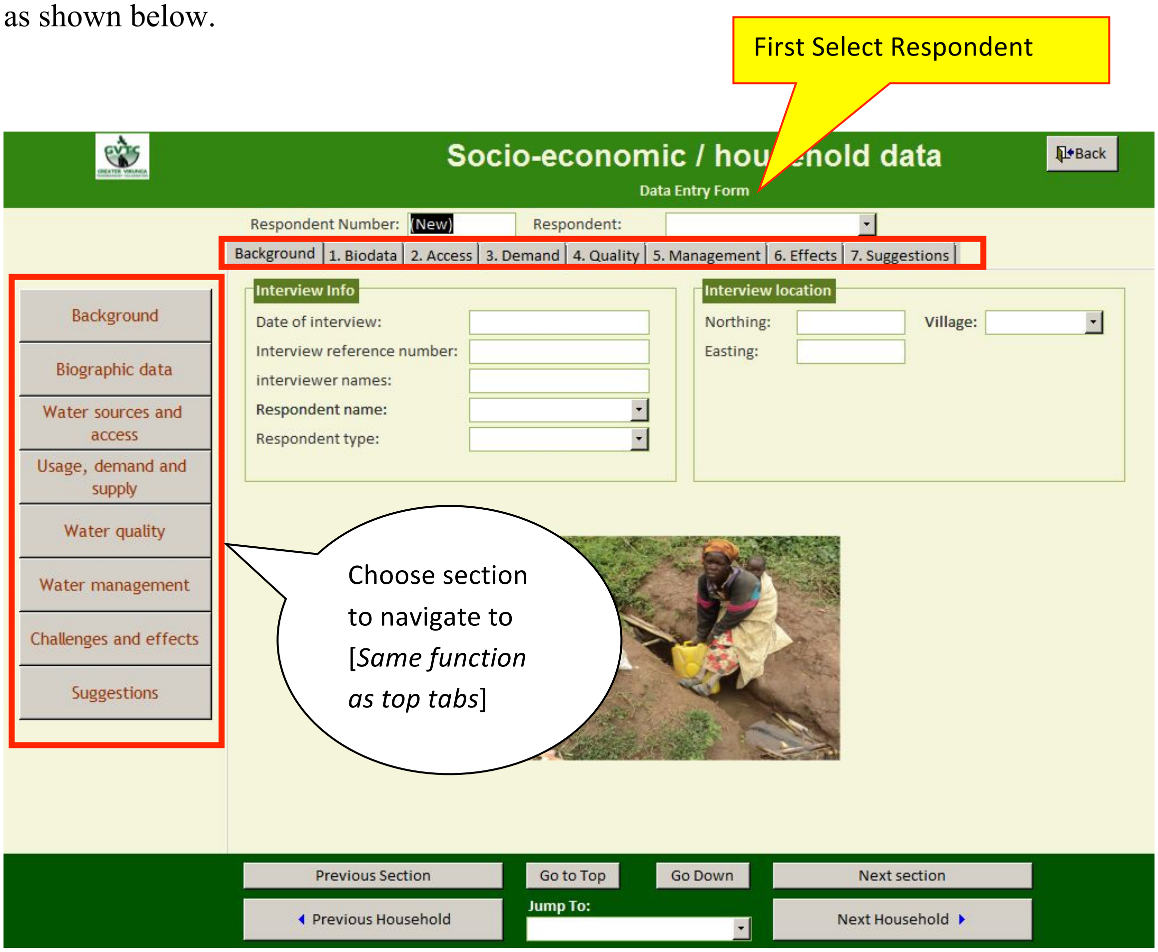


1.4 Entering, updating and viewing data

The dashboard provides access to various database sections by means of the navigation buttons located at the left side of the dashboard. See illustration below

1.4.1 Entering socioeconomic/household data

Click the button labeled "socio-economic data". This will display the socioeconomic data form as shown below.



This form is divided into various sections, which can be accessed by the section links provided as buttons on the left side of the forms. By default, the form displays the **background** section.

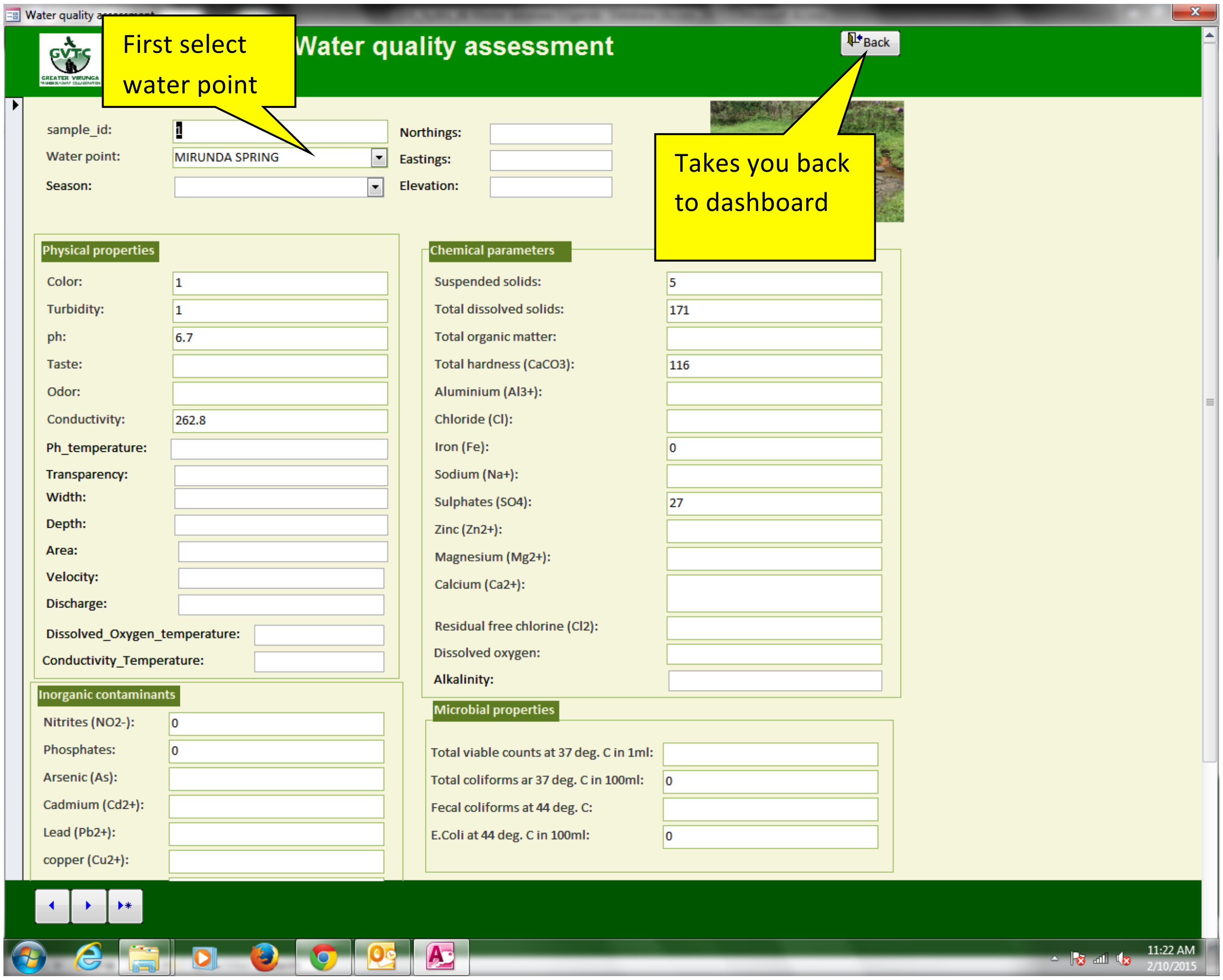
To enter socioeconomic data for a given household, **first select the respondent name** from the drop-down list provided at the top of the form. Then enter the background information pertaining to that household.

Navigating between sections

You can choose to navigate between sections by either clicking "Next/Previous section" buttons, OR by jumping straight to the desired section by selecting it from the left menu or the tab buttons located at the top of the data entry form.

1.4.2 Water quality assessment

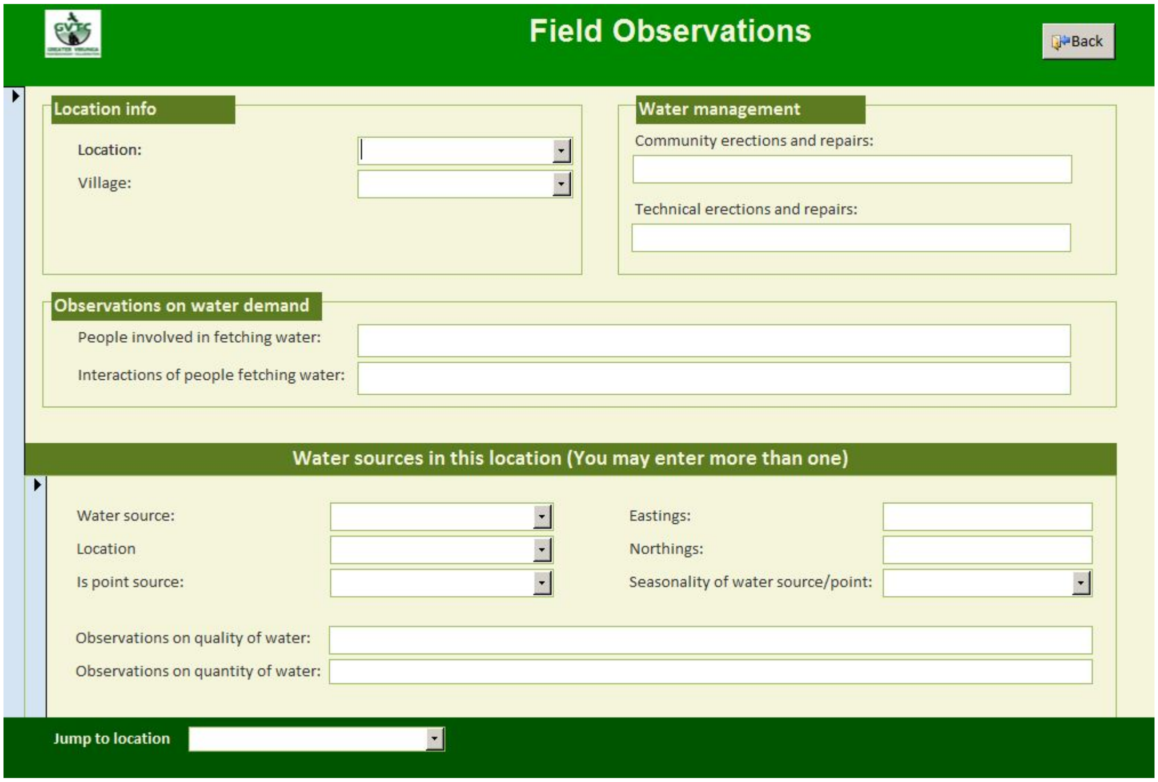
To enter information about water quality as measured in the field or laboratories, click the “Water quality and quantity assessment” button. This will bring a form similar the one below.



Choose the water point whose assessment you would like to record and enter the rest of the parameters.

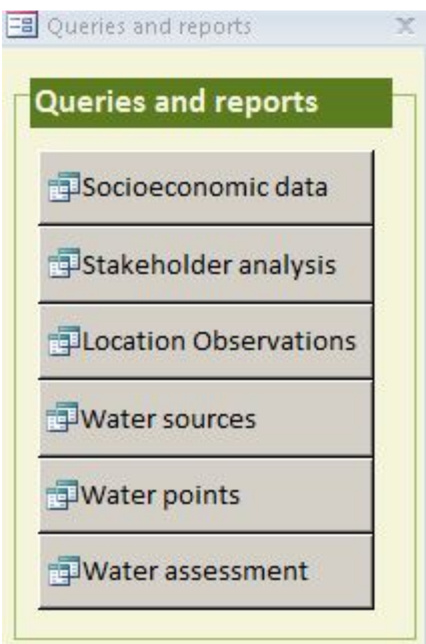
1.4.3 Field observations, water sources, and water points

To record observations about location, water source data, and water source information, click the “Fields observations” button from the left navigation buttons on the dashboard. This will show a form similar to the one below.

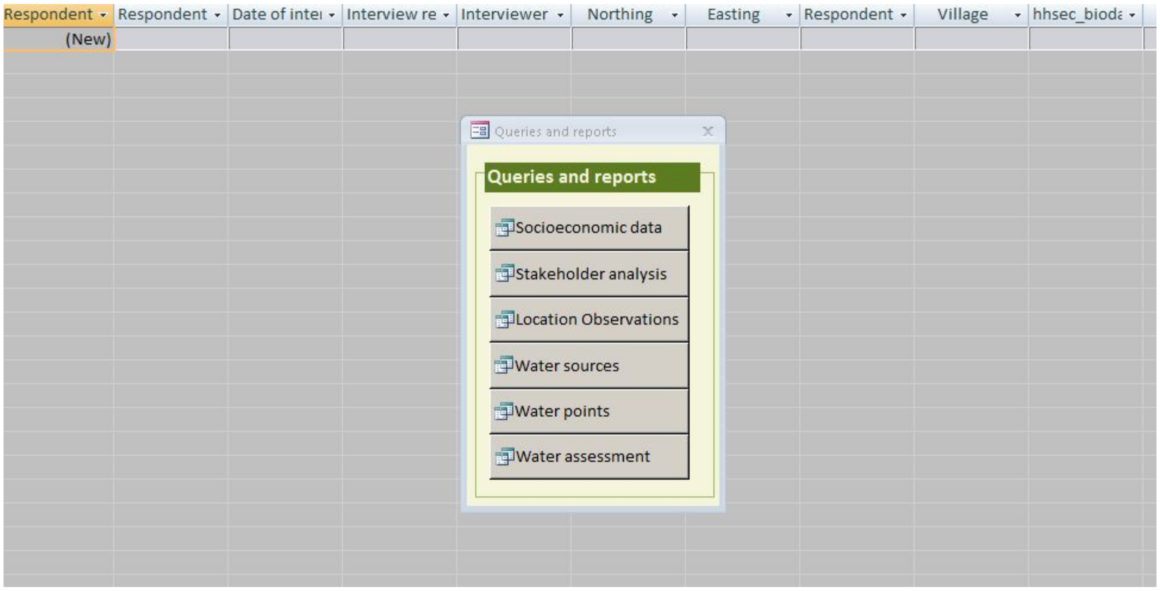


1.4.4 Queries and Reports

To view queries and reports that come with the database, click "queries and reports" from the left navigation buttons of the dashboard. This will display the popup menu of the different queries/reports as shown below.These queries have been generated to categorize required datasets in the database.

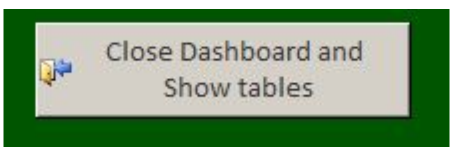


You can then click the button that corresponds to the query you desire and it will be displayed. For instance, clicking socioeconomic data will show a query similar to the one below.



2.0 Accessing the full list of tables, queries and forms in the database

To see all the tables, queries and forms in the database, click on the button labeled "" from the dashboard.



This will close the dashboard so that you can see the rest of the database objects (tables, queries, and forms).